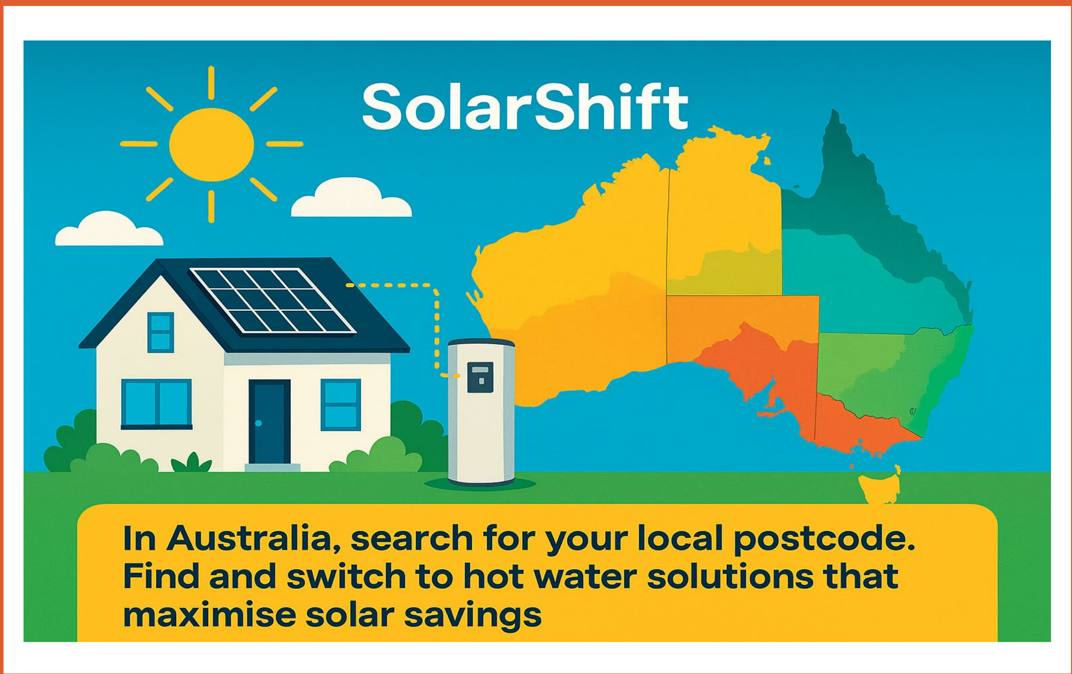
RACE for 2030
RELIABLE AFFORDABLE CLEAN ENERGY

H3 Using Home Energy Technologies for Grid Support

SolarShift

Turning household water heating systems into MW batteries

SolarShift Customer Hot Water Roadmap Tool Report



Final report

RACE for Homes

Research Theme H3 Using home energy technologies for grid support:

SolarShift
Turning electric water heaters into megawatt batteries

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Project partners

- Endeavour Energy
- Solar Analytics
- Ausgrid
- NSW DCCEEW
- Energy Smart Water

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Acknowledgement of Country

The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters, and culture and pay our respects to them, their cultures and to their Elders past, present, and emerging.

What is RACE for 2030?

Reliable, Affordable Clean Energy for 2030 (RACE for 2030) is an innovative cooperative research centre for energy and carbon transition. We were funded with $68.5 million of Commonwealth funds and commitments of $280 million of cash and in-kind contributions from our partners. Our aim is to deliver $3.8 billion of cumulative energy productivity benefits and 20 megatons of cumulative carbon emission savings by 2030. racefor2030.com.au

Disclaimer

About Collaboration on Energy and Environmental Markets (CEEM)

The UNSW Collaboration for Energy and Environmental Markets (CEEM) undertakes interdisciplinary research in the design, analysis and performance monitoring of energy and environmental markets and their associated policy frameworks. CEEM's research focuses on the challenges and opportunities of clean energy transition within market-oriented electricity industries. It does so through collaborations between UNSW researchers from the Faculty of Engineering, the Business School and the Faculty of Arts, Design and Architecture, working alongside Australian and International partners.

CEEM aims for impact through close engagement with energy stakeholders, development of open-source tools and submissions to relevant Australian policy and regulatory processes.

More details of this work can be found at our website. We welcome comments and suggestions and potential collaborations on this research and related tools development, and all our work in this area.

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Executive Summary

Australia leads globally in rooftop PV installations per capita, with over 25 GW installed across more than 40% of homes. While this provides access to cheap, clean energy, high PV penetration has introduced grid challenges like minimum demand issues and over-voltage in low-voltage networks. Conventional solutions often limit the benefits of rooftop PV due to their complexity or tendency to curtail generation.

An effective alternative is using the flexible demand of domestic electric water heaters (DEWHs), especially resistive and heat pump types — to soak up excess solar energy during the day. Since over 50% of Australian homes already use DEWHs, and smart meter penetration is growing, this presents an opportunity to leverage existing infrastructure to reduce bills, cut emissions, and stabilize the grid.

The SolarShift project, led by the Collaboration on Energy and Environmental Markets (CEEM) at University of New South Wales (UNSW) with funding from RACE for 2030. The project has Endeavour Energy, NSW DCCEEW, Solar Analytics, Ausgrid, and Energy Smart Water as the industry partners. The project explored the flexible demand opportunity of DEWH through:

- Detailed thermal modelling of DEWHs using TRNSYS and Python;
- Financial and emissions comparison of different water heating technologies;
- Analysis of real-world operational data from Endeavour Energy;
- Voltage impact assessments using PowerFactory;
- Day-ahead forecasting of DEWH demand using machine learning.

Key findings include:

- DEWH tanks show 67–72% storage efficiency; improving insulation could save 15% in energy and emissions.
- Premium heat pumps with CO_2 refrigerant can deliver averages COPs between 2.5–3.5 and the performance is sensitive to both ambient and tank water temperature.
- Switching from resistive to heat pumps reduces emissions by ~67%; further gains occur with smart solar soak control strategies.
- Financial analysis shows that with rebates, switching from resistive to low-cost heat pumps can have payback periods under 3 years
- Real-world from Endeavour Energy's Off-peak plus trial shows that on average 28% of daily DEWH load was shifted to solar hours. However, some retailers achieved up to 74% of shifted DEWH load via dynamic controls.
- Network voltage simulations show potential for DEWHs to provide voltage support, particularly with smart, location-aware control.
- A hybrid Convolutional Neural Networks and Long Short-Term Memory (CNN–LSTM) model accurately forecasted next-day DEWH demand with $R^2 > 0.95$, offering potential for better grid and market coordination.

Extension Work - SolarShift Customer Hot Water Roadmap Tool Report

Building on these foundational research, the project extended its impact by building an online tool that provides customers with estimates of annual water heating bills, net-present value, pay-back period and CO2 emissions based on:

- Water heating technologies,
- Hot water draw profiles (HWDP), that shows the timing and amount of water use during the day

- Number of people living in the house
- Postcode/climate zone
- Tariffs
- Different control strategies

This effort led to the launch of the SolarShift Customer Hot Water Roadmap WebApp, accessible at this link. The tool enables users to input their postcode and receive tailored guidance on technology options, cost savings, and emissions reduction potential. This nationwide tool increases accessibility and empowers households to make informed, climate-smart choices, accelerating Australia's transition to clean energy. This report provides details for the SolarShift Customer Hot Water Roadmap tool.

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1 Introduction

1.1 Background

Australia leads the world in per capita rooftop solar PV installation, with over 40% of households installing systems totalling more than 25 GW in capacity. While rooftop PV provides environmental and economic benefits, its high penetration also causes technical challenges on low-voltage networks—particularly minimum demand and over-voltage problems. Existing network responses, such as inverter control modes and export limits, may suppress PV output and reduce financial returns for consumers.

A more accessible and cost-effective solution involves leveraging the flexible demand of domestic electric water heaters (DEWHs). These systems—mainly resistive and heat pump types—are already installed in over 50% of Australian homes. Their large thermal storage capacity enables them to absorb excess daytime solar energy, reducing PV curtailment, cutting electricity bills, and improving grid stability. Given the slow uptake of household batteries, DEWHs present a widely available alternative for thermal storage.

The increasing penetration of smart meters—currently over 30% in the National Electricity Market (NEM) and expected to reach 100% by 2030—enables near real-time visibility and control of electrical loads, making them ideal for DEWH orchestration.

1.2 Summary of project scope

The SolarShift project, led by UNSW's Collaboration on Energy and Environmental Markets (CEEM), investigated the potential of DEWHs to act as flexible thermal batteries. The project has also participated in and contributed to the International Energy Agency (IEA) Solar Heating & Cooling (SHC) Program Task 69, Solar Hot Water[1]. Supported by RACE for 2030 and industry partners, the two-year project included five major components:

- Thermal modelling of DEWHs using Transient System Simulation Tool (TRNSYS)[2] in combination with Python programming[3];
- A financial roadmap comparing various hot water technologies;
- Real-world operational data analysis from Endeavour Energy's Off Peak Plus trial[4];
- Network power quality impact assessment using DIgSILENT[5] simulations;
- Day-ahead forecasting of DEWH demand using deep learning models.

1.3 SolarShift Customer Hot Water Roadmap Tool

The developed customer hot water roadmap tools considers comprehensive simulations which analysed the energy efficiency, hot water availability, and emissions of various DEWH technologies under different climates, household sizes, draw profiles, and control strategies. Key variables and inputs for the tool are described as below:

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[1] IEA Solar Heating and Cooling Programme Task 69 Solar Hot Water, available here.

[2] Transient System Simulation Tool (TRNSYS), available here.

[3] Python, available here.

[4] Endeavour Energy Off Peak Plus, available here.

[5] DIgSILENT, available here.

1.3.1 Hot water draw profiles (HWDP)

The hot water consumption pattern is modelled with six different hot water draw profiles (HWDP), as defined by previous research [6] : 'morning and evening only', 'morning and evening with daytime', 'evenly distributed through the day', 'morning dominant', 'evening dominant', and 'late night'.

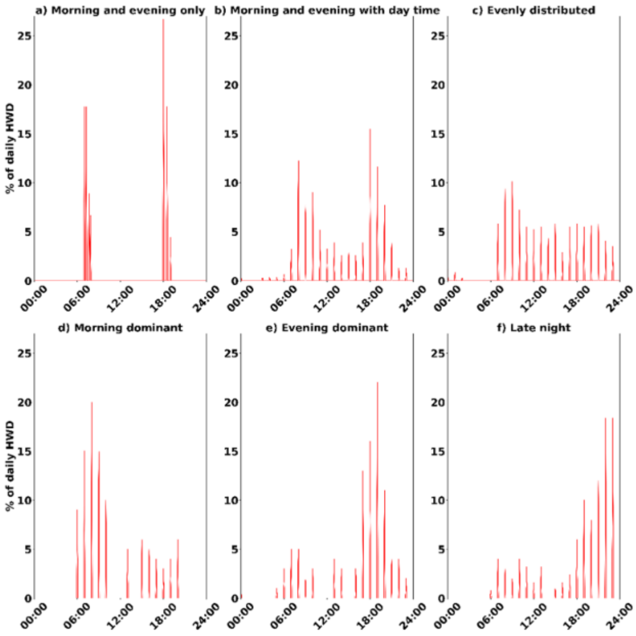

Figure 1. Typical hot water draw profiles (HWDP) in Australian households [8]

1.3.2 Control strategies

Five different control strategies were studied for the control and scheduling of DEWH. These combinations cover a wide range of possible cases in Australia as shown in the Table 1 below:

Table 1. Studied control strategies for DEWH

Control Type	Abbreviation	Description
General Supply (GS) with flat a	GS_flat	Always connected
General Supply with Time of Use	GS_tou	Always connected
Controlled Load 1	CL1	Overnight – at least 6-hour period between 10 pm and 7 am
Controlled Load 2	CL2	24/7 except seasonal peak demand periods - more than 6 hours between 8 pm and 7 am and more than 4 hours between 7 am and 5 pm
Controlled Load 3	CL3	CL1 with Solar Soak window between 9am-3pm
Timer flat (Solar Soak)	timer_SS	Timer control for sunny hours between 9am-3pm aiming for self-consumption
Timer time of use (Off-peak)	timer_OP	Timer control aiming for off-peak tariff
Diverter ToU (Off-peak)	Diverter_tou	Diverter for self-consumption with ToU off-peak top up
Diverter + CL1	Diverter_CL1	Hypothetical case (currently not allowed by DNSPs) using diverter for self-consumption during the day with CL1 tariff for night time heating

[6] Analysis of electricity consumption and thermal storage of domestic electric water heating systems to utilize excess PV generation available, here.

