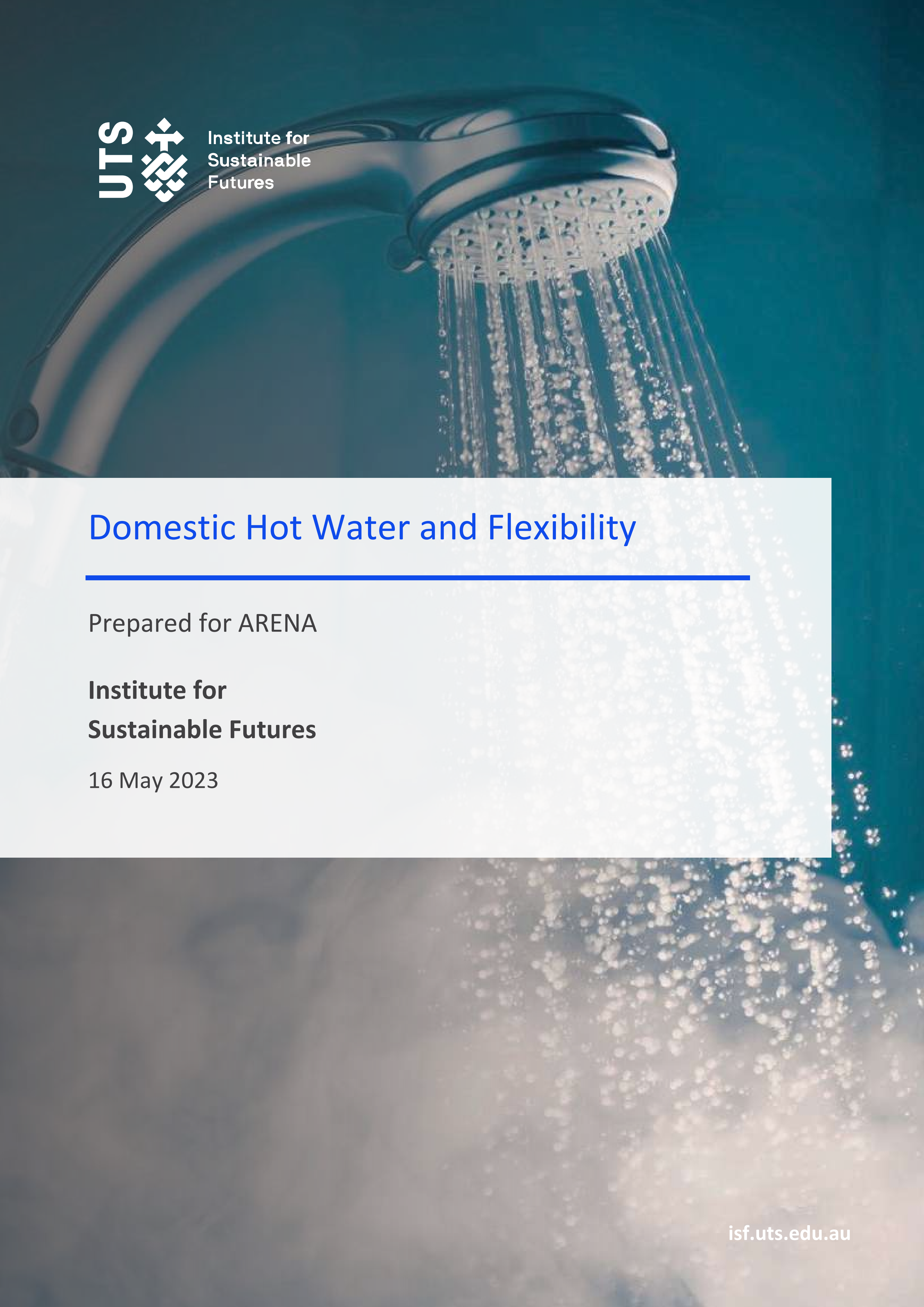

Domestic Hot Water and Flexibility

Prepared for ARENA

Institute for
Sustainable Futures

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ARENA

Australian Government
Australian Renewable Energy Agency

Executive summary

Background

Domestic hot water use is responsible for around a fifth of Australian residential greenhouse gas emissions and a quarter of household energy use. The Australian Government has committed to a 43% reduction in carbon emissions by 2030 and net zero by 2050.

Deploying electric water heating technologies is a key instrument for achieving these targets through enabling fuel switching, increasing efficiency, and supporting more renewables in the grid. However, the technologies best suited for this—heat pumps and electric storage—offer differing benefits in terms of efficiency, emissions reductions, upfront and running costs, flexibility, and ease of retrofit.

Heat pump water heaters can reduce energy use and emissions significantly and have received generous government incentives, but are not suitable for all homes. Electric resistance water heaters with storage are less efficient, but with 'smart' controls can provide greater demand flexibility that can support the integration of renewable energy in the grid while helping overcome resulting challenges such as minimum demand. Potential pathways are therefore likely to include optimising of existing electric storage systems to use renewable output, increased uptake of heat pumps where they can be installed, and a decline in the installed base of gas water heaters. However, these transition pathways are yet to be interrogated, while the costs and benefits of alternative scenarios remained unquantified.

ARENA commissioned the UTS Institute for Sustainable Futures to investigate these pathways and assess the potential role of domestic hot water as a flexible load that can accelerate the path to net zero. Four scenarios were developed following a review of the available literature, interviews with key stakeholders, and modelling of Australia's water heater stock out to 2040. A range of possible futures were explored in these scenarios, including a Business as Usual scenario, and alternative scenarios that emphasise flexibility (Highly Flexible), efficiency (Highly Efficient) or both (Rapid Electrification).

Key research findings

The results from this research found:

A Business as Usual scenario would represent a major missed opportunity to use domestic water heaters as a significant source of flexible demand equal to 15–31 GWh/day. Under the Highly Flexible scenario, electric water heaters could provide about 24 GW/50 GWh/day of flexible demand capacity by 2040, the equivalent of 70%/61% of AEMO's projections for behind-the-meter, coordinated DER storage capacity. This compares to 22 GW/45 GWh/day (64%/55%) for the Rapid Electrification scenario, 17 GW/34 GWh/day (48%/41%) for the Highly Efficient scenario, and only 9 GW/19 GWh/day (25%/23%) for the Business as Usual scenario.

The phasing out of gas water heaters in homes would provide consumers with combined annual savings of $4.7–6.7 billion by 2040. While the average user of gas hot water had lower annual bills than those with electric water heating in 2020, by 2030 they were projected to be significantly worse off. The gap between gas and electric household will further increase by 2040, with gas households then paying $660–960 per year more than those with a heat pump water heater.

Rapid electrification of water heating could reduce emissions three to five times more than remaining on the current trajectory. Both the Highly Efficient and Highly Flexible scenarios have similar emissions reduction potential by 2040 (1.2–1.4 Mt CO_2-e with 44–39% of emissions from gas DHW systems), while the Rapid Electrification scenario without any gas domestic water heating is able to reduce carbon emissions to 0.71 Mt CO_2-e. Under the Business as Usual scenario, annual GHG emissions from domestic water heating remain at 3.5 Mt CO_2-e in 2040, with 85% of this from gas systems.

Many barriers remain for driving the uptake of electric water heating in homes, and the activation of their flexible demand capacity. Heat pump water heaters offer higher efficiency and lower lifetime operating costs than gas or electric storage heaters. Government incentives and a growing consumer push towards electrification are increasing adoption of this technology, but this is being slowed by their higher capital cost, supply chain barriers, a lack of customer awareness, and existing policies that favour gas technologies. Electric resistance storage water heaters with 'smart' controls offer excellent potential for demand flexibility while having lower upfront costs and being easier to retrofit than heat pumps. However, their running costs and short-term emissions are higher, while activating this potential flexibility is currently hindered by a lack of easy solutions and compelling customer proposition.

When electrifying water heating, achieving positive outcomes does not require a choice between *either* efficiency *or* flexibility. All modelled alternative scenarios to Business as Usual resulted in significant positive outcomes in terms of reduced emissions, reduced energy costs to consumers, and increased demand flexibility. The benefits of the Highly Efficient and Highly Flexible scenarios are similar in scale, implying that a choice between achieving *either* flexible *or* efficient water heating is not required—both can be achieved at scale with the right policy mix.

Recommendations

As the research findings show, the pathways and enablers required to decarbonise and increase the flexibility of water heating are complex and hindered by multiple barriers. This is due to the fragmented nature of the water heater market and its supply chains, disjointed and outdated policy frameworks, as well as the physical constraints and technical complexities associated with retrofitting more efficient or flexible electric water heaters in Australian homes.

There is a compelling case for a more coherent and updated approach to policy for residential water heating, particularly given the context of climate change and high energy prices. Electrifying water heating provides major opportunities to reduce energy use and carbon emissions, protect against future energy price rises, and tap into a major source of energy storage to support integration of renewable energy in the grid. Addressing the barriers that are slowing the uptake of more flexible and efficient water heating options will likely result in improved outcomes for customers, while supporting federal and state targets for energy efficiency, renewable energy and net-zero emissions. This will require an integrated approach to improving customer knowledge and awareness, developing and upskilling supply chains, investing in research and development (R&D), and encouraging innovation and new business models.

Extended summary

Introduction

Domestic hot water accounts for about 20% of Australian residential greenhouse gas (GHG) emissions and 25% of household energy use (DISER, 2020). This makes it an important element in pathways towards net-zero emissions in Australia. Heat pump technology is generally seen as an essential element of decarbonising domestic hot water (DHW) owing to its high efficiency and ability to electrify household energy consumption. However, resistance electric hot water systems with storage also provide flexible demand (FD), which can support the integration of variable renewable energy sources in the grid while helping overcome resulting challenges such as minimum demand.

The analysis undertaken explores the potential role of domestic hot water as a flexible load during the energy transition. The ISF Hot Water System Stock (HoWSS) model was updated and employed to assess the size of the opportunity for domestic hot water to contribute to energy efficiency, demand flexibility, and reductions in both costs and greenhouse gas emissions. We also identified and analysed various technical, commercial, regulatory and other barriers to realising this opportunity, while mapping a number of potential deployment pathways.

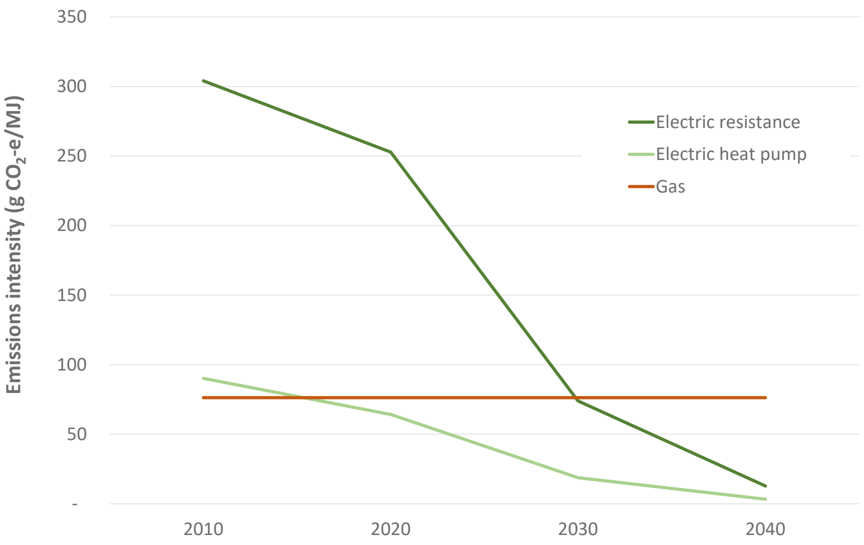
Background and review

Water heating technologies

Of the seven main types of water heater used in Australia, we focus mainly on the electrical technologies that enable demand flexibility (resistance, heat pump and solar), and the main competing gas technology (instantaneous gas). Additional technologies include instantaneous electric, gas storage and solar with gas boosters.

In 2021, electric resistance units comprised an estimated 42% of sales, followed by instantaneous gas (30%), gas storage (14%), heat pumps (7%) and solar (5%).

Electric resistance water heaters are among the cheapest technologies to install but are currently the most expensive to operate (without rooftop solar or highly concessional controlled load



GHG emissions intensity of different DHW technologies in NSW for the period 2010–2040.

Comparison of main water heater types.