1.3.3 Water heater technologies

This section outlines the key assumptions and technical specifications used to simulate the performance of various water heating technologies within the SolarShift project (Table 2). Leveraging the modular and object-oriented design of the open-source tm_solarshift codebase, the model simulates five Premium heater types under real-world Australian conditions: electric resistive, heat pump, solar thermal, gas storage, and instantaneous gas heaters. Each technology is represented using commercially available models, with parameters such as efficiency, capacity, and thermal losses tailored to reflect realistic performance. These assumptions form the basis for analysing storage efficiency and thermal state of charge (SOC), which are critical indicators of hot water system performance. These variables feed directly into the financial assessment in the subsequent section.

Table 2. Roadmap technology assumptions

Technology Assumptions
Heat Pump: • **Premium heat pumps considered are Reclaim Energy (315 L), glass lined heat pumps with a warranty of 10 years – more upper market option**   ○ **Variation for household size** • **Standard heat pump considered is the iStore heat pump (270 L), with a warranty of 5 years and a lifespan of a similar time**
Gas: • **Modelled with 80% boiler efficiency, calculated based on technical data** • **Methane for heat value (47 MJ/kg)** • **Rheem gas storage (170 L) and gas instantaneous (26 L) heaters considered**   ○ **Variation for household size**
Electric Resistive: • **Rheem electric resistive heaters (315 L) considered**   ○ **Variation for household size** • **All tanks have same values for losses (0.9W/m2-K) – not included in technical data** • **Efficiency of 1**

Solar Thermal:
• **4 square meter system**
• **Using standard values for optics and thermal losses**
    ○ **FRta= 0.6**
    ○ **FRUL = 0.6 W/m2-K**
    ○ **IAM coefficient = 0.2**
• **Electric auxiliary heater**
• **Rheem loline solar thermal heater (315 L) considered**

1.3.4 Summary of simulation variables

All of the studied variables are summarised in Table 3 below:

Table 3. Studied variables for thermal modelling

Variable type	Variables
Location	All states & postcodes across Austalia
Hot Water Draw Profile (HWDP)	1, 2, 3, 4, 5, 6 (see Figure 1)
Household number of people	2, 3, 4, 5+
PV ownership	Yes - 5kW AC system (PV), No (nPV)
Water Heaters	Resistive (R-DEWH), heat pump – high-cost (HPhc), heat pump low-cost (HPlc), solar thermal evacuated tubes with electric boost (STC), gas storage (GStg), gas instantaneous (GI)

Control Strategies	Controlled load (CL), general supply (GS), timer, diverter, gas
Tariff options	Flat, ToU, gas

Most of the thermal modelling results presented in this report includes the base case scenario for a household in Sydney with 4 people and HWDP = 1 due to space restrictions. All other scenarios are available through SolarShift Customer Hot Water Roadmap Tool as described below.

1.3.5 Extension Work: Postcode Mapping and WebApp Development

Using simulation outputs (Table 3), an online customer roadmap was created to guide households through cost, emissions, and technology comparisons. The online tool helps users to make tailored decisions.

The final phase of SolarShift project focused on improving the draft online tool and making further improvements and extensions to its capabilities. These include creating an online webapp, resolving various bugs, mapping all Australian postcodes to relevant climate and tariff zones and calculating payback periods for switching to heat pump water heaters from resistive or gas systems.

A public-facing WebApp—SolarShift Customer Hot Water Roadmap—was launched to allow users to input their postcode and receive customized advice on optimal water heating solutions, expected savings, and emission reductions. The tool empowers users to make informed decisions considering their locations, household water heating needs and energy goals. The tool can be accessed through this link.

1.4 Project knowledge sharing

SolarShift has had the following knowledge sharing activities throughout the project:

- Four project milestone and progress reports submitted to RACE for 2030
- Final knowledge sharing report
- Presentation at Australian Energy Market Commission (AEMC) on hot water control and smart meters
- Presentation at Energy Efficiency Council (3 presentations throughout the project)
- Policy submission to AEMC on the rule change on consumer energy resource (CER) benefits
- Conference presentations: Asia Pacific Solar Research Conference (APSRC 2023), Energy Research Institutes Council for Australia (ERICA) State of Energy Research Conference (2023), Asia Pacific Solar Research Conference (APSRC 2024), IEA SHC Task 69 Meeting (2023 & 2024), Energy Research Institutes Council for Australia (ERICA) State of Energy Research Conference (2025)
- Media article on Renew Economy [7]
- 2 Journal publications (submitted to Energy Conversion and Management and IEEE Transactions on Smart Grid)

1.5 Structure of the report

Section 2 presents the postcode mapping methodology and outcomes. **Section 3** analyses the payback period for switching from gas or resistive to heat pump water heaters across different regions. **Section 4** explains the SolarShift WebApp, including its functionality, user interface, and how households can use it to make informed decisions. **Section 5** concludes with final discussions and outlines recommended next steps.

[7] Renew Economy Electric hot water is a hero of flexible demand on, available here.

2 Postcode Mapping

2.1 Introduction

As part of the SolarShift project extension, comprehensive postcode mapping was conducted to support tailored analysis of hot water system performance, energy use, and cost-effectiveness across Australia. This geospatial mapping effort enables localized insights by linking every Australian postcode to its relevant climate zone and regional utility tariff data, enhancing the accuracy and usability of the SolarShift WebApp. This section outlines the methodology and considerations behind the postcode mapping framework, while the next section shows how these results can be used for financial analysis in creating a road map for a "customer hot water journey". The simulations are developed using an open-source repository built specifically for this project, called "*tm_solarshift*"[8].

2.2 Aligning Postcodes with Bureau of Meteorology (BOM) Climate Zones

To improve accuracy of the customer recommendations, each postcode was mapped with a Bureau of Meteorology (BOM)-defined climate zone. This decision reflects the vast climatic diversity across Australia (Figure 2). Even when the locations are classified under the same general climate zone (e.g., "Warm Summer, Cold Winter") solar radiation, ambient temperature, and cold-water inlet temperatures can differ significantly depending on their exact geographic location.

This classification identifies six key zones across Australia, based on a set of definitions relating to summer and winter conditions:

1- Hot humid summer,
2- Warm humid summer,
3- Hot dry summer, mild winter,
4- Hot dry summer , cold winter,
5- Warm summer, cold winter,
6- Mild/warm summer, cold winter.

As seen in Figure 2 , NSW contains 4 BOM climate zones, Queensland 5, Victoria 3, South Australia 2, Tasmania 2, the Northern Territory 3, Western Australia 4, and the ACT 1. Mapping postcodes to the correct BOM climate zone within their respective states allows the tool to more accurately determine solar irradiance, ambient temperature, and cold-water input temperature relevant to that specific location.

[8] Repository *tm_solarshift*, available here.

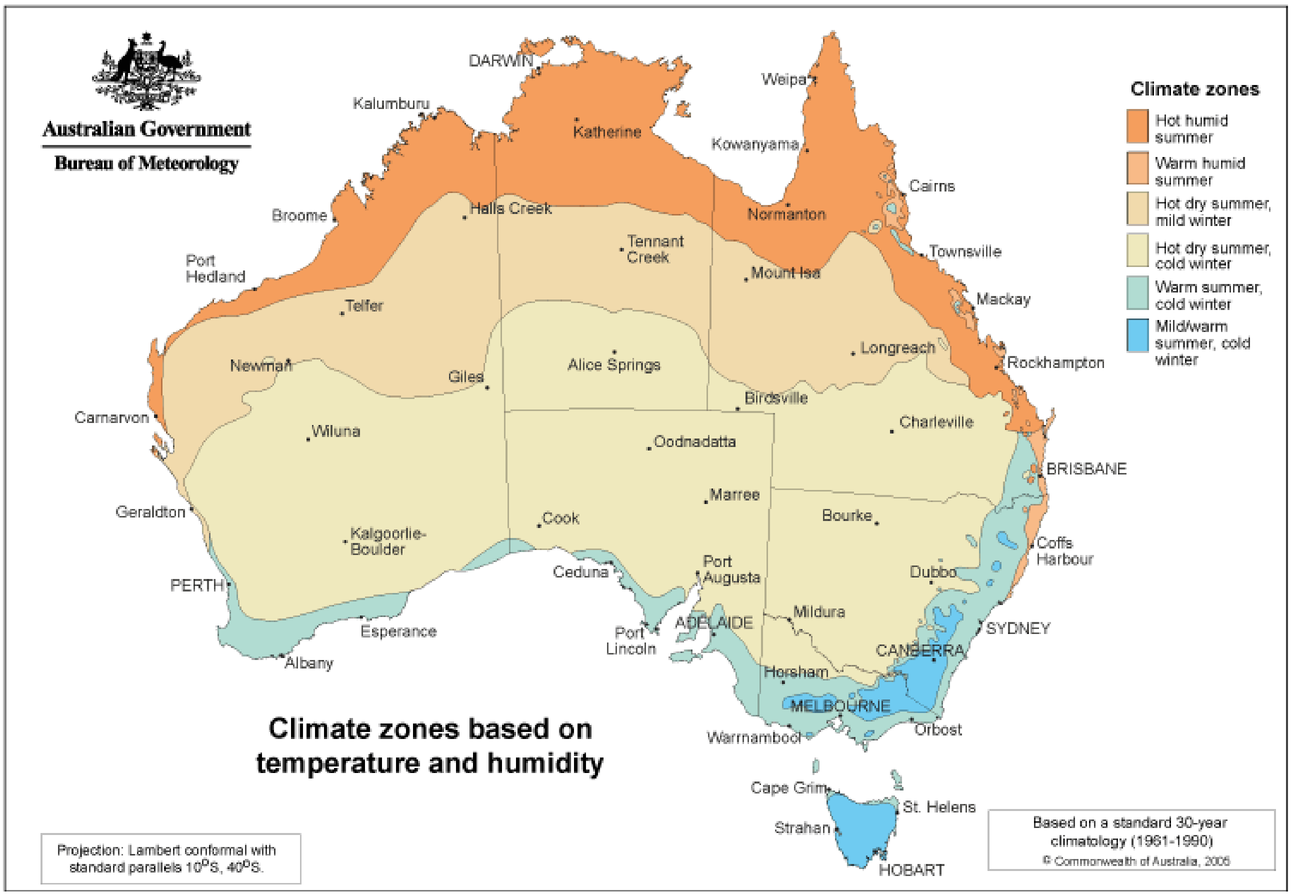

Figure 2. The temperature and humidity zone map shows the climate of Australia classified according to temperature and humidity properties across the country. These maps are based on temperature and humidity data collected over the period 1961 to 1990 [9].

2.3 Mapping Postcodes to Average Regional Energy Tariffs

All postcodes in Australia were linked to average electricity and gas tariffs based on state and regional data. For this purpose, postcodes were grouped by their corresponding state and the electricity distribution network service provider (DNSP) serving in that region. Within each DNSP area, average tariffs from the three major retailers' standing offers were calculated and assigned to the associated postcodes.

This method ensures a representative and regionally accurate cost comparison for various water heating technologies. Gas tariffs were included where available, acknowledging that not all regions (such as parts of the NT and remote WA) are connected to reticulated natural gas networks.

The DNSPs and dominant electricity and gas retailers in each state and territory are listed in Table 4 below:

Table 4. DNSPs and Main Retailers by State/Territory

State/Territory	DNSP	Main Retailers
New South Wales (NSW)	Ausgrid	Origin Energy, AGL, EnergyAustralia
	Endeavour Energy	Origin Energy, AGL, EnergyAustralia

[9] Climate Classification maps, available here.

	Essential Energy	Origin Energy, AGL, EnergyAustralia
Victoria (VIC)	Citipower	AGL, Origin Energy, EnergyAustralia
	Powercor	AGL, Origin Energy, EnergyAustralia
	Jemena	AGL, Origin Energy, EnergyAustralia
	AusNet Services	AGL, Origin Energy, EnergyAustralia
	United Energy	AGL, Origin Energy, EnergyAustralia
Queensland (QLD)	Energex	AGL, Origin Energy, EnergyAustralia
	Ergon Energy	Ergon Retail
South Australia (SA)	SA Power Networks	AGL, Origin Energy, EnergyAustralia
Western Australia (WA)	Western Power	Synergy (electricity); Kleenheat, Elgas (LPG)
	Horizon Power	Horizon
Tasmania (TAS)	TasNetworks	Aurora Energy (electricity and gas)
Australian Capital Territory (ACT)	Evoenergy	ActewAGL, Origin Energy
Northern Territory (NT)	Power and Water Corporation	Jacana Energy (electricity); Kleenheat, Elgas (LPG only)

2.4 Climate-Specific Energy and Technology Performance Analysis

With accurate climate zone assignment, the SolarShift Customer Hot Water Roadmap tool can now deliver more refined estimations of hot water energy demand and technology performance across Australia. This includes calculations of heating load, system efficiency, and potential emissions savings under local weather conditions.

In remote areas such as regional WA and NT, where climate and access to gas networks differ significantly from urban areas, tailored assumptions were incorporated. For example, in the NT, natural gas is typically unavailable, and households rely on LPG cylinders. The model was adapted to estimate LPG energy content relative to natural gas and calculate the effective cost per MJ based on LPG cylinder pricing. Additionally, supply charges for LPG were excluded since households pay only for delivered gas rather than network access.

2.5 Summary

The extension of the tool across Australia, mapping postcodes to climate regions and incorporating region specific tariffs provides localized, climate-sensitive, and tariff-accurate estimates of water heating performance, costs and emissions across Australia.

3 Payback Period Analysis

3.1 Introduction

Hot water systems are essential in all Australian households, and a range of technologies are available including electric resistive water heaters (R-DEWH), gas systems, and increasingly, heat pumps. While R-DEWH and gas remain common, heat pumps are gaining popularity due to improved energy efficiency, lower running costs, and government incentives. A critical financial consideration for households is whether to replace their current water heating technology now (while existing system is still functional) or wait until the system reaches the end of its life for the replacement. Each decision pathway has different financial implications, particularly in terms of capital costs, rebates, operational savings, and the resulting payback period.

The SolarShift Customer Hot Water Roadmap tool addresses this complexity by evaluating the economics of early replacement versus replacement at end-of-life, across all Australian climate zones, electricity/gas tariff regions, and control strategies. This section provides updated results on payback periods and outlines how customers can use this data to make informed, cost-effective decisions that also reduce emissions and enhance sustainability.

3.2 Method

To provide a comprehensive view of switching costs and savings, two types of payback period scenarios have been analyzed across various regions in Australia using climate zone-specific consumption profiles and regional electricity/gas tariffs:

***Switching scenario:** This applies when the customer chooses to replace a working resistive or gas system before it fails. In this case, the full capital cost of the heat pump is considered as an upfront investment.

Simple Payback Time = (Capital Cost of Heat Pump – Rebate) / Annual Savings

***End-of-Life scenario:** This applies when the existing system is no longer functional and a replacement is required anyway. The payback here considers only the additional cost of installing a heat pump over a like-for-like replacement.

Simple Payback Time = ((Capital Cost of Heat Pump -Rebate) − Capital Cost of Replacement Tech) / Annual Savings

Annual savings are defined as the difference between the running cost of the existing technology and the heat pump, accounting for tariff type, usage profile, and control strategy. In this analysis, we examined both “premium” (higher-cost, longer-warranty such as Reclaim) and “standard” (lower-cost, shorter-warranty such iStore) heat pump systems.

Figure 3 displays a schematic for the tool summarizing how key components come together to predict the annual water heating bill, net present costs (NPC) and payback period when switching across technologies and control methods.

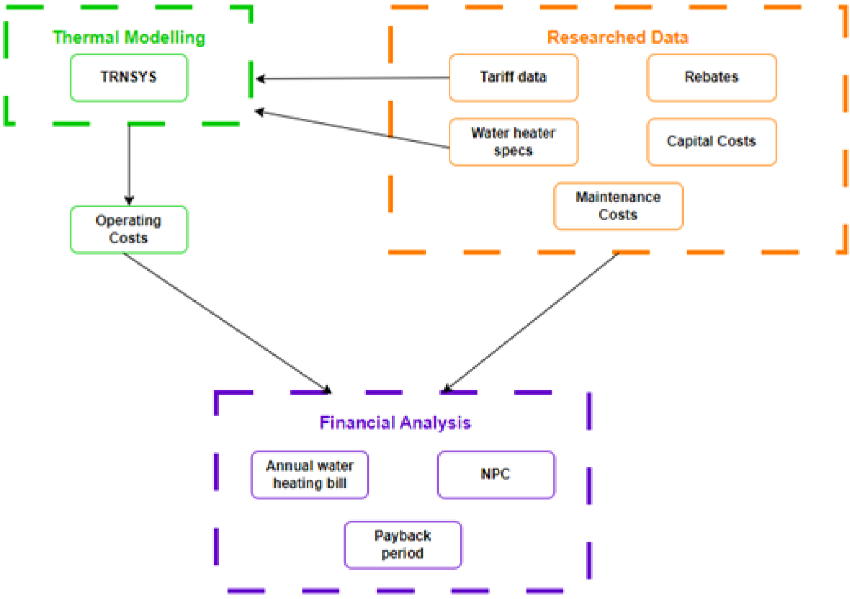

Figure 3. Schematic overview of Customer Hot Water Roadmap financial analysis process.

3.3 Results and Discussion

Our modelling reveals that switching from resistive and gas systems to heat pumps offers compelling financial and environmental benefits, especially in regions with access to solar PV and favourable climate conditions. Figure 4 below shows Annual Water Heating Costs Comparison by different Technology for a household in Sydney with 4 and HWDP = 1.

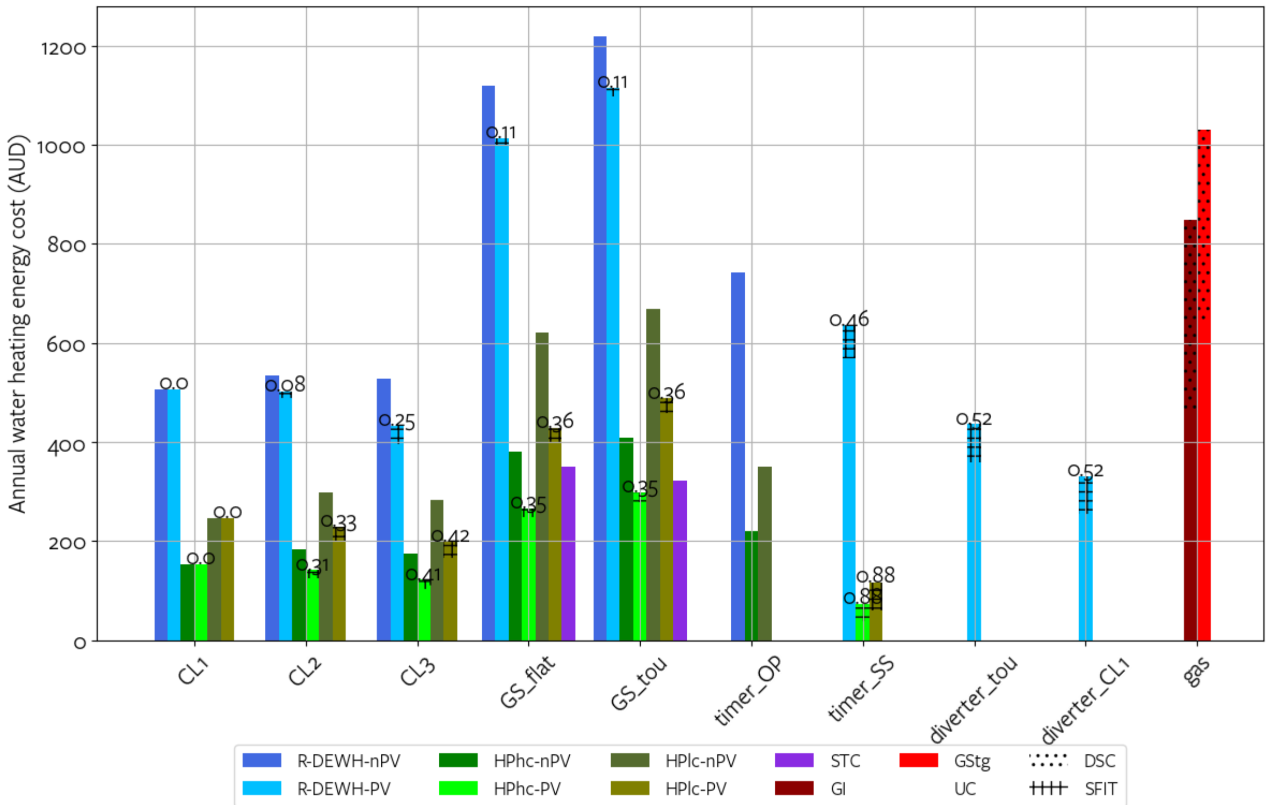

Figure 4. Annual water heating bill for household of 4 in Sydney with HWDP = 1.

Annual water heating bills are generally lower for controlled load tariffs than general supply due to the significantly cheaper kWh price of the controlled tariff. Energy retailers in Sydney charge the same usage rates for controlled load 1 and 2, the difference between these two results reflect the 5% larger period of use provided under CL2 as shown in Figure 4. Under general supply, heat pump and solar thermal systems with electric boost result in lowest annual bills. A water heating technology with PV option results in lower bills compared to no PV option, if one assumes that households can self-consume PV for water heating even for controlled load cases 2 and 3 (this is a theoretical scenario as it is not currently allowed by DNSPs). The lowest bills are achieved for a household with heat pump on general supply with rooftop PV and timer set to operate during solar hours (timer_SS).

Interestingly, the usage costs for gas systems, specifically an instantaneous system is competitive with some of the electric systems. This is because gas rates are generally lower compared to electricity rates. The gas connections costs known as a daily supply charge (DSC) heavily impact the total annual water heating bill for these systems where gas is not used for any other purpose in the house. It is important to note that gas systems result in higher emissions under all circumstances but especially compared to scenarios where rooftop PV is utilized, or grid electricity has significant proportion of renewable energy generation (i.e. South Australia or Tasmania).