Type	Peak electrical load	Cost (excluding installation)	Space requirements	Brands
Electric resistance storage	Typical rating 2.4–5.0 kW	Start at <$1000	50–400 L tank requires more space than instantaneous units. Can be installed indoors or outdoors.	Rheem, Rinnai, Stiebel Eltron
Electric heat pump	Typical rating <1 kW for heat pump and 2–5 kW for units with resistance element	$2000–4000	Usually installed outdoors, though split systems can include tank indoors and compressor outdoors. Indoor units need to be ducted for ventilation.	Chromagen, Bosch, Midea, Stiebel Eltron, Sanden, Rinnai, Daikin, Dux
Instantaneous gas	Negligible	Start at <$1000	Compact unit, usually installed outdoors owing to gas combustion.	Rinnai, Dux, Bosch, Rheem

tariffs). They also offer the most flexible demand capacity. Air-source heat pump water heaters offer efficiencies three- to five-times that of resistance water heaters. They are among the more expensive technologies to install, but their high efficiency makes them cheaper to operate and greatly reduces their GHG emissions. Instantaneous gas water heaters are compact, relatively cheap to manufacture and provide an effectively unlimited supply of hot water, making them an increasingly popular choice across much of Australia in recent decades and the default option for homes with gas connections. They constitute about 25% of all water heaters sold in Australia, and over 40% in Victoria.

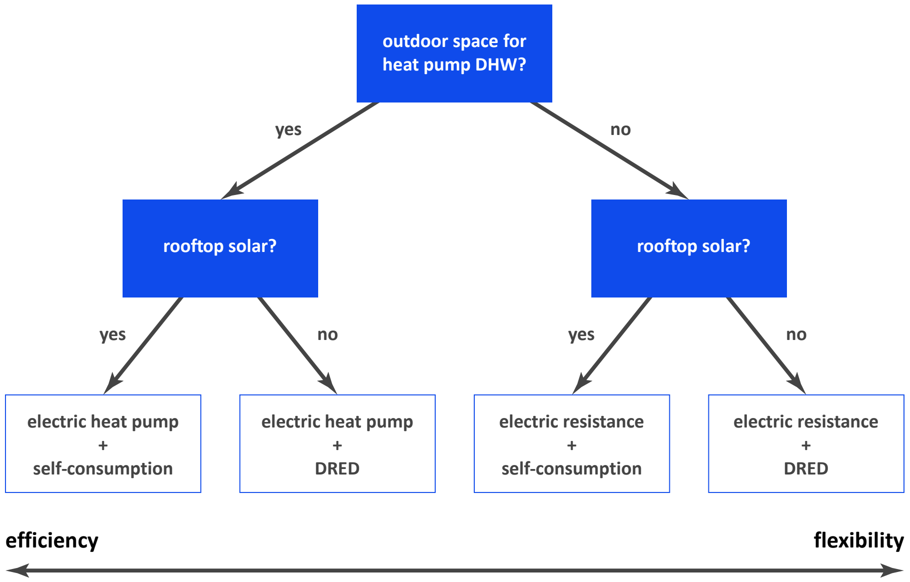
Enabling technologies for flexible demand

Flexible demand (FD) can be categorised in various ways and across different timescales. Electric water heaters fall principally into the categories of *shape* FD (e.g. using a timer to turn on a water heater during the day when excess solar is available) and *shift* FD (e.g. using ripple control to switch on conventional off-peak hot water).

Flexible demand of DHW requires some level of enabling infrastructure. The most fundamental item is a load control device that can change the state of the DHW unit, such as turning it on or off. This includes manual switches, smart meters, timers, solar relays, solar diverters and conventional ripple-control receivers for off-peak hot water. Other enabling infrastructure includes communications, which enables *shift* (versus *shape*) flexible demand, and metering, which can be used to separately meter the DHW unit or another controlled load.

Efficiency versus flexibility

There is a trade-off between the high flexible demand potential but low efficiency of electric resistance water heaters versus the much greater efficiency but lower flexibility of heat pumps. An option to maximise both efficiency and flexibility across the electricity system is to employ different technologies in different circumstances, sometimes emphasising efficiency and other times flexibility. The following figure illustrates this approach using a decision tree. If there is suitable outdoor space, a heat pump should be used in the first instance to maximise efficiency. Otherwise an electric resistance unit can be used to maximise flexibility. If rooftop solar is available, then *shape* FD can be activated in the form of self-consumption using a solar diverter, timer etc. Otherwise, controllable *shift* FD can be activated using a DRED or smart meter.



A decision tree used to select the most optimal configuration of DHW and FD technologies. The result is a varying level of balance between efficiency and flexibility, depending on the situation.

Size of opportunity

Scenarios

To understand the size of the flexible demand opportunity across the NEM, and the trade-offs between different DHW development paths, we further developed and applied our in-house HoWSS model to model the effect of four scenarios:

- **Business as Usual**—Assumes projection of hindcast trends, no forced gas phaseout and a slow uptake of DHW FD to 60% by 2050.
- **Highly Flexible**—Assumes a gradual phase out of DHW gas sales by 2040 (with accelerated decay after 2035), with gas units being predominantly replaced by electric resistance units, and 100% uptake of DHW FD by 2045.
- **Highly Efficient**—Assumptions similar to Highly Flexible, but with gas replaced predominantly by heat pump electric units, and 100% DHW FD uptake by 2050.
- **Rapid Electrification**—Assumes no sales of gas DHW after 2025, accelerated decay of gas after 2030, strong growth in heat pump sales to replace gas, and 100% DHW FD uptake by 2035.

Flexible demand capacity and depth potential

Under the Highly Flexible scenario, domestic hot water could provide about **24 GW** of flexible demand capacity by 2040, the equivalent of **70%** of AEMO's projections for behind-the-meter and coordinated DER storage capacity (AEMO, 2022). This compares to only **9 GW** (25%) for the Business as Usual scenario. The depth of the storage capacity modelled under the Highly Flexible scenario is about **50 GWh/day**, or **61%** of AEMO's projected storage depth, compared to only **19 GWh/day** (23%), under the Business as Usual scenario.

These results highlight that allowing a Business as Usual-type scenario to play out would involve a large missed opportunity to use DHW as a significant source of flexible demand. Alternative scenarios demonstrate an increase in self-consumption of renewables through the use of timer and diverter technologies, and allow smart domestic hot water to a play a role in providing *shift* flexible demand functionality across the grid.

Potential FD capacity and depth in 2040 for all four scenarios.

Scenario	Flexible demand potential	Percentage of AEMO forecast	Flexible demand depth	Percentage of AEMO forecast
	(GW)	(%)	(GWh/day)	(%)
Business as Usual	9	25	19	23
Highly Flexible	24	70	50	61
Highly Efficient	17	48	34	41
Rapid Electrification	22	64	45	55

Energy costs

For consumers, locking in gas as a fuel source for DHW poses a large risk to their energy bills. Under our BAU scenario, consumers across the NEM face an aggregate domestic hot water cost of **$8.7 billion**[1] in 2040. Gas comprises **63%** of this total, driven by an increasing number of gas units, increasing gas prices, and a lack of discounts for providing flexible demand services.

Phasing out gas hot water from the NEM would provide consumers with annual savings of up to **$4.7 billion** by 2040 under both the Highly Flexible and Highly Efficient scenarios, and **$6.7 billion** under the Rapid Electrification scenario. Furthermore, these aggregated cost savings are not shared equally among households, as increasing gas costs will negatively impact some households, while the remainder enjoy savings achieved through increased efficiency and discounted tariffs enabled by flexible demand. Although the average user of gas hot water was better off in 2020 than those with electric water heating technologies, by 2030 they are projected to be significantly worse off. The gap between gas and electric household only increases in 2040, with gas households paying **$660**–**960** per year more than households with a heat pump.

Greenhouse gas emissions

Modelling of greenhouse gas emissions indicates that decarbonisation of the NEM, as projected by the Australian Energy Market Operator (AEMO) in the step change scenario, will be the key driver for reducing the emissions intensity of DHW energy consumption. Assuming the NEM decarbonises in line with this step change scenario, removing gas DHW would play the second largest role in reducing DHW emissions. Under the Business as Usual scenario, annual GHG emissions remain at **3.5 Mt CO_2-e** in 2040, with 85% of this from gas.

These emissions are about three times higher than the figures of **1.2–1.4 Mt CO_2-e** (44–39% gas) under the Highly Efficient/Flexible scenarios, and five times higher than the figure of **0.71 Mt CO_2-e** (0% gas) under the Rapid Electrification scenario. Removing gas water heaters from the DHW stock should therefore be an important policy objective.

Our results show similar emission reduction pathways for both the Highly Efficient and Highly Flexible scenarios, indicating that electrification and electricity decarbonisation are more important than efficiency for reducing emissions from domestic hot water.

Barriers and drivers

The project identified numerous drivers but also several significant barriers to both the uptake of more efficient domestic water heating technology, such as heat pumps, and the activation of flexible demand capacity. Air source heat pumps offer higher efficiency and lower lifetime operating

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[1] All costs are expressed in 2020–21 Australian dollars.

costs than gas or electric resistance heaters. Government incentives and a growing consumer push towards electrification are slowly driving uptake of this technology. However, high capital costs and existing policies that favour gas technologies represent a major barrier to the expanded uptake of this technology. The existing experience of off-peak hot water and the existing fleet of electric resistance storage units provide a significant opportunity on which to build flexible demand capacity. However, this is hindered by a lack of easy solutions. The identified barriers and drivers are summarised in the tables below:

Summary of main drivers and barriers for three focus DHW technologies.

	Resistance		Heat pump		Instantaneous gas	
	Drivers	**Barriers**	**Drivers**	**Barriers**	**Drivers**	**Barriers**
Social	• Traditional and familiar product.		• Newer technology – appeals to early adopters. • 'Electrify everything'.	• Lack of consumer understanding. • Potentially noisy.	• Unlimited supply of hot water.	
Technical	• Simple and reliable. • Only available option for some homes. • Options to reduce losses.	• May require separate circuit with high current rating (~3.6 kW). • Low self-consumption potential for some states/ climates.	• Efficient option for all electric homes.	• Outdoor installation not suitable for some apartments etc.	• Reliable. • Compact and unobtrusive units.	
Economic	• Cheap to install. • Off-peak and flex tariffs. • Self-consumption by PV system owners.	• Very high running costs using grid electricity.	• Higher efficiency and lower running costs. • Self-consumption by PV system owners. • Off-peak and flex tariffs.	• Higher capital cost than other options. • Declining STC value.	• Cheap to install and operate.	• High and rising gas prices.
Policy		• Discouraged by some policies (e.g. NCC, SA policy). • Lack of policy and standards enabling uptake of FD	• Government incentives through STCs and state White Label schemes. • Energy efficiency, NCC, NatHERS etc.	• Declining STC value. • No MEPS. • Policies favour gas.	• Lack of policy to transition away from gas. • NCC threshold of 100 g CO_2-e/MJ.	• NCC provision for net zero pathway in large developments. • Other policies (e.g. ACT).
Supply chain	• Like-for-like replacement when units fail. • Existing supply chain infrastructure.			• Nascent local industry. • Potential lack of supply capacity volume. • Anecdotal evidence of variable quality of installation and products.	• Like-for-like replacement when units fail. • Existing supply chain infrastructure.	
Environmental	• Reduced solar curtailment.	• High GHG emissions when powered by grid electricity.	• Alternative to gas with net zero pathway.			• Fossil fuel with no immediate substitution pathway. • Gateway for gas home heating and cooking, with detrimental health outcomes.

Summary of main drivers and barriers for activating DHW flexible demand.

	Drivers	Barriers
Social	• Existing familiarity with off-peak DHW. • Growing understanding.	• Lack of trust and understanding. • Retailer inertia. • Confusing marketplace. • Consumer complacency.
Technical	• Availability of enabling technologies—ripple control, smart meters, HEMS, solar diverters, existing fleet of electric storage DHW units. • Potential for integration with batteries and other storage technologies.	• Requires additional hardware/rewiring, method for metering (DRM4). • Lack of single product solution. • Lower flexible demand capacity of heat pumps without resistive elements due to high efficiency • Small tanks for apartments.
Economic	• Solar soak tariffs. • Self-consumption. • Network benefits (avoided emergency load shedding, upgrade deferrals).	• Resistance DHW expensive to operate. • Tariffs inadequate.
Policy	• AS 4755.	• Policies largely focus on energy efficiency, not flexibility. • Policies that facilitate gas DHW. • Market rules limit value of FD.
Supply chain	• Integration of DRM into new units. • Solar/heat pump units with resistive elements.	• Like-for-like replacement when units fail. • Concentrated supply chain lacking innovation.
Environmental	• Increased penetration of renewables.	

Recommendations

As the research findings show, the pathways and enablers required to decarbonise and increase the flexibility of water heating are complex and hindered by multiple barriers. This is due to the fragmented nature of the water heater market and its supply chains, disjointed and outdated policy frameworks, as well as the physical constraints and technical complexities associated with retrofitting more efficient or flexible electric water heaters in Australian homes.