It should be noted that although heat-pumps are analysed under controlled load, this may not be recommended by certain manufacturers. A sudden power cut to the heat pump during operation may damage the compressor impacting unit’s lifespan. Moreover, controlled load may interrupt with de-frost cycles of heat pumps that are used in colder climates.

To provide a more comprehensive financial analysis, the Net Present Cost (NPC) over 10 years is evaluated in Figure 5. This includes initial capital costs (IC), usage costs (UC), maintenance (MC), daily supply charges (DSC), and missed solar feed-in tariff (SFIT) revenue when solar energy is used for water heating. While heat pumps and solar thermal systems have lower annual bills, their high upfront costs lead to higher NPCs than resistive systems. The analysis assumes full system replacement and excludes upgrade rebates. NPC variation across control strategies is modest, though using a standard heat pump with a timer results in the lowest NPC, comparable to heat pumps on controlled load. Although premium heat pumps cost more, their longer lifespan may yield the lowest NPC in practice. Instantaneous gas could also be cost-effective if supply charges were removed.

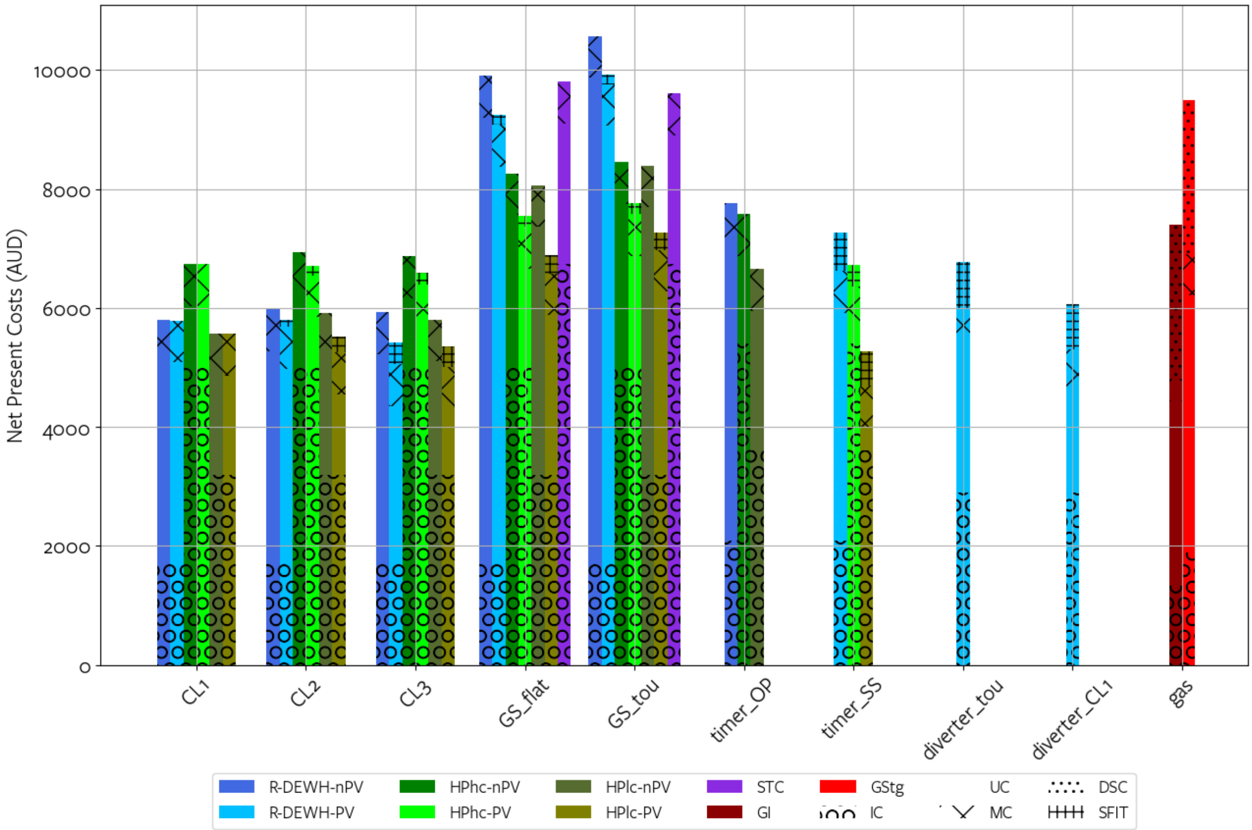

Figure 5. Payback Period – End-of-Life Scenario for Replacement from R-DEWH and Gas to Heat Pumps.

Figure 6 illustrates the payback periods for hot water system upgrades under two key scenarios: Switching Scenario (top graph) and End-of-Life Scenario (bottom graph). These scenarios represent two different decision-making points for households:

- The Switching Scenario reflects the case where a household chooses to replace a functioning resistive or gas hot water system with a more efficient technology such as a heat pump or solar thermal system.
- The End-of-Life Scenario considers system replacement at the point of failure or natural retirement, meaning the household would need to install a new system regardless, making efficient options even more cost-effective due to avoided baseline system costs.

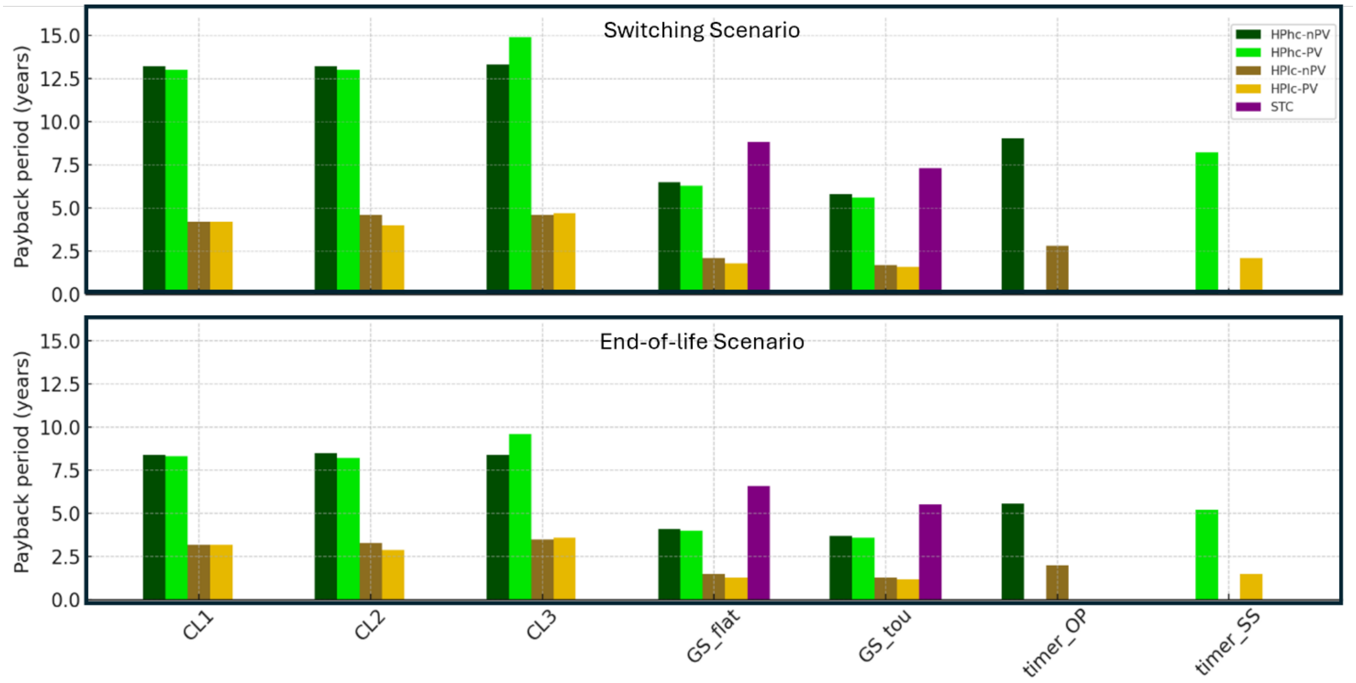

Figure 6. Payback period for a household of 4 in Sydney with HWDP=1, comparing upgrades from a resistive DEWH to either a Premium (higher-cost) heat pump, Standard (lower-cost) heat pump (with and without rooftop PV), or solar thermal system under two scenarios

The SolarShift WebApp enables users to explore these scenarios in detail by selecting different tariffs, control strategies, and technologies. In both scenarios, heat pumps emerge as a compelling choice. They are highly efficient, reduce household energy bills, and provide additional emissions reductions when coupled with rooftop PV. Importantly, they are not dependent on gas infrastructure, making them particularly attractive for remote communities or households using bottled LPG, such as those in parts of the Northern Territory and Western Australia.

Under the Switching Scenario, payback periods are generally longer due to upfront capital costs; however, all DEWH configurations analyzed show paybacks within their respective warranty periods, a promising signal for consumers. Notably, general supply connections (GS_flat and GS_tou) achieve payback in around 4 years, even for the premium heat pumps.

By contrast, the End-of-Life Scenario reflects shorter payback periods across the board, since baseline replacement costs are already assumed. This scenario demonstrates how timely upgrades at system retirement can deliver even greater financial returns.

Additionally, the NSW Energy Savings Scheme (ESS) provides rebates for energy-efficient hot water upgrades, which are incorporated into these payback estimates. These incentives help lower upfront costs and improve the attractiveness of investment for households when choosing a sustainable water heating solution.

Key findings:

- Households with rooftop solar and a heat pump configured to operate during solar soak periods achieve the lowest annual hot water bills.
- The high upfront cost of premium heat pumps and solar thermal systems can present a financial hurdle for households investing in new systems, as highlighted by the NPC results.
- The largest cost over a ten-year period for resistive heaters is the annual usage costs, whereas for both the premium and standard heat pumps and solar thermal heater, it is the initial costs and investment.

- Controlled Load tariffs can delay payback due to their lower energy costs; however, timer or solar soak strategies under general supply results in significantly lower payback periods.
- Payback periods are generally shorter under the End-of-Life scenario compared to the Switching scenario, due to avoided baseline system costs. Lower-cost heat pumps paired with rooftop PV consistently deliver the lowest payback across both scenarios.
- General supply connections (GS_flat and GS_tou) offer the most favourable economic outcomes, with payback often within 4 years. Timer-based controls show moderate improvements, but less benefit than tariff-optimized connections.

3.4 Summary

The SolarShift Customer Hot Water Roadmap Tool now includes payback calculations under two pathways, standard (early switch) and end-of-life—enabling users to weigh decisions across different financial circumstances. Households can evaluate their individual case based on postcode, tariff, system size, and climate.

Advantages of switching to heat pumps:

- Substantial reduction in annual water heating bills
- Significantly lower emissions, especially when using PV
- Attractive payback periods for Standard heat pump (<3 years, <2 years with rebates)
- Independence from gas infrastructure or LPG refills in remote regions

Considerations:

- Upfront capital cost is higher than resistive systems
- Requires suitable electrical connections and installation conditions
- Controlled load tariffs may interrupt compressor operations, limit defrost cycles or operational efficiency in cold regions

This financial lens is critical to support customer decision-making. In the next chapter, with integrated postcode, tariff, and climate data will be explained in more details with personalized, scenario-based recommendations.

4 SolarShift WebApp

4.1 Introduction

To ensure that the findings of the project are accessible to everyday Australian households, a public-facing interactive WebApp has been developed and deployed at: SolarShift.Streamlit.app. This tool is designed to guide users through the decision-making process for upgrading or replacing their hot water systems by providing localized insights into energy use, technology options, costs, emissions, and payback periods.