There is a compelling case for a more coherent and updated approach to policy for residential water heating, particularly given the context of climate change and high energy prices. Electrifying water heating provides major opportunities to reduce energy use and carbon emissions, protect against future energy price rises, and tap into a major source of energy storage to support integration of renewable energy in the grid. Addressing the barriers that are slowing the uptake of more flexible and efficient heating options will likely result in improved outcomes for customers, while supporting federal and state targets for energy efficiency, renewable energy and net-zero emissions. This will require an integrated approach to improving customer knowledge and awareness, developing and upskill supply chains, investing in research and development (R&D), and encouraging innovation and new business models.

Key recommendations

Our key recommendations are summarised in the following table. See Section 5 for a full list of recommendations. The key recommendations are those identified as having a short-to-medium term timeframe, high or medium impact, and good or moderate ease of implementation.

Supply chains

Investigate ways in which DNSPs or other system actors could take on responsibility for delivering hot water as a service, and owning DHW units

Policy

Given the nature of the residential domestic hot water market and policy environment in Australia, most priority levers sit in the policy category. There are several short-term policy changes that could underpin a transition pathway to a highly efficient or a highly flexible DHW system.

Innovation and business models

New and innovative business models that facilitate the transition towards more flexible (and efficient) DHW are likely to be underpinned by emerging technologies and demonstration projects relating to smart devices, monitoring and optimisation. These areas can be supported by existing research funding programs.

Research and development

Research and development funding can support further trials, data collection and knowledge sharing in relation to electrified and flexible DHW to provide the evidence base required for ambitious policy change.

Customers

Given heat pumps and smart water heating systems are an emerging segment of the residential DHW market, there is a need to support the market in better understanding how their customers can make appropriate choices for their needs. This can occur through existing knowledge sharing channels, as well as collaboration with consumer energy groups to create online resources. Such resources could highlight the costs, benefits and payback times of differing hot water technologies for typical households in each state.

Category	Lever	Who?	Time-frame	Impact	Ease	Priority
Supply chains	Investigate ways in which DNSPs or other system actors could take on responsibility for delivering hot water as a service, and owning DHW units	State governments, DNSPs, water utilities	S	🟨	🟩	🟩
Policy	Convene a workshop with regulators, policymakers, consumer groups (from energy, water, built environment) to discuss the project findings—refer to Figure 23	ARENA and ISF	S	🟩	🟩	🟩
	Develop national strategy for flexible DHW that accounts for state differences—supporting efficiency where possible and the uptake of FD-enabled resistance heaters	Federal Government (supported by states through COAG)	S	🟩	🟨	🟩
	Gas policy reforms to accelerate phase out of gas DHW (with priority for new buildings)		M	🟩	🟨	🟩
	Policy reforms to remove perverse incentives against heat pumps in new homes		M	🟩	🟩	🟩
	Strengthen Greenhouse and Energy Minimum Standards (GEMS) and Minimum Energy Performance Standards (MEPS) for DHW	Federal Government (DCCEEW) and Standards Australia	S	🟩	🟨	🟩
	Develop energy rating and quality performance standards for heat pump DHW		S	🟨	🟨	🟩
	Expand and clarify Demand Management Innovation Allowance (DMIA) scope—better encourage capital and operating expenditure for rollout of projects enabling *shape* and *shift* FD resistance DHW through existing and emerging technologies	ENCRC (AEMO, AER, AEMC)	S	🟨	🟩	🟩
	Expand and clarify Demand Management Incentive Scheme (DMIS) scope—increase ease for DHW projects to be considered through flexibility around 'demand management proposal' and relevant indicators of management (e.g. kWh instead of just kVA/year)		S	🟨	🟩	🟩
Innovation & business models	Retailer programs that support flexible hot water while reducing customer churn—may include hot water as a service and leasing models	ARENA (CfP targeting energy retailers)	M	🟨	🟨	🟨
	Support inclusion of hot water in water utilities' existing water efficiency schemes for strata buildings (c.f. NT Power and Water)	State governments, water utilities	S	🟨	🟩	🟩
R&D	Detailed cost benefit analysis of policy options	ARENA, RACE for 2030	S	🟨	🟩	🟩
	Fund research focussing on constrained sections of network and conducting DMIS calculations (with aim of demonstrating advantages of flexible DHW to AER)		S	🟩	🟨	🟩
	Support better data collection across electricity networks to better understand the role and opportunities for flexible DHW		M	🟨	🟨	🟩
	Support innovative tariff trials, with better reporting and open publication of trial results		S	🟩	🟨	🟩
	Pilot DHW flex projects with support of AER	ARENA, RACE for 2030, AER	S	🟩	🟨	🟩
Customers	Support improved customer education and awareness	Governments, ARENA, ECA, Choice	M	🟨	🟩	🟩
	Better decision-making tools for customers		S	🟨	🟩	🟩

Contents

Glossary of terms

ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AMI	Advanced Metering Infrastructure
ARENA	Australian Renewable Energy Agency
AS/NZS	Australian Standard/New Zealand Standard
BASIX	Building Sustainability Index (NSW)
BAU	business as usual
BRC-A	Business Renewables Centre Australia
BTM	behind the meter
CEFC	Clean Energy Finance Corporation
CLR	controlled load relay
COAG	Council of Australian Governments
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent
COP	coefficient of performance
CPI	Consumer Price Index
CPP	critical peak pricing
CRC	Cooperative Research Centre
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DER	distributed energy resources
DHW	domestic hot water
DMIA	Demand Management Innovation Allowance
DMIS	Demand Management Incentive Scheme
DNSP	distribution network service provider
DR	demand response
DRED	demand response enabling/enabled device
DSM	demand side management
ECA	Energy Consumers Australia
ENCRC	Energy National Cabinet Reform Committee
ERF	Emissions Reduction Fund
ESC	Energy Savings Certificate (NSW)
EV	electric vehicle
FCAS	Frequency Control Ancillary Services
FD	flexible demand
GED	General Environmental Duty
GEMS	Greenhouse and Energy Minimum Standards
GHG	greenhouse gas
GJ	gigajoule
GSM	Global System for Mobile Communications
GW	gigawatt
GWh	gigawatt-hour
HAN	home area network
HEMS	home energy management system
HoWSS	Hot Water System Stock, ISF's proprietary hot water system stock model
HVAC	heating, ventilation and cooling
IEA	International Energy Agency
IFTM	in front of the meter
IRENA	International Renewable Energy Agency
ISF	Institute for Sustainable Futures (UTS)
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelised cost of energy
MEPS	minimum energy performance standard
MJ	megajoule
MW	megawatt
MWh	megawatt-hour
NatHERS	National House Energy Rating Scheme
NCC	National Construction Code
NEM	National Electricity Market
NGER	National Greenhouse and Energy Reporting
NSW	New South Wales
OPCL	off peak controlled load
PV	photovoltaic
RACE for 2030	Reliable Affordable Clear Energy for 2030 Cooperative Research Centre
REC	Renewable Energy Certificate
REPS	Retailer Energy Productivity Scheme (SA)
SA	South Australia
SAPN	SA Power Networks
SEPP	State Environmental Planning Policy
SMS	short message service
STC	Small-scale Technology Certificate
TNSP	transmission network service provider
TPA	Technology and Policy Assessment
ToU	time of use
UTS	University of Technology Sydney
VEEC	Victorian Energy Efficiency Certificate
VEU	Victorian Energy Upgrades
VPP	virtual power plant
VRE	variable renewable energy
WA	Western Australia
WiMAX	Worldwide Interoperability for Microwave Access

1 Introduction

1.1 Domestic hot water and carbon emissions

Domestic hot water (DHW) systems can play a key role in achieving Commonwealth renewable energy and emissions reduction targets and the target for net zero by 2050 through improving demand flexibility, fuel switching and increasing efficiency. DHW accounts for about 20% of Australian residential greenhouse gas (GHG) emissions and 25% of household energy use (DISER, 2020). This makes DHW an important element in pathways towards decarbonising building stock.

Electric hot water systems with storage also provide demand flexibility, which can support integration of variable renewable energy (VRE) sources in the grid while helping overcome resulting challenges such as minimum demand. A typical 300 litre DHW system can store about 15 kWh of energy, or about the same amount as a standard home battery. However, the flexible demand potential of DHW has not yet been realised, with many units configured to operate during fixed off-peak (overnight) periods rather than dynamically optimised for solar output. Hence there is an opportunity to switch DHW units to operate during the day as solar sponges and help address challenges associated with maintaining power security amid falling minimum demand.

In addition to supporting higher penetration of VRE in the grid, DHW can also significantly improve home efficiency. There is a difference in efficiency of about four-to-five times between the heat pumps and electric resistance or gas hot water systems. Despite the advantages of heat pumps, end-of-life DHW replacements are typically like-for-like, owing to a range of factors, including convenience, cost and supply chain inertia.

Improving DHW stock can also support the net-zero targets of Australian state governments, which will require a planned phasing out of fossil fuels in many sectors by 2050 or earlier. However, Australia’s current residential building policies are driving an increasing proportion of homes with gas hot water systems, particularly instantaneous gas systems. Approximately 50% of the energy used for water heating now comes from natural gas. Based on previous modelling conducted by ISF for the Australian and Victorian governments, by 2035 gas DHW could release 5.8 Mt of CO_2-e emissions annually, with over 75% of these emissions from instantaneous gas heaters.

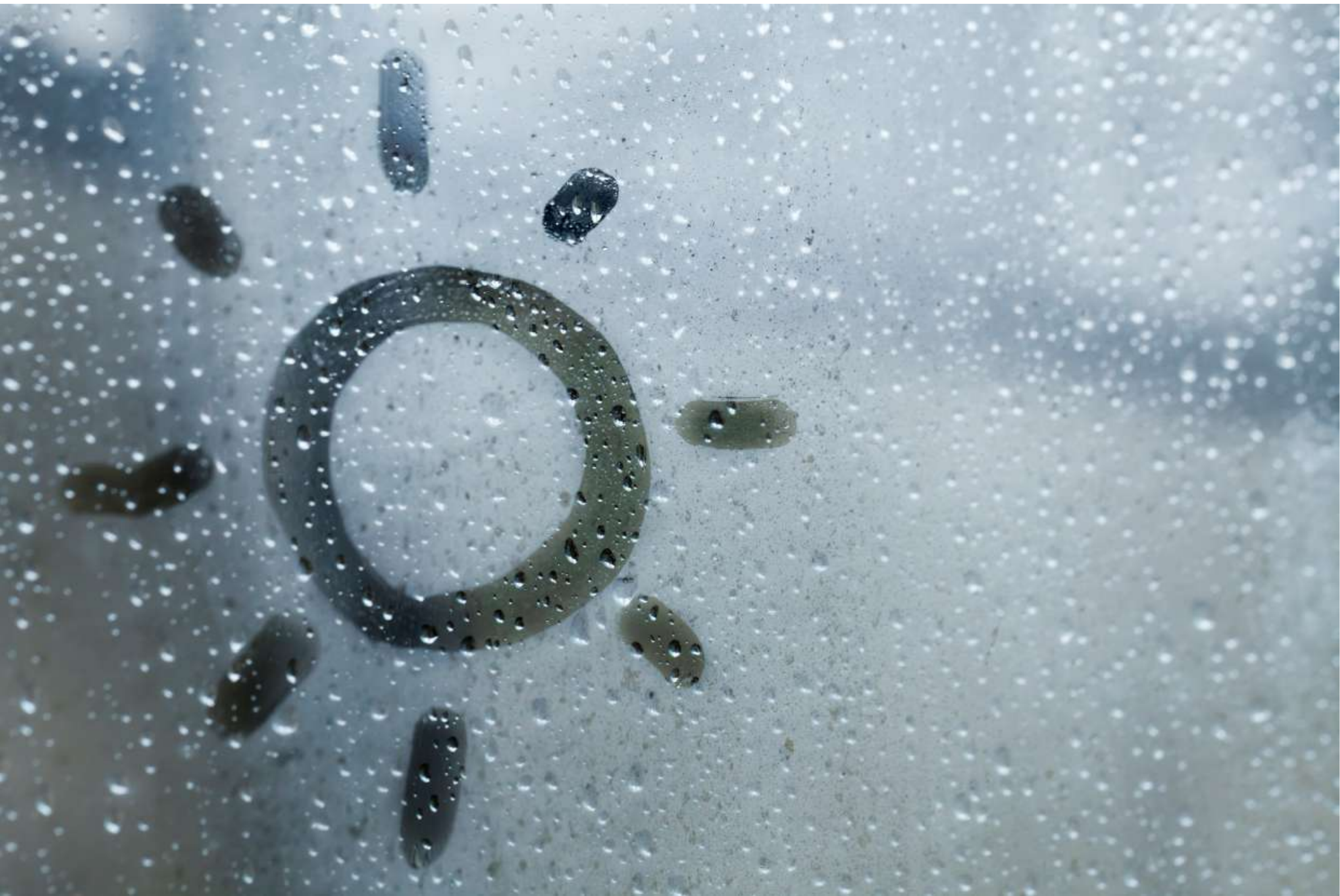
Without better understanding the opportunity for more efficient and flexible DHW and the reasons for our current failure to realise this opportunity, Australia risks locking-in increased fossil fuel-dependency and locking-out a significant opportunity for domestic demand flexibility for at least a decade. Realistic pathways would see optimising of existing electric storage systems to use renewable output, increased uptake of heat pump DHW systems, and reduced uptake of gas systems. This report maps out some of these transition pathways, and the costs and benefits of alternative scenarios.