The app enables postcode-specific analysis by integrating real-world tariff data, climate zone mapping, and energy performance models of different water heating technologies, including resistive, gas, solar thermal, and heat pump systems. It allows users to explore technology performance under current and future scenarios and compare financial and environmental outcomes in a simple, user-friendly interface. This section serves as a user manual, demonstrating each step of the household decision-making journey within the tool.

4.1.1 Functionality and User Experience

The SolarShift WebApp is built using Python and the Streamlit framework. The tool extracts data from a large database (spread-sheet) which includes all the parameters and results for each simulation configuration. The structure of the application includes several core tabs that help users navigate their journey (Figure 7):

- **Home Tab**: Provide context about the SolarShift project, partners, and methodology.
- **Begin Tab**: Allows users to enter their postcode, household size, technology type, PV ownership, and tariff type to get their water heating energy bills and emissions
- **Compare Tab**: Helps users compare multiple technologies side-by-side to identify the most cost-effective and sustainable option.
- **Advanced Explorer Tab**: Displays detailed analysis for various simulations for specific technology setup in terms of cost, emissions, energy use, and bill components. This section is geared more towards experienced users or researchers.

4.1.2 Home Tab

This tab introduces the WebApp and outlines its objectives. It gives users an overview of what the tool offers, including support for assessing resistive, gas, solar thermal, and heat pump systems, along with various control strategies (timers, diverters, controlled loads). By clicking on the button “Start your journey to smarter water heating today” (shown in Figure 7), users can start their journey throughout the WebApp which prompts them to the Begin Tab.

Figure 7. SolarShift Customer Hot Water Roadmap WebApp Home Page.

4.1.3 Begin Tab

In the Begin tab, users are first prompted to enter their postcode. For example, Figure 8 shows the entry of postcode 2600 for the city of Canberra. Once a valid postcode is entered, the remaining questions appear in order. Figure 8 illustrates a sample scenario for a hot water system in Canberra, based on the following inputs:

- Household size
- Hot water usage pattern
- Solar PV ownership
- Current water heater technology (e.g., Electric, Gas Instant, Gas Storage)
- Tariff type (Flat rate electricity, Time-varying rate, Gas)
- Control strategy (e.g., Run as needed, Timer, Controlled Load)

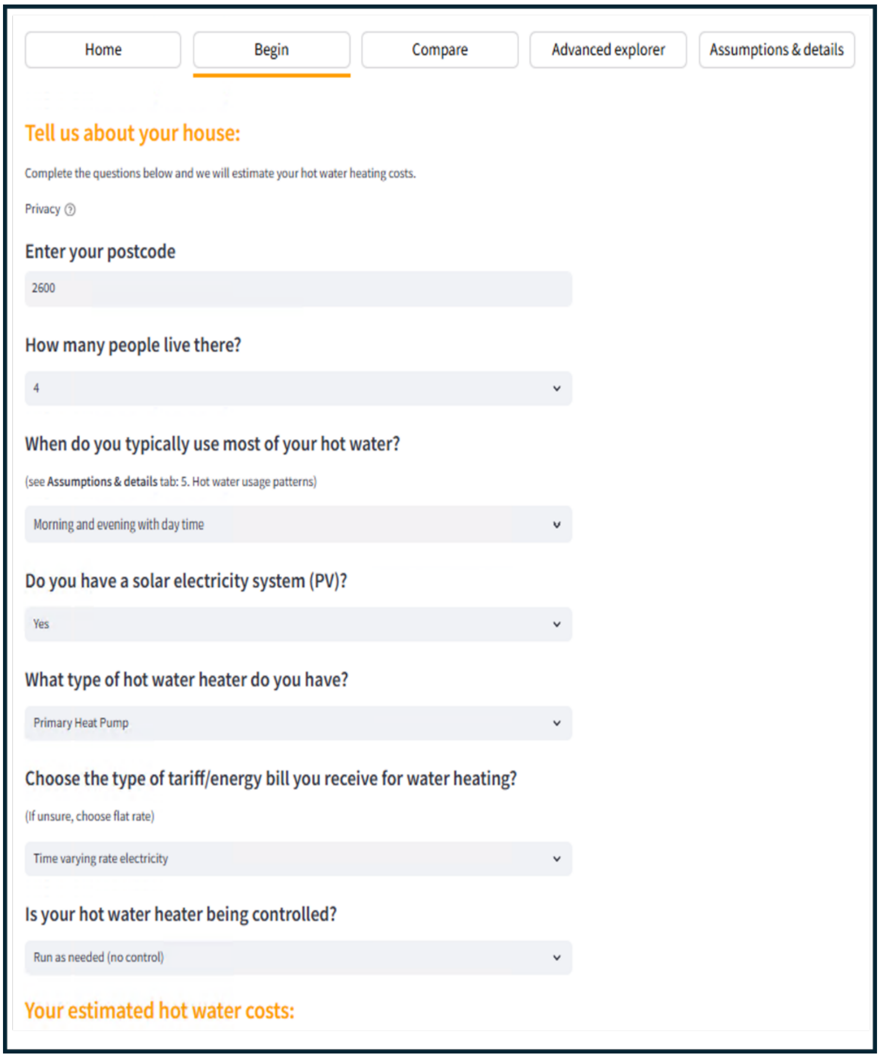

Figure 8. Begin tab in SolarShift WebApp, users enter household details for a custom analysis.

Each selection made by the user dynamically filters through a precomputed dataset stored in a large excel spreadsheet, returning accurate and fast results without requiring the user to have technical knowledge (Figure 9). Results include annual cost, up-front cost, rebates and decrease in solar export revenue in spending summary chart, following by net present cost (NPC) over 10yrs and annual CO_2 emission in the simple financial summary and environmental summary charts, respectively.

If the current system was selected as Electric, Gas Instant, or Gas Storage, payback periods under both early replacement and end-of-life scenarios will be appeared as described more in details in section 4.2.2.1. After reviewing the payback and emissions summary, users can click one of the "Compare" buttons located at the bottom of the section. This action takes them directly to the Compare tab, where they can evaluate side-by-side results between their current system and a selected alternative under the same postcode and household configuration.

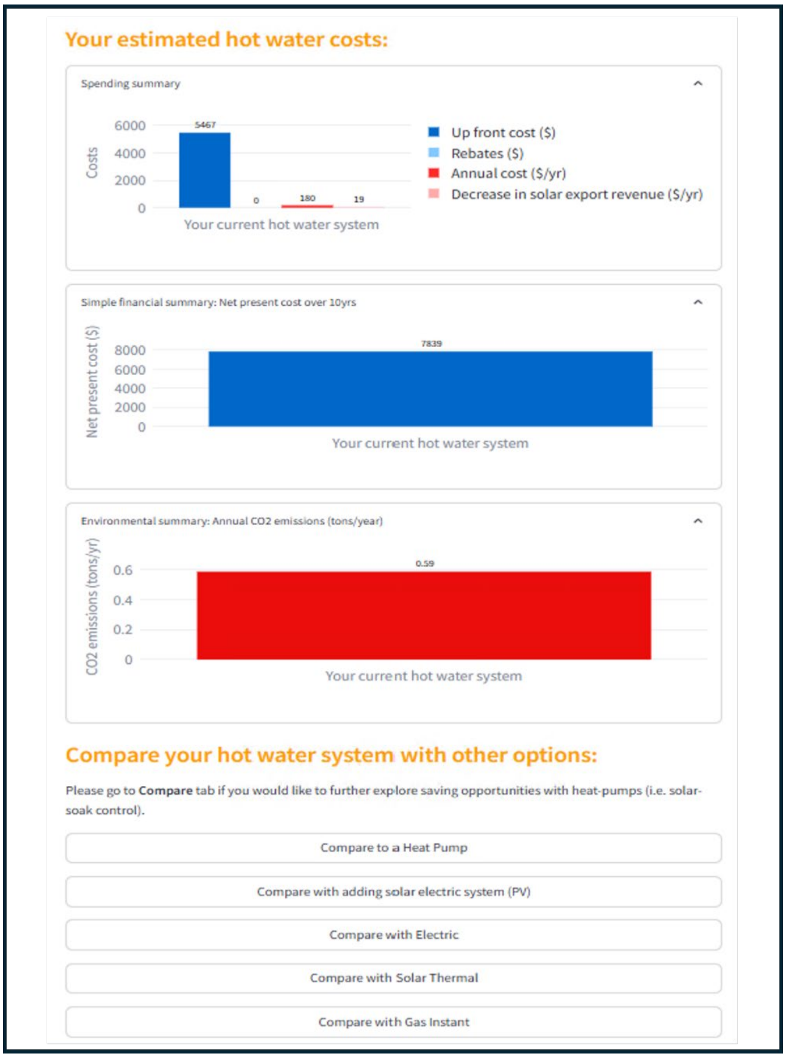

Figure 9. Begin tab in SolarShift WebApp provides an instant estimate of the current hot water system's annual cost and offers options to compare with alternative technologies.

If the user selects Electric, Gas Instant, or Gas Storage as their current technology, an additional prompt appears:

"Would you like to find out the finances and emissions after switching to a heat-pump?"

They are then offered the following options:

- Yes, my current system comes to the end of life and needs a replacement (End-of-Life scenario)
- Yes, I just want a more efficient system (Switching scenario)
- No

If "Yes" is selected, payback period under Switching and End-of-life scenarios are calculated to switch the current system to a Premium or Standard heat pump options. User can select from three discount rate options (0.02, 0.04, 0.06) to explore the financial benefits considering the interest rate. Followed by payback period charts, annual CO_2 emissions for current and alternative systems are also shown.

In Figure 10, payback period is calculated for both payback scenarios when switching from an electric resistive hot water system to a premium (higher cost) and standard (lower cost) heat pump. When calculating the payback period, other parameters such as tariffs, HWDP and number of people remains the same. Currently, premium heat pumps offer a longer payback period and lower emission intensity compared to standard heat pump. User can also experience a shorter payback period by choosing the first option 'end-of-life scenario', in case their current system needs to be replaced urgently.

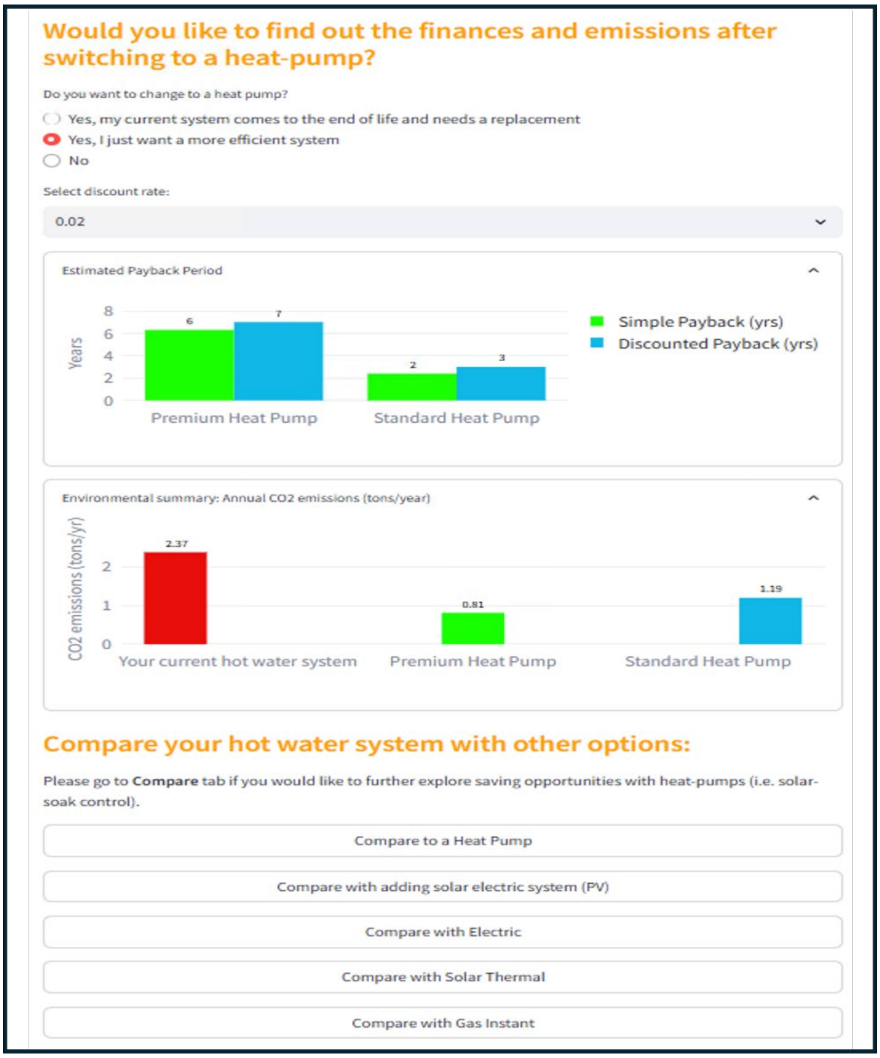

Figure 10. Begin tab in SolarShift WebApp provides payback period for both Standard and End-of-life scenarios. It also provides annual CO_2 emissions for current and alternative systems.