1.2 Research methodology

The research methodology adopted for this project consisted of:

- **Literature and data review**—We conducted a literature scan and current market review to determine recent developments in DHW load flexibility, update statistics and data for the modelling and scenario development, and review case studies and the outcome of trial projects. The literature review included relevant ARENA studies, data sources from the ARENA knowledge bank, and publicly available references. Market data was also sourced from the Australia Bureau of Statistics (ABS), state databases and reports, previous ISF research, company websites, external consulting organisations, industry guides, news reports, specialist publications, contacts, and other grey and academic literature.

- **Interviews and synthesis**—Semi-structured interviews were undertaken with 12 key stakeholders drawn from ISF's network of contacts and supplemented with those suggested by ARENA. Those sought for interview included industry associations, supply chain partners (particularly manufacturers), policymakers, and other researchers.
- **Modelling**—To determine the size of the opportunity for flexible DHW, ISF's Hot Water System Stock (HoWSS) model, first developed in 2018, was updated to include additional functionality relating to water heater efficiency, costs and greenhouse gas emissions. The data underpinning the model was updated and verified, and multiple scenarios were developed in consultation with ARENA and applied to the model (see Section 3).
- **Barriers analysis**—Through the literature review and interviews, various categories of barriers to flexible DHW were identified, analysed and tested (See Section 4).
- **Solutions and pathways**—Building on the previous work and culminating in an internal sense-making workshop involving ISF and ARENA team members, solutions and pathways were identified and mapped (see Section 5 and Appendix C).



2 Background and review

2.1 Domestic hot water

In Australia, water heating accounts for around 24% of residential energy use and 18% of residential electricity use (DISER, 2020), making it one of the most extensive energy-using activities in households and a significant contributor to household greenhouse gas (GHG) emissions. The total energy demand for electric domestic hot water (DHW) across the National Electricity Market (NEM) is about 25 GWh/day, representing about 5% of total daily electricity consumption across the NEM (AEMO, 2022).

Hot water is a standard item of comfort in residential buildings in developed regions worldwide, and hence a key target for improving energy and water efficiency in buildings. From a life-cycle perspective, water heating is the most energy-intensive phase of the urban water cycle, corresponding to 84–97% of total energy consumption for cold and hot water supplies and sewage collection, treatment and disposal in buildings (Kenway *et al.*, 2008).

Across Australia, there are about 10.2 million DHW units, or about one for each of Australia's 10 million households (ABS, 2021). The number of households is increasing by about 1.7% per year, driven by population growth and a reduction in average household sizes. About 830,000 DHW units are sold annually across Australia, with about 660,000 (79%) of this total being replacements and about 170,000 (21%) being for new homes.

From our modelling, we estimate that domestic water heating resulted in GHG emissions of about 12.4 Mt CO_2-e in 2020, comprising 10.1 Mt from electricity and 2.3 Mt from natural gas.

2.2 Flexible demand

As Australia works towards decarbonising its electricity system, it is rapidly replacing dispatchable, thermal power generation with highly variable renewable energy (VRE) sources, principally solar and wind power. To address the technical challenges of this transition requires a combination of energy storage, backup generation and flexible demand (Alexander *et al.*, 2021).

Demand side management (DSM) is a well-established practice of reducing demand during periods of peak grid demand. Flexible Demand (FD) is an emerging concept that encompasses DSM within a wider scope of demand-side functions and services. In addition to reducing demand at certain times, FD incorporates increasing demand when excess electricity is available, such as soaking up excess rooftop solar. This controllable energy consumption can be regarded as a distributed energy resource (DER). FD can improve grid reliability, help optimise renewable integration, and benefit consumers through lower energy bills (Swanston, 2021).

FD can be categorised in various ways and across different timescales. The taxonomy proposed by the Lawrence Berkeley National Laboratory divides FD resources into four main categories (Alstone *et al.*, 2017):

- **Shape FD**—resources that modify the load of an end-user on a consistent or permanent basis, such as through Time-of-Use (TOU) tariffs or programs that change consumer behaviour.
- **Shift FD**—load changes that optimise the use of surplus renewable generation or exploit fluctuations in market prices (times of surplus

- renewables usually have lower, or even negative prices).
- **Shed FD**—conventional downward demand response (DR), whereby loads are curtailed during periods of high demand, without increasing energy use at other times to compensate.
- **Shimmy**—dynamic load-flexing, involving rapid response to changes in system demand that affect the stability and quality of delivered power.

Electric water heaters fall principally into the categories of *shape FD* (e.g. using a timer to turn on a water heater during the day when excess solar is available) and *shift FD* (e.g. using ripple control to switch on conventional off-peak hot water).

2.3 Peak and minimum demand

On electricity networks such as Australia's National Electricity Market (NEM), electricity demand fluctuates continuously. Peak demand for any section of the network is the maximum demand experienced on that section over a given period. To ensure reliable operation, the network must have sufficient generation, transmission and distribution capacity to meet peak demand, which adds significantly to the costs of building and operating the network. Reducing peak demand through FD can therefore reduce electricity costs.

Minimum demand is an emerging problem caused by high penetration of both utility-scale and rooftop solar. This can cause net demand on the network to fall to very low levels during the day, with a subsequent rapid increase in demand towards the end of the day as solar generation decreases. This is best illustrated by the so-called 'duck curve', as shown in Figure 1. This increased variability in power flows can cause high voltages on the distribution network and limit its capacity to host additional rooftop solar (Rheem, 2021).

Given the relatively high electricity demand from domestic electric water heaters and their ability to store energy in the form of hot water for use at a later time, they offer electricity networks an opportunity to address some of the challenges of both peak and minimum demand. In particular, scheduling electric water heaters to consume excess solar photovoltaic (PV) generation during the day can help reduce variability in the range of power flows, moderating voltage fluctuations and avoiding the need for more expensive solutions such as transformer taps, voltage regulators or load compensators (ARENA, 2021; EEC, 2022).

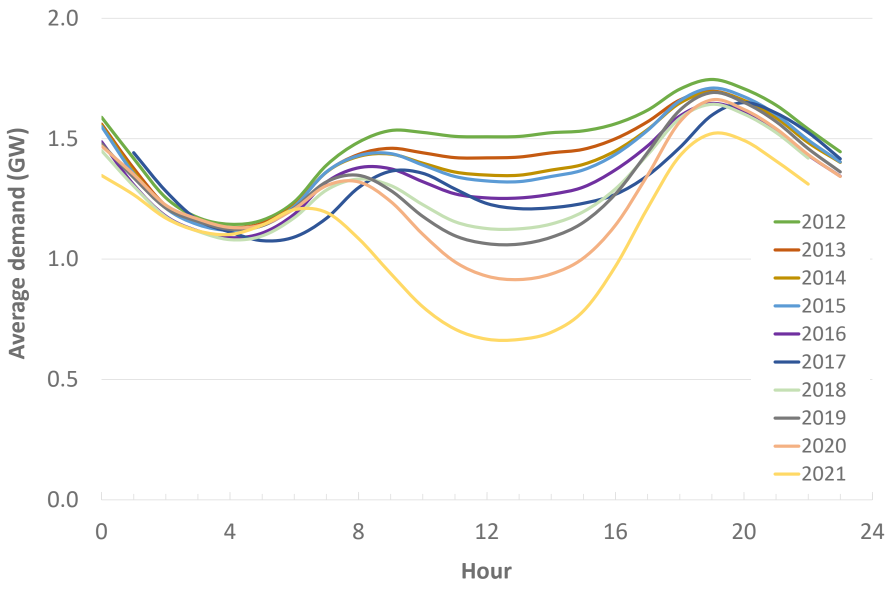


Figure 1. Average hourly electricity demand in South Australia has decreased during the day as a result of increasing solar penetration.
Data source: (AEMO, 2021)

(a) (b)

(c) (d)

Figure 2. The four main water heater types analysed in this report. (a) Electric resistance. (b) Air source heat pump. (c) Solar. (d) Instantaneous gas.

2.4 Water heater types

There are seven main types of water heater used in Australia. These water heater types can be classified by:

- **Fuel type**—Water heaters are usually powered by electricity, gas (natural gas or LPG) or solar. Most solar water heaters include a booster to account for periods of reduced solar output and can therefore be classified as electric or gas boosted units.
- **Storage** versus **instantaneous**—Heated water can be stored in an insulated tank for later user (storage heaters) or used immediately (instantaneous or 'on-demand' heaters).

The seven main types of water heater used in Australia are:

- electric resistance water heaters (Figure 2a)
- air-source heat pump water heaters (Figure 2b)
- instantaneous electric water heaters
- instantaneous gas water heaters (Figure 2d)
- gas storage water heaters

- solar electric water heaters (Figure 2c)
- solar gas water heaters.

Throughout this report, we focus mainly on the electrical technologies that enable demand flexibility (resistance, heat pump and solar), and the main competing gas technology (instantaneous gas).

There are several other water heating technologies that are currently rarely deployed in Australia and are not considered in this report. These include:

- Solar heat pump units combine a heat pump with a rooftop solar collector. They were once readily available in Australia but have since been largely replaced by air-source heat pumps, which are cheaper to manufacture, more compact and leave valuable roof space available for PV panels.
- Ground-sourced heat pump units (also known as geothermal heat pumps), which use heat sourced from a waterbody, shallow trench or deep bore, instead of the air. Their high capital cost makes them only suited to multi-residential applications. They are rarely deployed in Australia.
- Water heaters using wood, coal, oil or other liquid or solid fuels, while once more common, are no longer commercially available in Australia.

2.4.1 Electric resistance water heaters

Electric resistance water heaters simply heat water by passing electricity through a resistive heating element and store this heated water in a tank for later use (see Figure 2(a)). They remain a dominant hot water technology across much of Australia, largely thanks to their simplicity, low cost and once generous off-peak tariffs (previously around 25% of the standard electricity tariff). They still comprise about 47% of water heating stock and over 40% of sales across the NEM. Electric resistance water heaters are among the cheapest technologies to install. Given their low relative efficiency (around 90% with storage losses) and increases in electricity tariffs, they are the most expensive to operate (without rooftop solar or highly concessional controlled load tariffs). Under the latest revision of the National Construction Code (NCC 2022), resistance heaters are effectively prohibited from new builds across much of Australia from 1 May 2023, owing to their high GHG emissions (see Figure 3 and Section 4.4.4), though the NCC provisions are in some cases overridden by state-based rules. Their deployment in new builds is becoming increasingly less common except where alternatives are not feasible.

2.4.2 Heat pump water heaters

Air-source heat pump water heaters are powered by electricity and use a storage tank similar to electric resistance units. However, much like a reverse cycle air conditioner (AC), each includes a compressor-based heat pump that extracts heat from the surrounding air. The compressor uses a fan, which makes some noise. The compressor may be integrated, sitting atop the storage tank (see Figure 2(b)), or located separately like a split-system AC. A heat pump has a coefficient of performance (COP) of around 3–5. The COP measures the ratio of heat energy delivered to the amount of electrical energy consumed, and is much higher than the typical value of ~0.95 for an electric resistance water heater. A heat pump compressor should be located outside, making it unsuitable in some situations such as apartments that lack a suitable installation location. Not all models are suitable for cold locations where it regularly drops below 5°C. Many models also include a resistance element to boost output during the colder months. Heat pump water heaters are among the more expensive technologies to install, but their high efficiency makes them cheaper to operate (see Section 4.3.1). Sales of heat pump water heaters increased sharply in 2021 to 60,000 units, or

Table 1. A survey of currently available heat pump water heaters with tank sizes around 270–300 L.