4.1.4 Compare Tab

Once a hot water technology is selected for comparison in the "Begin" tab (Figure 9), the app automatically navigates the user to the "Compare" tab (Figure 11). This tab shows a side-by-side performance comparison of their current water heater technology and set up against an alternative one. Inputs from the Begin tab are preserved, and users can then select and explore a variety of configurations, such as different household sizes, hot water usage patterns, heater types, billing/tariff types, control strategies, and with or without a solar system to compare against their existing setup. The output includes:

- Cost comparison: upfront, rebate, annual cost
- Net Present Cost comparison over 10 years
- Emissions comparison (CO2 tons/year)
- Tabular breakdown of financial and environmental performance

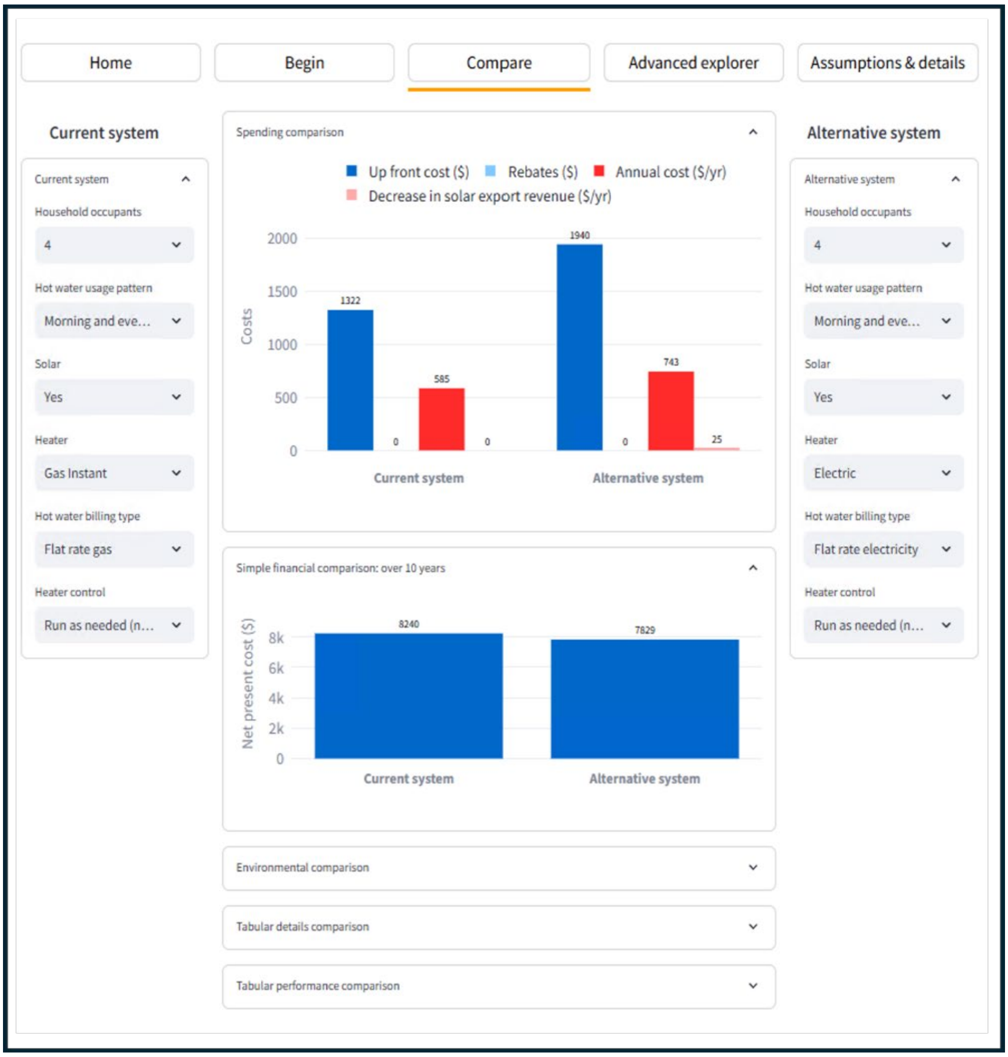

Figure 11. Compare Tab showing side-by-side comparison of Gas Instantaneous vs electric systems for Postcode "2600" selected in Begin Tab.

4.1.5 Explore Tab

This tab is designed for more experienced users such as researchers and analysts. It supports multi-postcode input shown in Figure 12, 800 and 2600 for Darwin and Canberra, respectively, enabling comparisons across several regions simultaneously. Users can filter and explore all available technologies specific to all postcodes across Australia. In this tab, the visual output includes:

- Scatter plots of annual costs by technology
- Tabular summaries of Net Present Cost, annual cost, supply cost, export loss, and emissions

By inputting household characteristics and selecting different heater and control types, users can interactively explore tailored simulation results. Users can further customise their analysis by selecting specific parameters through the "Chart Options" panel on the left-hand sidebar. Available parameters, such as those shown in the table header at the bottom of Figure 12, allow for tailored exploration of key financial and environmental metrics.

At the bottom of the page, in Tabular Summary, additional insights are available to help guide decisions. Selecting the "Average" option displays the average financial and environmental outcomes for the selected technologies considering all relevant simulation outputs. Alternatively, choosing the "Show All" option reveals a comprehensive breakdown of all combinations of these parameters, presented in detail based on simulation results (Figure 12)

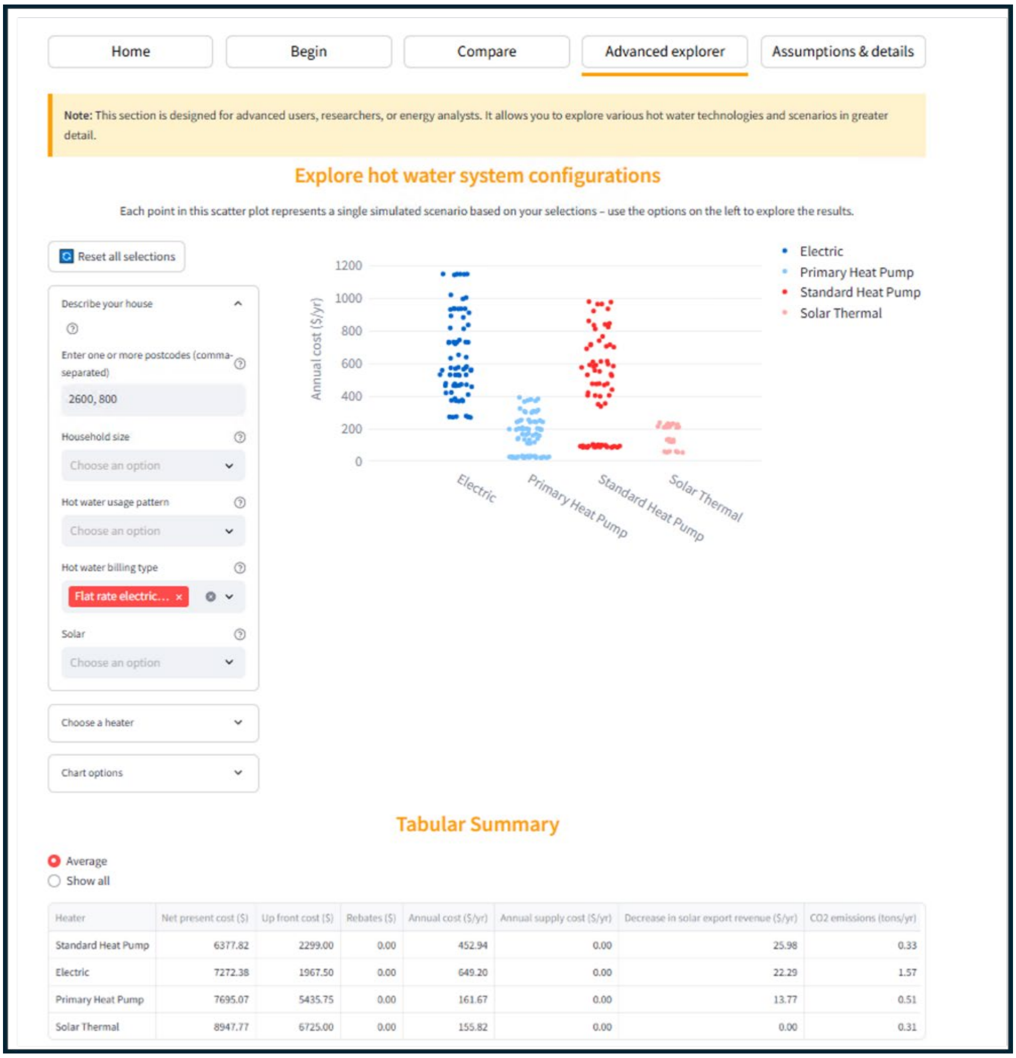

Figure 12. Advanced Explorer tab showing all detailed information.

4.1.6 Assumptions & Details Tab

This tab provides comprehensive background information on how the SolarShift simulations are conducted and the assumptions behind the results. It outlines the underlying assumptions used in the simulations and includes:

- Technology cost parameters
- Tariff structures
- Efficiency assumptions and hot water draw profiles
- Maintenance and rebate schedules

It explains the methodology used to estimate both the energy consumption and financial costs of hot water systems, including a two-stage process: thermal simulation and cost calculation. This section also explains how different system types, electric, heat pump, gas (instant and storage), and solar thermal, are modelled under varying usage patterns, tariffs, and control strategies. Users can explore the different billing structures (flat rate, controlled load, time-of-use), hot water draw profiles, and the environmental impacts such as CO_2 emissions. It also outlines all available heater control options (e.g., running overnight or matching solar generation) and highlights the various technology combinations explored in the simulations. Overall, the Details tab provides transparency by providing users with the technical context and assumptions behind the app's outputs.