Brand	Model	STCs[2]	Tank size	COP[3]	Heat pump input power	Resistive element	Element power	Warranty tank/other
			(L)		(W)		(W)	(years)
Sanden	GAUS-300FQS	32	300	4.69	950	no	–	10–15/6
Reclaim Energy	REHP-CO2-315GL	32	315	6.02 [4]	870	no	–	15/6
Eco Alliance	ECO-260LE	32	260	4.23	850	no	–	5/2
Quantum	270-08AC6-290	31	270	4.53	840	no	–	5/2
iStore	270L	27	270	3.83	940	yes	1,500	5/1–2
Hydrotherm	DYNAMIC/X8 Gen 5	30	260	4.15	880	yes	1,800	6
Stiebel Eltron	WWK302	28	300	3.58	550	no	–	5/2
Stiebel Eltron	WWK302H	28	300	3.58	550	yes	1,700	5/2
ThermalArk	Ark 270	26	270	3.62	940	yes	1,500	5/1–2
Rheem	HDc270	29	270	4.50	985	yes	2,400	7
Solahart	270HAV	29	270	4.50	985	yes	2,400	7/2–3
Solahart	325HAV	27	325	3.35	800	yes	3,600	5/2–3
Average		**29**	**284**	**4.32**	**836**		**2,129**	

about 7% of the market, and are likely to exceed that number in 2022 (CSIRO, 2022).

Table 1 provides a summary of selected heat pump water heaters currently available on the Australian market, with tank sizes around 270–300 L.

2.4.3 Instantaneous electric water heaters

Instantaneous electric water heaters use a large amount of electrical power to rapidly heat water on demand, much like a conventional electric resistance water heater but without the storage tank. They are relatively common in some overseas jurisdictions and in some non-residential settings such as hotels. They offer several advantages: they are compact, relatively cheap to manufacture, provide effectively unlimited supply, and avoid standing losses to provide higher efficiency than resistive storage units. However, they are substantially less efficient than heat pump units and require very high levels of power to simultaneously achieve high flow rates and temperature differentials. While adequate for some basins and sinks, typical units are unable to achieve the sorts of rates expected for a domestic shower in Australia. Even with a dedicated 32 A circuit (well above the 10 A plug-in limit for typical domestic circuits), a single-phase unit is physically limited to delivering 7.36 kW of power at 230 V_{ac}. With a temperature differential of 25°C, this translates to a flow rate only 4.2 L/minute. While three-phase units can deliver power levels comparable to instantaneous gas water heaters, such connections are present in only a minority of Australian homes.

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[2] Assuming a 10-year deeming period (i.e. installation in 2021) for a unit installed in Sydney, derived from registry.gov.au/rec-registry/app/calculators/swh-stc-calculator

[3] Under test condition 2 of AS/NZS 5125 (18–20°C ambient, 60–70% relative humidity, inlet water temperature of <15°C), unless otherwise stated.

[4] At 32.6°C ambient, 21.1°C cold water inlet.

2.4.4 Instantaneous gas water heaters

Instantaneous gas water heaters heat water on demand using the combustion of gas, most commonly reticulated natural gas (see Figure 2(d)). They are compact, relatively cheap to manufacture and provide an effectively unlimited supply of hot water, making them an increasingly popular choice across much of Australia in recent decades and the default option for homes with gas connections. They constitute about 25% of all water heaters sold in Australia, and over 40% in Victoria.

2.4.5 Gas storage water heaters

Gas storage water heaters heat water using the combustion of gas and store this heated water in a tank for later use. With decreasing demand for hot water in recent years, gas storage units are generally less energy efficient and cost competitive than instantaneous gas units.

2.4.6 Solar water heaters

Solar electric water heaters use a roof-mounted solar collector to heat water, which is stored in a tank (usually mounted on the roof near the collectors—see Figure 2(c)). They usually include either an electric resistance element or gas burner to boost water temperatures when required. Solar water heaters are the most expensive technology to purchase, but are the most efficient and therefore cheapest to operate. Sales have been declining in recent years and in 2021 fell below 40,000 units, or about 5% of the market (CSIRO, 2022). This decline is being driven by the rising popularity of rooftop solar PV (which occupies available roof space), the availability of cheaper water heating options, particularly gas, and the increasing popularity of heat pumps.

2.5 Water heater characteristics

As detailed above, each of the seven main water heating technologies differs in terms of key characteristics, namely capital cost, running cost, capacity to flex electrical demand, size (and form factor), ease of retrofit and greenhouse gas emissions (see Figure 3). Both running cost and greenhouse gas emissions are a function of efficiency and fuel type. Efficiency is also a function of several factors, namely:

- **Heating efficiency**—a more efficient technology requires less energy to heat a given quantity of water by a given temperature differential. Resistance heating is close to 100% efficient, while heat pumps provide effective heating efficiencies of 350% or more.

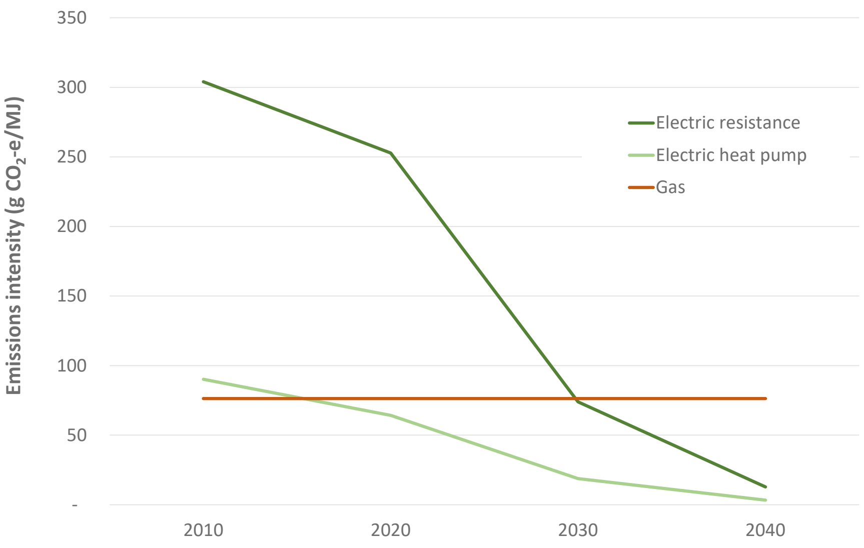

Figure 3. GHG emissions intensity of different DHW technologies in NSW for the period 2010–2040.

- **Standing losses**—hot water left in a storage tank will cool as heat escapes into the surrounding space. Storage tanks are insulated to slow (but not eliminate) this loss of heat. See Section 4.4.1.
- **Distribution losses**—heat is lost from pipes as water is distributed from the water heater to end-use appliances. Technologies that lend themselves to being installed closer to where hot water is required can reduce these losses.

Figure 4 shows a qualitative comparison of the four main technologies considered in this report in terms of their key characteristics.

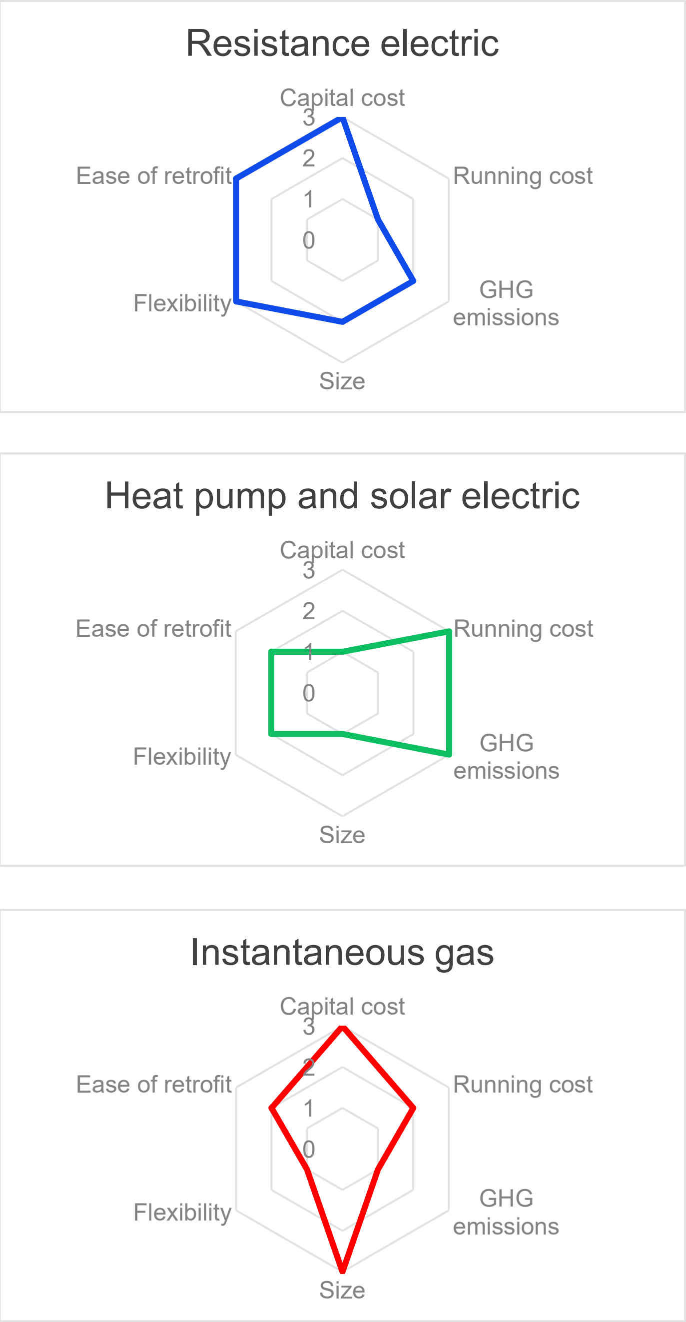

Figure 4. Comparison of four main DHW technologies considered in this report in terms of capital cost, running cost, GHG emissions, size, flexibility and east of retrofit.

3 = better
1 = worse

2.6 Prevalence of water heater types

Across Australia's stock of DHW units, electric resistance storage is the most common technology type (estimated at about 4.5 million units in 2020 or 46%), followed in descending order by instantaneous gas (2.4 million; 24%), storage gas (1.4 million; 14%), solar (1.2 million, 12%) and heat pumps (350,000; 4%).

In 2021, electric resistance units comprised an estimated 42% of sales, followed by instantaneous gas (30%), gas storage (14%), heat pumps (7%) and solar (5%).

According to the Australian Housing Conditions Dataset of Baker *et al.* (2020), which includes self-reported data extracted from phone interviews of a sample of 4501 people from SA, NSW and Victoria, 57% of households had gas as a main source of energy and almost one quarter (24.6%) had replaced electric with gas hot water.

According to Ryan and Pavia (2016), there is an overall trend from storage to instantaneous gas DHW units, and consumers moving to solar and heat pump water heaters from electric storage water heaters, encouraged by incentives from state and federal governments and regulations that required new homes to install solar and heat pump water heaters. Similar to the space heating trends, there is an expectation that hot water system preferences will move from gas to electricity as the source of energy. The total energy use for water heating is now forecast to increase slightly, as the fuel switching rate declines and no other minimum energy performance standard (MEPS) or water efficiency measures are planned to be implemented.

Warranties for water heaters are typically 10–12 years for instantaneous gas and the cylinder of electric storage heaters. According to Wilkenfeld (2009), based on analysis of data from BIS Shrapnel, the average lifetimes of electric storage water heaters is about 13 years.

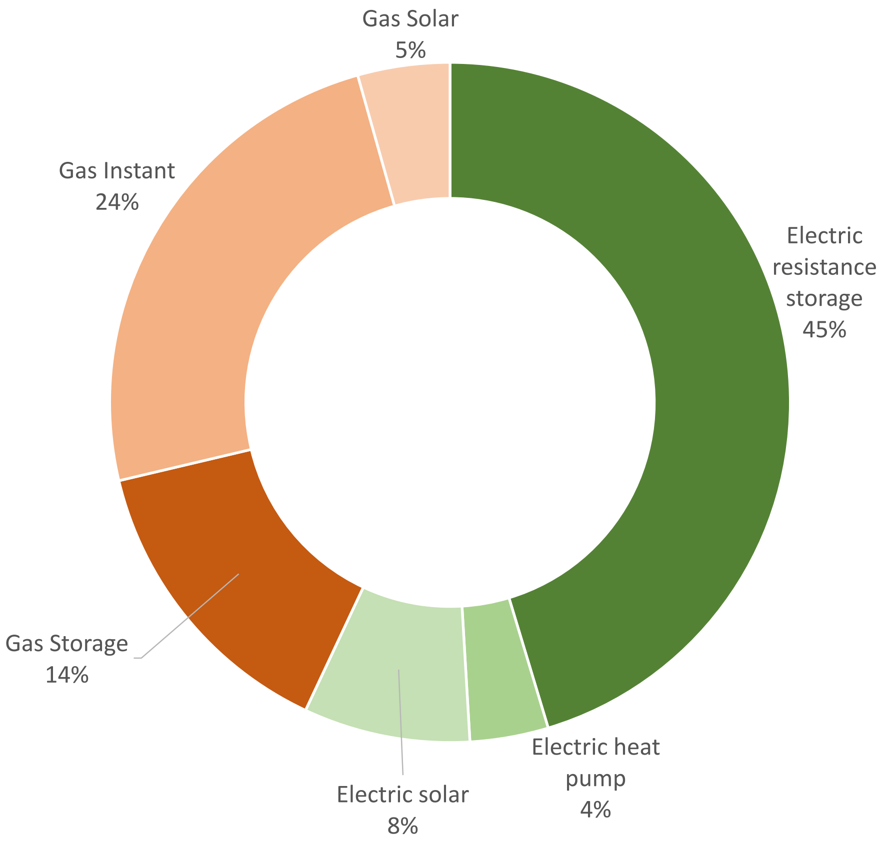

Figure 5. Estimated stock of water heater types across Australia, 2020.

Table 2. Comparison of main water heater types.

Type	Peak electrical load	Cost (excluding installation)	Space requirements	Brands
Electric resistance storage	Typical rating 2.4–5.0 kW	Start at <$1000	50–400 L tank requires more space than instantaneous units. Can be installed indoors or outdoors.	Rheem, Rinnai, Stiebel Eltron
Electric heat pump	Typical rating <1 kW for heat pump and 2–5 kW for units with resistance element	$2000–4000	Usually installed outdoors, though split systems can include tank indoors and compressor outdoors. Indoor units need to be ducted for ventilation.	Chromagen, Bosch, Midea, Stiebel Eltron, Sanden, Rinnai, Daikin, Dux
Instantaneous gas	Negligible	Start at <$1000	Compact unit, usually installed outdoors owing to gas combustion.	Rinnai, Dux, Bosch, Rheem

2.7 Enabling technologies for flexible demand

Flexible demand of DHW requires some level of enabling infrastructure. The most fundamental item is a load control device that can change the state of the DHW unit, such as turning it on or off. Other enabling infrastructure includes communications, which enables *shift* (versus *shape*) flexible demand, and metering, which can be used to separately meter the DHW unit or another controlled load.

The following section provides details of the various technologies that enable DHW demand flexibility. As shown in Figure 6, the various technologies can be classified and mapped in terms of their accessibility (cost and complexity) versus ability to enable flexible demand capacity (e.g. *shape* versus *shift*). They can be controlled either by the customer or from the network side (either by the network operator or an agent). And they can employ simple on-off controls or more sophisticated controls that can incrementally ramp the DHW unit up and down as required.

2.7.1 Off-peak hot water

Off peak controlled load (OPCL) exists for all states in the NEM. By controlling when loads such as water heaters operate, OPCL has traditionally been used to shape network demand, increasing minimum demand during the night (typically between 11pm and 7am) when thermal generators must continue to operate, while reducing demand during the day. OPCL can be activated using various mechanisms, including ripple control (Section 0), timers (Section 2.7.3) or smart meters (Section 2.7.7).

Increasing penetration of rooftop solar is moving minimum demand to the middle of the day and making traditional OPCL periods less relevant. Hence there is an opportunity to repurpose OPCL to enhance DER integration. The size of this opportunity is summarised in Table 3. below.

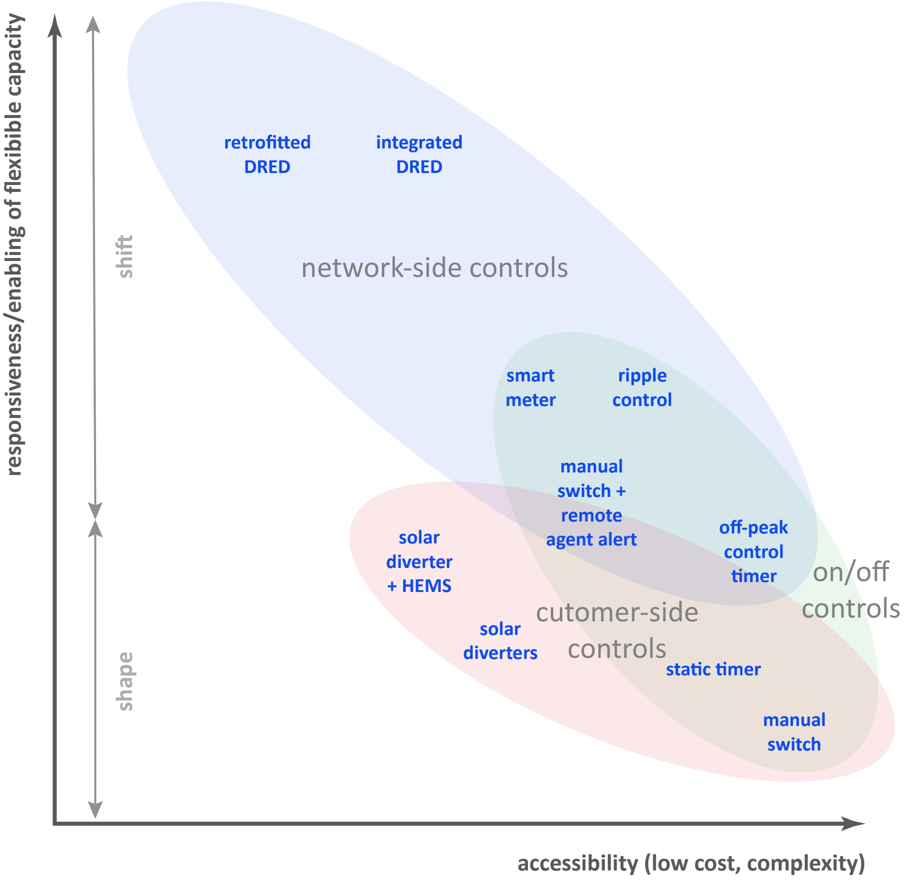

Figure 6. Classification of DHW control technologies in terms of their ability to enable flexible capacity, versus their accessibility in terms of cost and complexity.

Table 3. Existing market potential for flexible DHW, based on existing off-peak DHW. These figures are estimates based on the percentage of customers with off-peak DHW. Each estimate was derived from the available DNSP data in the relevant state.

DNSP	State	Source	No. off-peak hot water storage heaters	DER load (untapped) (@average power draw of 3.6 kW)
				(MW)
Ausgrid	NSW	(Ausgrid, 2016)	500,000	1,800
Essential Energy	NSW	(Ausgrid, 2016)	290,000	1,044
Endeavour Energy	NSW	(Ausgrid, 2016)	333,000	1,199
Ergon	Qld	(Ergon Energy & Energex, 2018)	320,000	1,152
Energex	Qld	(Ergon Energy & Energex, 2018)	770,000	2,772
SAPN	SA	(AEMC, 2014; Rheem, 2021)	300,000	1,080
AusNet	Vic	(AEMC, 2014; Rheem, 2021)	148,000	533
CitiPower and Powercor	Vic	(Deloitte, 2011)	250,000	900
Jemena	Vic	(Deloitte, 2011)	75,000	270
Total			**2,986,000**	**10,750**

2.7.2 Ripple control

Ripple control has been used in Australia since the 1950s and is currently the most common form of DHW load control in Australia, particularly in NSW and Queensland. Ripple control involves superimposing a high-frequency signal (492, 750 or 1050 Hz) on the standard 50 Hz mains power signal to tell the receiving device to switch off or on. Ripple control receivers may be assigned to one of several ripple channels, enabling network operators to control units in stage. Consumers with a controlled DHW unit or other load typically have two meters, one for their controlled load and another for everything else.

2.7.3 Timers, manual switches and solar relays

DHW units can be controlled using a manual switch, timer or solar relay. For maximum benefit, a manual switch requires a user to respond to an explicit or implicit price signal, such as switching on their heater during the day to take advantage of excess electricity from a rooftop solar PV system or in response to an SMS alert from a remote agent.

A timer can automate the process of switching a DHW unit on or off to take advantage of price changes (or excess rooftop solar). However, it is unable to respond dynamically to price signals or other incentives. Timers can be installed by the customer (usually to maximise solar self-consumption) or by the Distribution Network Service Provider (DNSP) as a form of off-peak load control.

A solar relay combines the functions of both a timer and manual switch and may include Bluetooth connectivity for more convenient manual control (Catch Power, 2022).

2.7.4 Solar diverters

A solar diverter is a device that can divert excess electricity generated from rooftop solar to a behind-the-meter load, such as an electric storage DHW system or pool pump, ensuring this excess electricity is used productively rather than being exported (with a low tariff) or wasted via curtailment. If insufficient electricity is available to fully meet demand, such as during winter, the DHW unit can be supplied with electricity from the grid. Hence solar diverters dynamically shape

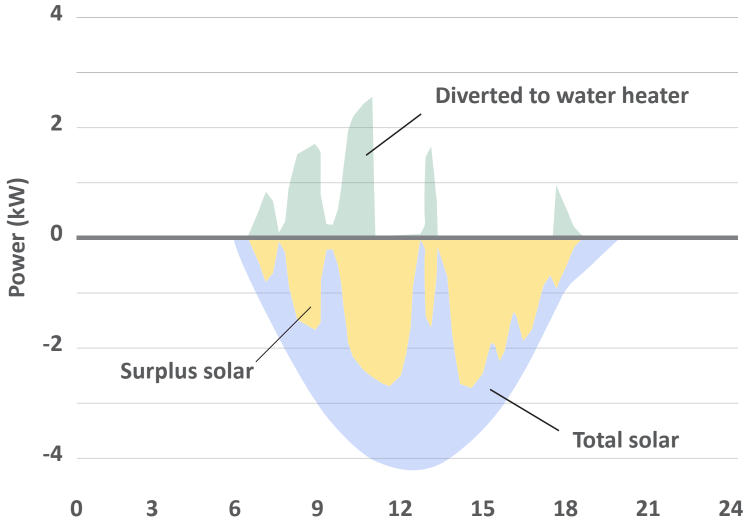

Figure 7. A solar diverter helps householders with rooftop solar to maximise their self-consumption by diverting surplus power from the solar system to a water heater or other load.

DHW demand in response to an implicit price signal to maximise solar self-consumption (see Figure 7). However, they typically cannot connect to a HEMS and provide no means of responding to an external signal to provide network-side control.

There are several companies offering solar diverters in Australia, such as Catch Power, which sells its GREEN Gen II unit for A$757 before installation (Catch Power, 2020).

2.7.5 Demand response enabling devices (DREDs) and smart hot water systems

A demand response enabling device (DRED) provides a communications interface between an electrical appliance and a remote agent. It can be a standalone unit, connected to one or multiple appliances, or integrated into the appliance. Smart water heaters, such as the Rheem Prestige range and Solarhart Powerstore, combine a standard electric resistance storage water heater with a DRED.

Activation of a DRED can be via home Wi-Fi, the GSM mobile network, or a controlled load relay. Using a DRED, a remote agent such as a DNSP can vary the amount of power an appliance consumes, either reducing overall power consumption at times of excess demand or increasing it at times of low demand.

The interface adds about $10 to the cost of an appliance. Activation costs are usually paid by the remote agent and are in the range $75–180 (Wilkenfeld, 2013).

2.7.6 Home energy management systems

A home energy management system (HEMS) combines hardware that connects to home appliances, such as air conditioners, pool pumps, electric water heaters and rooftop solar, and software to monitor and control those appliances to minimise electricity bills. Appliances can be controlled manually on a schedule or in response to price or other signals.

2.7.7 Smart meters

Smart meters offer considerable advantages to retailers and network operators, including reduced meter reading costs and greater visibility across low voltage networks. They can also benefit residential customers through real-time energy use monitoring and time-of-use tariffs. Residential smart meters have been rolled out across many parts of Australia, particularly Victoria, which initiated a state-wide rollout in 2009 for all households and small businesses. Across the rest of the NEM, penetration reached 17.4% or 1.04 million units in October 2020 (AEMC, 2021).

Smart meters typically contain at least two metering elements, each with a relay to switch the attached load completely on or off. By connecting an electric DHW unit to one metering element and the rest of a home's loads to the other, a smart meter can be used by a DNSP to remotely control the DHW unit without affecting the remaining loads.

Smart meters can use various means of communication. Victorian smart meters are either linked through a wireless mesh network, WiMAX or the GSM network. Most also include a low power (nominal 50 mW) 2.4 GHz ZigBee transceiver that can connect to a home area network. However, this capability is rarely employed at present (Total Radiation Solutions, 2015).

2.7.8 Communication and control pathways

To activate shift FD, a communication pathway is required to control a DHW unit. Communication pathways include:

- the electricity network (including ripple control)
- smart meter control via the electricity network
- GSM mobile network
- home area network (e.g. Wi-Fi)
- other radio frequency communication networks, including WiMAX, ZigBee and wireless mesh networks.