4.2 Architecture and Development

The WebApp is built with Python and Streamlit. Its source code is available at:

https://github.com/UNSW-CEEM/SolarShift.
The key components include:

- “app.py”: Sets up the WebApp structure.
- “tabs/”: Contains modular files for each user-facing tab.
- “data/hotwater_data.csv”: Core lookup table containing all model outputs.
- “helpers/` and `data_processing/”: Manage backend logic for filtering, selecting, and processing input data.
- “graphics/” and “images/”: Responsible for all visual styling and images including logos and usage charts.
- “style.py”: Controls UI consistency and layout.
  This modular design allows the research team to update model inputs and user interface features efficiently without rewriting the full codebase.
-

4.3 Summary

The SolarShift Customer Hot Water Roadmap tool incorporates simulation results into a platform that allows users to assess water heating technologies based on cost, emissions, and payback. The modelling confirms that heat pumps with rooftop PV, and solar-soaking controls typically result in the most favourable outcomes. By providing postcode-specific financial and environmental comparisons, the tool supports evidence-based technology evaluation for Australian households. Key upgrades include:

- A case-specific payback feature for Electric, Gas Instant, and Gas Storage users
- Discount rate selection for financial analysis
- Updated postcode-first workflow in the Begin tab
- Multi-postcode comparison in the Advanced Explorer
- Refined structure and rebranded "Assumptions & Details" tab

5 Discussions and conclusions

5.1 Key Insights and Implications

5.1.1 Postcode Mapping and Climate/Tariff Alignment

- Mapping all Australian postcodes to Bureau of Meteorology (BOM) climate zones and distribution network service providers (DNSPs) allowed for more localized and accurate modelling of heating demand and system performance.
- Regional tariff data, including electricity (flat, TOU, controlled load) and gas rates, were integrated into the modelling, ensuring location-specific financial results across Australia.
- This mapping provides a powerful framework for tailoring hot water technology recommendations based on climate, pricing, and energy infrastructure.

5.1.2 Financial Payback and Technology Comparison

- Two financial pathways: standard replacement and end-of-life upgrade, were modelled across thousands of postcode-climate-tariff combinations.
- Households switching to low-cost heat pumps, especially in solar-rich regions with favourable tariffs, can achieve payback periods under 2-3 years.
- The most financially beneficial configuration involved a heat pump + rooftop PV + timer control, which consistently delivered the lowest annual bills and emissions.
- Although solar thermal systems also provided low running costs, their high upfront costs and complexity limited their financial competitiveness in many cases.
- Controlled load tariffs offered modest savings but they may be incompatible with some heat pump brands due to interrupting compressor cycles and potential shortening of lifecycle.

5.1.3 WebApp Development and User Empowerment

- The SolarShift Customer Hot Water Roadmap WebApp translates research into actionable insights, allowing users to compare annual costs, emissions, net present cost (NPC), and payback periods across technology options.
- The app’s interactive design enables users to input household size, location, PV ownership, heater type, tariff, and control strategy, returning tailored results without needing technical expertise.
- Tabs like Compare, Advanced Explorer, and Details offer different levels of information depth, from high-level recommendations to full transparency on methodology and model assumptions.
- This publicly available tool bridges the gap between complex modelling and consumer decision-making, supporting large-scale adoption of efficient technologies.

5.2 Reflections on Broader Impacts

The integration of real-world tariff structures, weather data, and user behavior into a unified water heating modelling and recommendation platform is a novel contribution. The SolarShift framework offers:

- For households: Confidence in making cost-effective and sustainable technology choices tailored to their conditions.
- For policymakers: Evidence-based insight into where incentives and standards could have the greatest impact.
- For industry and utilities: A foundation for customer engagement tools and future DER orchestration strategies.

While this report focuses on modelling, WebApp development, and customer impact, it also complements earlier SolarShift research that explored the broader benefits of smart DEWH control, such as grid voltage support and participation in wholesale energy markets.

5.3 Limitation and Future Work

While the current model is robust and nationally scalable, several opportunities exist for refinement:

- More granular climate and tariff datasets could further increase result accuracy at suburb or feeder level.
- Smart meter integration could enable real-time feedback or control recommendations.
- Behavioural trials could validate user interactions with the WebApp and the likelihood of uptake.
- WebApp enhancements may include lifecycle costs, carbon offset estimates, or co-benefits like reduced LPG reliance in remote areas.
- A more efficient web hosting platform can improve reliability of the tool
- Integration with battery energy storage system and EVs can make the tool more comprehensive

5.4 Conclusion

Thermal modelling conducted in the SolarShift project quantifies the cost and emissions impacts of switching from conventional water heating systems to alternatives such as heat pumps, with and without rooftop PV. Scenario analysis using postcode-specific tariff and climate data indicates that combinations involving heat pumps, PV systems, and solar-aware control strategies typically result in lower operational costs and emissions. The WebApp presents these outcomes in a structured format, enabling households to compare technologies and make informed decisions based on research and modelling focusing on real-world conditions.

Appendix A: Nomenclature and abbreviations

Table 5. Nomenclature

Abbreviations	Explanation
DSC	Daily supply charge Costs
SFIT	Solar feed-in tariff – missed opportunity costs from using solar generation rather than exporting to the grid
CL	Controlled Load
tou	Time of Use
GS	General Supply
SS	Solar Soak
OP	Off-Peak
HWDP	Hot Water Draw Profile
DEWH	Domestic electric water heating system
R-DEWH	Resistive type domestic electric water heating system
HP-DEWH	Heat-pump type domestic electric water heating system (used interchangeably with heat-pump, HP)
HP	Heat-pump (used interchangeably with HP-DEWH)
DNSP	Distributed network service provider
Plot Legend	
R-DEWH-nPV	Resistive domestic electric water heater with no PV
R-DEWH-PV	Resistive domestic electric water heater with PV
HPhc-nPV	Premium (higher cost) heat-pump with no PV
HPhc-PV	Premium (higher cost) heat-pump with PV
HPlc-nPV	Standard (lower cost) heat-pump with no PV
HPlc-PV	Standard (lower cost) heat-pump with PV
STC	Electric boosted solar thermal water heater
GI	Gas instantaneous water heat
GStg	Gas storage water heater
IC	Initial Costs
US	Usage Costs
MC	Maintenance Costs
DSC	Daily supply charge Costs
SFIT	Solar feed-in tariff – missed opportunity costs from using solar generation rather than exporting to the grid

Appendix B: Parameter Descriptions and Assumptions

Table 6. Cost Parameter Assumptions

Feature	Estimated costs ($AUD)	Additional Information
Resistive heater (4 people, 315L), Rheem, NSW supply and install	1690	
Higher cost Heat pump (4 people, 315L), Reclaim Energy, NSW supply and install	5000	Including small-scale technology certificate rebate
Lower cost heat pump (4 people, 270L), iStore, NSW supply and install	3200	Including small-scale technology certificate rebate
Solar thermal heater (315L), Rheem, Split system, supply and install	6500	Including small-scale technology certificate rebate
Gas storage heater (170L), Rheem, NSW supply and install	1785	
Gas instantaneous heater (26L), Rheem, supply and install	1322	
Resistive maintenance	550	• Every 4 years • Anode replacement • General maintenance
Heat pump maintenance	550	• Every 4 years • Anode replacement • General maintenance
Solar thermal maintenance	550	• Every 4 years • Anode replacement • General maintenance
Gas storage maintenance	550	• Every 4 years • Anode replacement • General maintenance
Gas instantaneous maintenance	300	Every 4 years
Timer, supply and install	400	
Diverter, supply and install	1200	
Establish new electric connection	250	

Table 7. Ausgrid DNSP tariff rates, taken as an average on Origin, AGL and Energy Australia Rates

Tariff Name	Tariff Rate ($AUD)
Ausgrid CL 1	DSC = 0.00/day
	Rate = 0.179/kWh
Ausgrid CL 2	DSC = 0.00/day
	Rate = 0.179/kWh
Ausgrid CL 3	DSC = 0.00/day
	Rate = 0.179/kWh
Ausgrid flat	DSC = 1.01/day
	Rate = 0.370/kWh
	SFIT = 0.0500/kWh exported
Ausgrid tou	DSC = 1.12/day
	Peak rate = 0.645/kWh
	Off-peak rate = 0.251/kWh
	Shoulder rate = 0.346/kWh

	SFIT = 0.0500/kWh exported
Gas	DSC = 1.0549/day
	0 – 20.71MJ = 0.0545/MJ
	20.71 – 41.1MJ = 0.0386/MJ

Table 8. Customer hot water roadmap general assumptions

General Assumptions
• **PV system used for analysis: 5 kW AC rooftop PV system**
• **Households with solar thermal water heaters will not also have a PV system**
• **Solar thermal heater will only be considered for households with 3 or more people**
• **Lower cost heat pump will only be considered for households of 4**
• **Controlled load (CL) strategies are modelled with self-consumption assumption for cases with PV (i.e., as if they can switch circuits between the general supply & controlled load). In reality this is not possible as hot water system are connected to a separate electrical circuit. This assumption allows a potential future scenario where switching between the control load and general supply is possible**
• **State specific supply and installation costs are considered where possible, and an average is taken where it is not.**
• **Solar feed in tariff (SFIT) is considered as a missed opportunity cost when it is used for water heating. The solar generated power is self-consumed rather than exported/sold to the grid at the rate specified by energy retailers**
• **Daily supply charge for electric systems connected to general supply not included in cost calculations (because household will have electricity for all other loads from general supply)**
• **Additional DSC specially for CL tariff is taken to be zero, as outlined by energy retailers in 2024-25 energy prices. It should be noted that DNSPs do include an additional DSC for controlled load circuits that is seemingly not passed on by energy retailers. Additionally, DNSP rates reveal different pricing for CL1 and CL2, energy retailers price the two CL rates the same.**
• **Gas daily supply charge (DSC) included in analysis, assumed when switching to an electric system gas account is not closed and the DSC will continue to be billed**
• **Weather data: JRC's TMY files for main cities in Australia (included in TRNSYS)**
• **For all systems with hot water storage tanks** ○ **Thermostat high temp = 65ºC** ○ **Deadband = 10ºC** ○ **Hot water consumption temperature = 45ºC**
• **Average daily hot water draw for household with 4 people = 200[L/day]**
• **PV option represent best case scenario, real results fall somewhere in-between this best-case scenario and nPV (no PV) options** ○ **In best case scenario, it is assumed water heating has priority over household load**

Table 9. Customer hot water roadmap technology assumptions

Technology Assumptions
Heat Pump: • Premium heat pumps (higher cost) considered are Reclaim Energy, glass lined heat pumps with a warranty of 10 years – more upper market option   ○ Variation for household size • Standard heat pump (lower cost) considered is the iStore heat pump with a warranty of 5 years and a lifespan of a similar time
Gas: • Modelled with 80% boiler efficiency, calculated based on technical data • Methane for heat value (47 MJ/kg) • Rheem gas storage and gas instantaneous heaters considered   ○ Variation for household size
Electric Resistive: • Rheem electric resistive heaters considered   ○ Variation for household size • All tanks have same values for losses (0.9W/m2-K) – not included in technical data • Efficiency of 1

Solar Thermal:
• 4 square meter system
• Using standard values for optics and thermal losses
    ○ FRta= 0.6
    ○ FRUL = 0.6 W/m2-K
    ○ IAM coefficient = 0.2
• Electric auxiliary heater
• Rheem loline solar thermal heater considered

Table 10. Net present cost assumptions

Net Present Cost Assumptions
Determined based on implementing an entirely new system, potential rebates for switching or upgrading old water heaters not included, however Small-scale Technology Certificate rebates are included.
Considering net present costs over a 10-year period with a discount rate of 8%
Scenario of reinvestment in cheaper heat pump is considered where system is replaced within the 10-year period (a second new system within bought in the 10-year period)

Table 11. Payback period assumptions

Payback Period Assumptions
Initial cost for current/old heater • Switching from resistive – initial costs included • Switching from gas storage – initial costs = $0
If payback period > 20 years, plotted as 20 years
If payback period < -20 years, plotted as -20 years
Switching cases considered switching between same tariff/control type • E.g. switching from a resistive heater on CL1 to a heat pump on CL1
Inclusive of state specific rebates for upgrading and switching scenarios (rebates for heat-pumps and solar thermal and in some cases resistive if you are switching from gas)

Appendix C: tm_solarshift open-source repository

The thermal simulations are carried out using the open-source repository "tm_solarshift" built specifically for this project. It is an object-oriented codebase providing a set of modules to perform thermal simulations, define control strategies, manage weather data and other timeseries profiles, specifically for domestic water heating systems. The python repository architecture is presented in Figure 13.