Traditional demand response (DR) control systems effect a system demand reduction when some aggregating entity (e.g. the DNSP or an independent aggregator) acts to turn off, modulate or cycle connected loads. This is generally done on some triggering event (a curtailment call), but actions may also be taken on a more regular basis to achieve a diversified permanent load reduction.

2.7.9 Virtual power plants (VPPs)

A virtual power plant (VPP) is an aggregated set of distributed energy resources (DERs) that can be orchestrated to provide energy and grid services, including wholesale arbitrage, demand response, and frequency and voltage regulation. Several companies, including the US-based company Shifted Energy (shiftedenergy.com), aggregate DHW units into VPPs by retrofitting DREDs to existing electric resistance DHW units and communicating temperature and other status information via Wi-Fi or a cellular network to a cloud-based platform. The benefits of the VPP are shared between the network operator, aggregator and residential customers.

2.8 Efficiency and electrification

The high energy demand of domestic water heaters makes them candidates for energy efficiency and electrification programs. Various state white label schemes (see Section 4.4.6) provide financial incentives to improve energy efficiency, such as switching from electric resistance and gas water heaters to heat pumps.

Electric water heaters also provide a pathway for electrification and eventual decarbonisation of residential buildings (see Section 4.6). Across much of the NEM, the GHG emissions of a heat pump electric unit are already comparable to those from a gas unit, even before accounting for any self-consumption of rooftop solar. As the NEM decarbonises through increasing penetration of renewables, heat pumps offer a much less carbon intensive solution than gas (see Figure 3 and Section 3.7).

2.9 Efficiency versus flexibility

There is an obvious trade-off between the high flexible demand potential but low efficiency of electric resistance water heaters versus the much greater efficiency but lower flexibility of heat

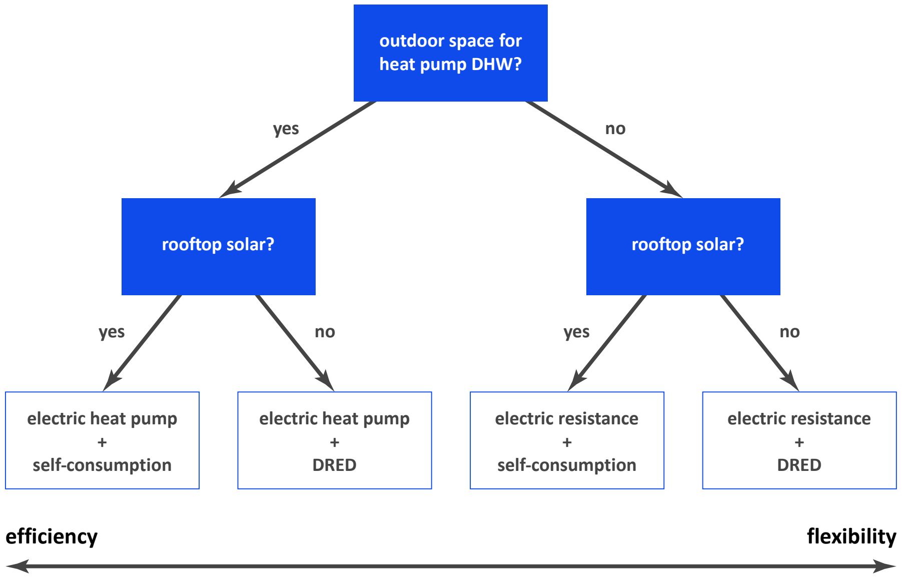

Figure 8. A decision tree used to select the most optimal configuration of DHW and FD technologies. The result is a varying level of balance between efficiency and flexibility, depending on the situation.

pumps. One option that can provide both efficiency and maximise FD is to deploy heat pump DHW units that include resistance elements. In experimental tests, such DHW units were found to be as effective at providing demand response as standard electric resistance DHW units. Although they use around four times less power, they are more available to provide peak load reduction and short-term response services (Mayhorn *et al.*, 2015).

Another option to maximise both efficiency and flexibility across the electricity system is to employ different technologies in different circumstances, sometimes emphasising efficiency and other times flexibility. Figure 8 illustrates this approach using a decision tree. If there is suitable outdoor space, a heat pump should be used in the first instance to maximise efficiency. Otherwise an electric resistance unit can be used to maximise flexibility. If rooftop solar is available, then *shape* FD can be activated in the form of self-consumption using a solar diverter, timer etc. Otherwise, controllable *shift* FD can be activated using a DRED or smart meter.

2.10 Case studies and trials

There is significant interest in the potential of DHW to provide flexible demand services that would benefit both consumers and the network. This has led to a variety of trials testing the efficacy of using DHW as a flexible load in the residential space. Table 4 provides details of trials undertaken to date. The type of flexible service being trialled varies from traditional *shape* services provided by off-peak controls to more active control projects that can provide *shift* flexible demand services.

Another trial of interest was Jemena’s ‘Power Changer’ trial, which enabled customers to earn points using an innovative phone app for reducing demand during periods requested in the app. These points could then be redeemed for gift vouchers. Initial results from the trial were positive, demonstrating engagement from customers with the app and leading to a reduction in demand (Jemena, 2019). For a number of years, Evoenergy has used a voluntary program called ‘Energy Share’, whereby customers who opt in to the program receive SMS messages during periods of heavy demand that ask them to reduce their consumption if possible (Evoenergy, 2022). These types of programs have the potential to become more common in the short–medium term given the low technology barriers and the potential benefits to DNSPs.

Table 4. Flexibility trials involving DHW.

Project title	Partners	Years	Summary
SolarShift	UNSW, Ausgrid, Endeavour Energy, Solar Analytics, NSW OECC, IEA, iHub, Energy Smart Water, RACE for 2030	2022–24	The SolarShift project extends UNSW's prior experience modelling the potential of a household to use solar PV to power their DHW (Yildiz *et al.*, 2021a; Yildiz, *et al.*, 2021b). The project has three phases: (1) desktop modelling, network-tariff design, (2) field trial, and (3) assessment of field trial and analysis of results. The field trial includes coordinating and operating about 2850 electric resistance DHW units as a giant 'megawatt scale' thermal battery to soak up excess solar generation and support electricity networks. New water heater control strategies and tariffs will be designed, aimed to create savings for energy users, balance supply and demand on the network and alleviate challenges attributed to the integration of high levels of rooftop solar power systems. The trial is expected to include partnering with an electricity retailer. The project is part of the International Energy Agency (IEA) Solar Heating and Cooling Program, Smart Solar Hot Water for 2030 task (task69.iea-shc.org).
Rheem Active Hot Water Control[5]	Rheem, Combined Energy Technologies, Simply Energy, SAPN, Marchment Hill Consulting	2021–ongoing	Rheem's trial explores a number of approaches to demonstrate active control over approximately 2400 DHW units in South Australia. Residential customers with and without solar panels are able to participate. The project was launched under Rheem Australia's renewables brand, Solahart. The project has experienced delays owing to COVID-19 and disruptions to semiconductor chip supply chains. To date, it has been difficult to get substantial uptake of the costlier active control system, particularly in the breakdown/replacement market. Uncertainties around VPPs and FCAS market participation were also identified as project risks (Rheem, 2021; Rheem 2022).
Project Symphony[6]	Western Power, Synergy, AEMO, UTS, UWA, UTas	2021–23	An innovative pilot project designed to 'orchestrate' 900 DER assets (including 250 DHW systems) across 500 homes and businesses in the Southern River areas of Western Australia into a Virtual Power Plant (VPP). The area chosen for the pilot has high (50%) penetration of rooftop solar. To date a minimum viable product (MVP) has been tested and the initial recruitment process has shown positive results (Project Symphony, 2022).
Ausgrid Hot Water Load Control	Ausgrid	2016	Ausgrid undertook three separate projects in which they trialled approaches to increasing and optimising their control load tariffs related to DHW. Project 1 saw installation of control load devices on small tank DHW systems that were previously not eligible for control tariffs. There were low response rates for this project, despite customer incentives. The majority of participant did not mind the impacts of being on a control load tariff. Project 2 targeted customers with eligible DHW systems that did not yet have control devices. This project had poor uptake rates owing to upfront installation costs for customers. Project 3 demonstrated that optimising off-peak scheduling provided cost-competitive network benefits (Ausgrid, 2016).

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[5] arena.gov.au/news/storing-excess-solar-from-the-grid-using-hot-water-systems

[6] arena.gov.au/projects/western-australia-distributed-energy-resources-orchestration-pilot

Table 4. Flexibility trials involving DHW.

Project title	Partners	Years	Summary
Parkes NSW 'Solar Soak' Trial	Essential Energy, Origin Energy, IntelliHub	2021–ongoing	This 1000-site trial in Parkes NSW uses smart meter functionality to enable more flexible and responsive controlled loads for customers on Essential Energy's hot water tariff. IntelliHub (as the meter provider on behalf of Origin Energy) has been installing new smart meters on trial sites, configured so that load control is provided via the meter rather than an external relay. The aim is to have more active FD, particularly to shift controlled load into the solar soak period (Essential Energy, 2021).
Off Peak Plus Program[7]	Endeavour Energy, NSW Government, IntelliHub	2021–ongoing	Endeavour Energy and IntelliHub partnered with 10 retailers to deliver smart meters to 2500 homes across Albion Park. The goal is to soak up solar energy: "The installed meters can dynamically control hot water systems, allowing them to be switched on during the day when surplus power is being generated from household solar systems, helping lower customers' electricity bills."
Power Saver[8]	Endeavour Energy	Until 2025	This program provides free HEMS devices to a limited number of customers to help assist with demand management. This can also assist in shifting demand to solar hours.
Mallacoota Reverse-Flow Management	AusNet	2019	AusNet installed a grid-scale battery at Mallacoota in 2020. In 2018–19, there was a rapid expansion of solar PV uptake in Mallacoota, which could cause problems if the battery disconnects from network (upon detecting a power outage) as there could be more generation from solar than load in the town. In 2019, a specific project was also initiated to directly control hot water systems in Mallacoota to reduce the level of reverse power from a high volume of renewable generation (AusNet, 2021).

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[7] endeavourenergy.com.au/news/media-releases/smart-hot-water-storage-set-to-soak-up-solar

[8] endeavourenergy.com.au/modern-grid/projects-and-trials/powersavers/smart-hot-water-system

3 Size of opportunity

To understand the size of the flexible demand opportunity across the NEM, and the trade-offs between different DHW development paths, we further developed and applied our Hot Water System Stock (HoWSS) model. In this section we discuss the methodology and outcomes of the modelling exercise. The results project the realistic flexible potential of DHW under various scenarios, grounded by the literature review and stakeholder engagement undertaken as part of this project. NEM-wide DHW stock results are presented for the years 1990–2040 to provide appropriate historical context. Other results of flexible demand, consumer outcomes and emissions are plotted for the reference years 2020, 2030 and 2040. Detailed results for each NEM region modelled are presented in Appendix B.

3.1 Model overview

ISF built on its HoWSS model to evaluate the size of the FD opportunity across four future scenarios. The process undertaken to complete the modelling is illustrated below in Figure 9. This process began with acquiring and verifying historical data on stock sales to enable modelling of stock hindcast and forecast sales. Several scenarios were then developed, as discussed in Section 3.2. Finally, the techno-economic capabilities of the model were extended using emissions intensity, efficiency and other additional data sources to produce the model outputs.

A conceptual overview of the resulting model is illustrated below in Figure 10. The model comprises several modules to forecast residential hot water demand, the stock of water heating technologies, and the uptake of flexible capacity in the system. These forecasts are then used to calculate the main outputs of the model, namely:

- electricity and gas demand for domestic water heating
- flexible demand potential capacity and depth
- operating costs for domestic hot water (aggregate and average per household)
- GHG emissions.

Various scenarios can be modelled by changing three key variables: DHW stock sales, unit lifetimes for DHW stock (varied by technology) and FD uptake. Further details of the model are provided in Appendix A.