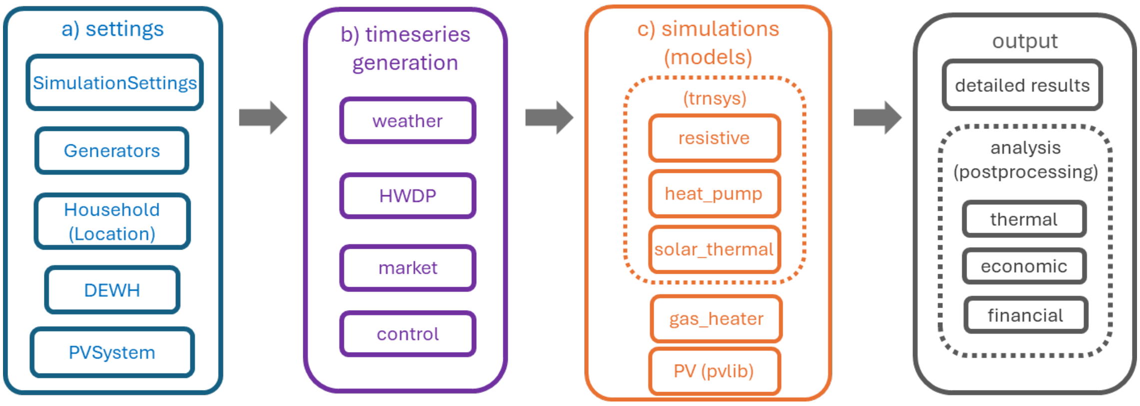

Figure 13. Architecture of the Python codebase for DEWH management system.

The package uses TRNSYS as the numerical engine to simulate the DEWH systems. TRNSYS is a commercial simulation software, widely used in renewable energy and building engineering, designed to perform fast annual simulations of complex interconnected systems. It includes an extensive library of component models (called *Types*) as well as tools for control and analysis. In the case of hot water systems, it includes 1D models for tanks that take into account the thermal stratification on the tank. TRNSYS is a widely used and accepted thermal simulation tool however, the main drawback is that testing different configurations and input parameters can be challenging because automating these simulations is not straightforward. Additionally, integrating external code from other sources like Python is not simple, and it does not allow external libraries (such as numpy, pandas, or scipy). For these reasons, this repository is almost completely based on Python, using TRNSYS only as the DEWH tank thermal engine.

A simulation is defined in this repository by four steps:

a) Defining the simulation settings (blue box in Figure 13),

b) Generating the timeseries required for the simulations (purple box),

c) Running the thermal simulation on TRNSYS with the conditions defined in the previous steps (orange box), and

d) Post-processing and analysis (grey box).

In the first step (simulation settings), three types of objects are created: General objects, Timeseries Generators and Models. The General objects contain the "real-world" data, such as the household's location, energy plan, and device's technical specifications. The Generators are modules designed to provide the required time-series using external sources (such as market or weather data) and/or synthetic data methods (for HWDP or control randomization). For DEWH system, specifically, TRNSYS models required weather variables (ambient and mains temperatures), hot water draw profiles (HWDP), and tank control signals. The Model objects run the simulations using the data provided in the previous two steps. In the results presented in this report, the most important object is the DEWH Model, which includes methods to run the TRNSYS simulations.

TRNSYS simulations are set using its graphical user interface (GUI) layout tool called Simulation Studio. Three layouts were developed in this research, one for immersive resistive heaters, one for heat pumps, and one for solar thermal collectors.

Figure 14 shows the layout for resistive heaters. On the resistive layout the following *types* (which corresponds to components in TRNSYS nomenclature) were used:

- Type 158: cylindrical storage tank with multiple ports and auxiliary heaters.
- Type 1226: Electric water heater with control signal.
- Types 647 and 649: mixer and flow diverters, respectively,
- Type 9a; plain-text data reader, used for timeseries,
- Type 953: controller for tempering valve,
- Type 1503: N-stages Aquastat, as maximum temperature control,
- Type 25c: printer for outputs (as plain text).
- Type 42b: double interpolator (for heat pump), and
- Equation types.

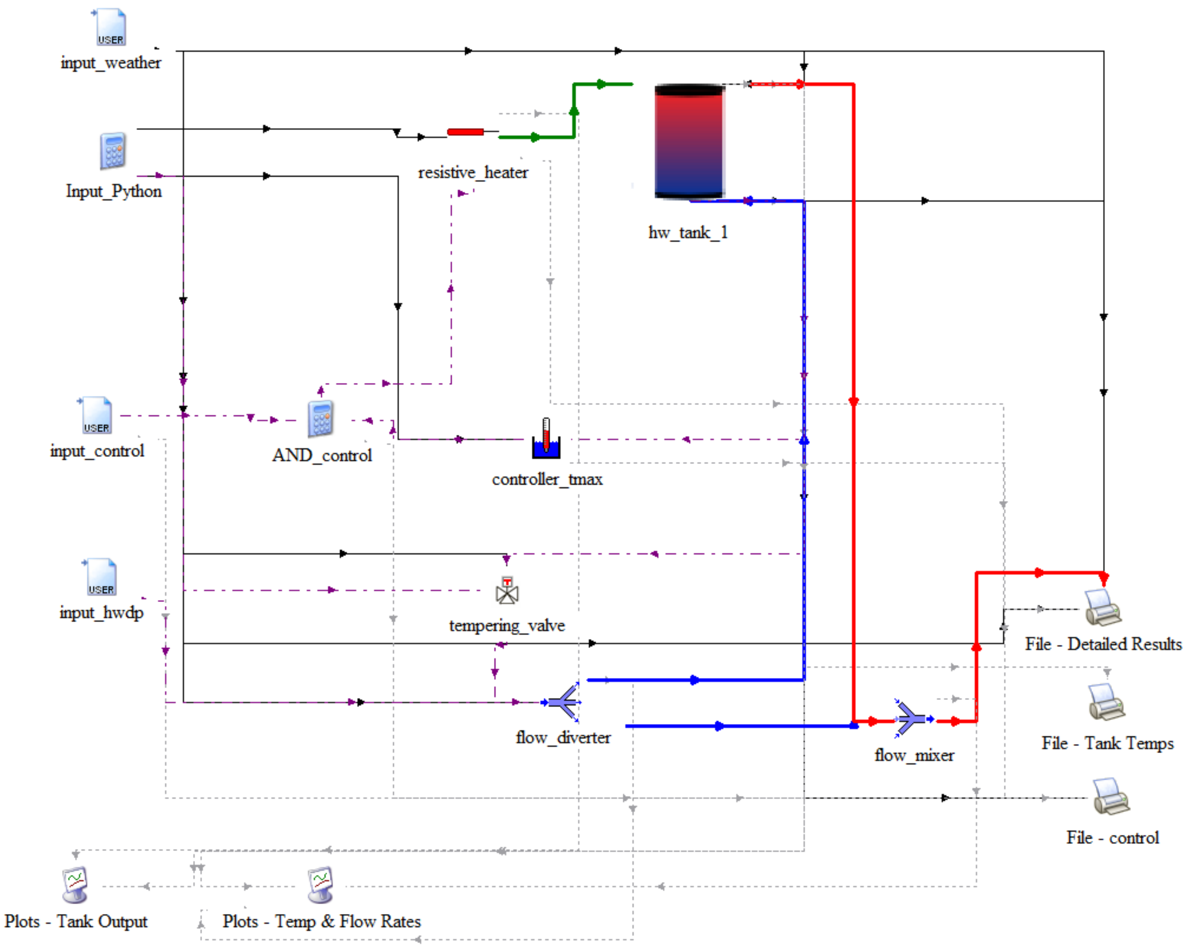

Figure 14. Layout in TRNSYS for resistive heater.

Appendix D: SolarShift WebApp open-source repository

The SolarShift Streamlit-based application provides a lightweight yet powerful front-end to explore the outcomes of the broader SolarShift research project. It serves as a user-facing tool to allow consumers and stakeholders to better understand different hot water heating options and their financial and environmental performance. The figure below outlines the core architecture and logic of this repository, in a way that parallels the simulation-oriented structure used in thermal simulations (as previously illustrated in Figure 13). The python/streamlit repository architecture is presented in Figure 15.

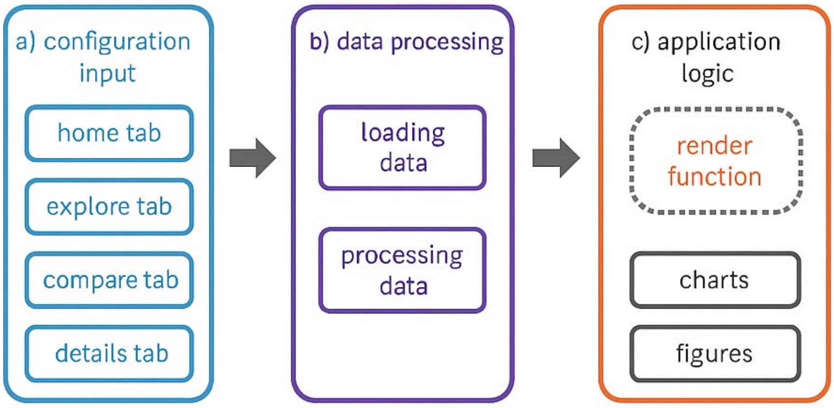

Figure 15. Architecture of the SolarShift Hot Water Roadmap WebApp built with Python and Streamlit.

The architecture of the SolarShift WebApp consists of three Premium layers represented by blue, purple, and orange boxes in the diagram, explained below.

The Configuration Input (Blue Box) layer is the user entry point of the application. It includes interactive tabs such as the home tab, explore tab, compare tab, and details tab. These tabs reside in the /tabs/ folder and each serves a specific function for guiding users through the tool—whether introducing concepts, comparing options, or viewing detailed outcomes. Input choices like location, heater type, and tariff are captured here. These inputs are complemented by the system_configs.py file, which defines how different system types (e.g., heat pump, gas, resistive) are categorized and displayed throughout the interface. Additionally, the data/hotwater_data.csv file acts as the repository of precomputed results for a wide range of configuration scenarios.

The Data Processing layer (Purple Box) handles backend logic for turning raw CSV data into tailored insights. This is primarily done via data_processing.py, which reads and validates the core dataset. Further transformation is conducted through helper scripts like data_selectors.py in the /helpers/ directory. These functions dynamically filter and restructure the dataset based on selections made by users in the input layer.

The Application Logic layer (Orange Box) forms the interactive and visual core of the application. Each tab file includes a render() function, which processes the user inputs and coordinates the data pipeline and interface updates. Visual outputs are created using charts.py and images.py within the /graphics/ folder, while styling is handled via style.py. These tools collectively produce clear, interactive visualizations such as bar graphs, emissions plots, and cost comparisons.

The application is built using the following technologies:

Streamlit for the user interface and dashboard interactivity.

- **Pandas** and **Altair/Plotly** for data manipulation and visual rendering.
- **UV** as the Python environment and dependency manager.

It is important to note that this application does not run simulations in real time. Instead, it leverages precomputed simulation results from the tm_solarshift pipeline and presents them in a highly accessible and intuitive format, effectively bridging technical results with consumer-facing insights.

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