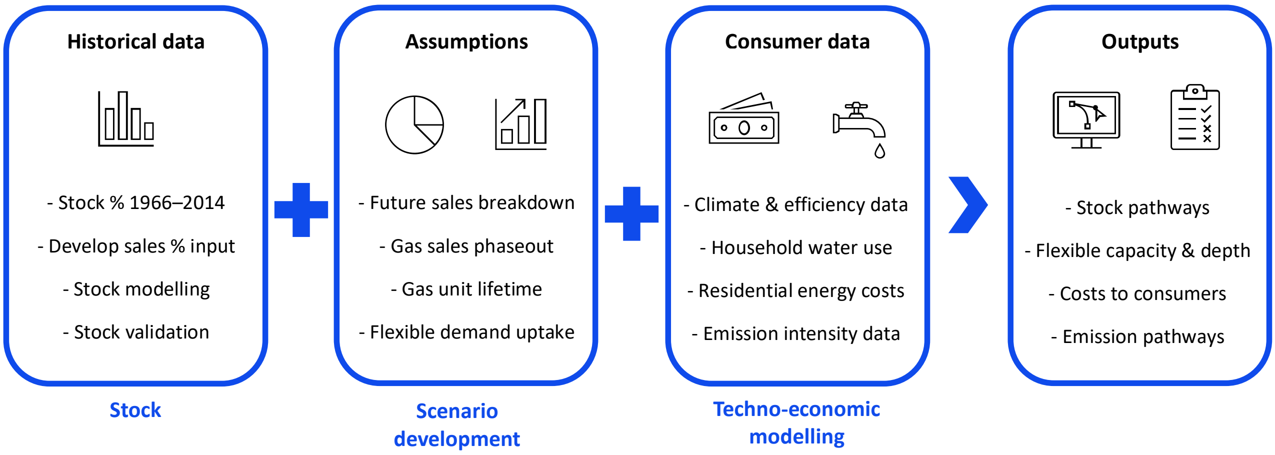

Figure 9. Modelling process used to assess size of DHW FD potential.

3.2 Current situation and future scenarios

As discussed in Section 3, Australia's current stock of DHW units does not easily lend itself to providing FD services to the NEM. This is due to factors such as high penetration of gas DHW, previous government policies aimed at disincentivising electric resistance DHW, ripple control being largely limited to Queensland and NSW, and DNSP timer and clock controls requiring site visits to enable solar soaking. Despite the large potential for FD services to be provided by electric DHW, as discussed in Section 2, uncertainties around the energy transition (e.g. the future prevalence of residential batteries and electric vehicles) have resulted in a current lack of targeted policy encouraging uptake of FD-enabling technologies for electric DHW.

Given the above, four future scenarios were modelled, labelled **Business as Usual**, **Highly Flexible**, **Highly Efficient** and **Rapid Electrification**. These scenarios aim to capture the full spectrum of possible future worlds regarding the uptake of DHW as well as possible accompanying FD-enabling technologies. These scenarios are described in Table 5, and were created by applying different assumptions to the following three key variables:

- forecast sales of water heaters by type
- lifetimes of water heaters, and
- maximum market uptake of flexible demand.

Sections 3.3–3.7 present and discuss the modelling results. The results are provided on a NEM-wide basis, with detailed results for each state available in Appendix B. The NEM-wide results were obtained by simply summing results for each of the NEM jurisdictions modelled: the Australian Capital Territory (ACT), New South Wales (NSW), Queensland, South Australia (SA), Tasmania and Victoria.

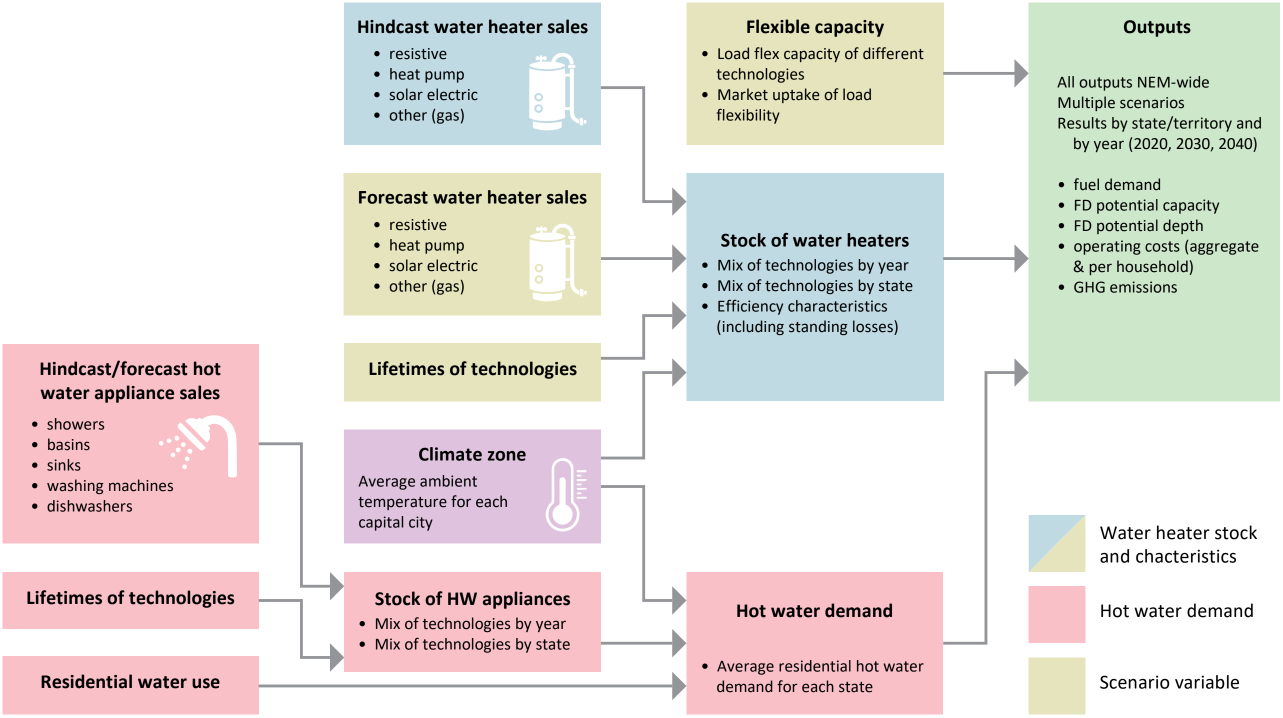

Figure 10. Conceptual overview of the Hot Water System Stock (HoWSS) model used to model the size of the opportunities to improve DHW efficiency and flexibility.

Table 5. Scenario parameters.

Scenario	Gas phaseout	Sales forecasts	Maximum FD uptake[9]
Business as Usual	No forced gas phaseout	Projection of hindcast trends	60% by 2050
Highly Flexible	Gradual phase out of gas DHW sales by 2040, slight acceleration of gas DHW decay after 2035	Gas replaced predominantly by electric resistance	100% by 2045
Highly Efficient		Gas replaced predominantly by heat pump electric	100% by 2050
Rapid Electrification	No sales of gas DHW after 2025 Accelerated decay after 2030	Strong growth in heat pump sales to replace gas	100% by 2035

3.3 Domestic hot water stock

The model calculates DHW stock for each state given the relevant scenario selected and the corresponding sales figures. As shown in Table 5, the choice of scenario dictates key parameters that impact the stock of different DHW technologies: sales forecast, gas phaseout, accelerated gas decay, and transition period for the relevant policy to take effect. Appendix A provides more detail on the variables controlled by choice of scenario.

The NEM-wide results shown in **Figure 11** indicate the aggregate potential that various policy settings could have on the removal of gas hot water relative to the Business as Usual (BAU) case. Results vary significantly by state or territory, owing to different historical starting points (see Appendix B). Policy development should therefore consider the specific situation of each state or territory.

The main finding from the DHW stock modelling exercise is that, under the BAU case, gas DHW units (instantaneous and storage) will make up 38% of the NEM-wide water heater fleet in the year 2040, equating to more than 4.4 million gas DHW units. Without policy intervention, gas DHW will continue to grow, negatively impacting long term customer and emissions outcomes (discussed further in Sections 3.6 and 3.7). The high penetration of gas DHW units under the BAU case also represents a lost opportunity for electrification and a reduced potential for DHW to provide flexible demand.

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[9] This percentage reflects the maximum uptake FD-enabling technology can provide for a given category of electric water heater. For example, resistance heaters will reach the maximum FD market uptake much earlier than heat pumps, owing to factors such as the maturity of available control technology. For further detail, see Appendix B.

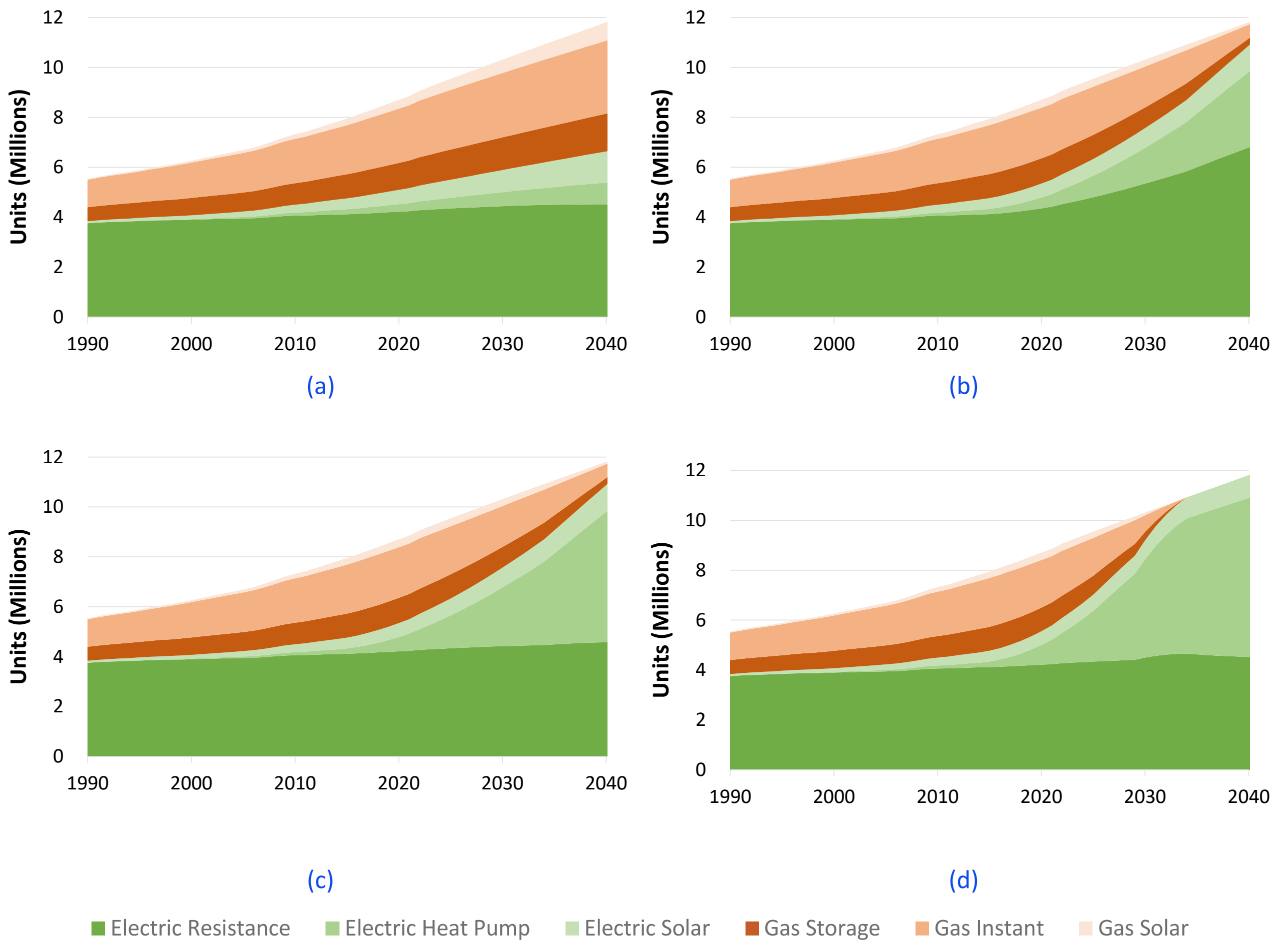


Figure 11. Projected DHW stock for NEM. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

3.4 Flexible demand capacity

Three key parameters were used to derive a detailed breakdown of FD capacity from the DHW stock model output: the maximum FD uptake applicable to any of the three electric hot water technologies (resistance, heat pump and solar), the level of realisation each electric hot water technology achieves in each year relative to this maximum potential, and the proportion of FD-enabling technology that makes up the FD capacity across the different water heater technologies. The model was updated so that an accurate reflection of FD capacity could be provided for each individual state or territory, as well as to reflect a realistic capacity of FD across the NEM. This was required as only Queensland and NSW have widespread use of ripple control technology. Refer to Appendix A for a detailed explanation of the methodology used to model FD capacity.

To provide context to the FD capacity results, the outcomes of the modelling were plotted alongside AEMO's 2022 ISP figure for DER storage (AEMO, 2022). The figures used combine AEMO's projection for behind-the-meter storage and coordinated DER storage (which can occur through VPPs or vehicle-to-grid capability). These figures were used owing to the uncertainty in VPP growth that AEMO identifies in the ISP; if VPPs do not grow as forecast, the NEM will require additional storage capacity (either through further DER or utility storage). Since smart/HEMS-enabled flexible electric DHW can contribute towards VPP capability, and since AEMO predicts that less than

8% of EVs will have vehicle-to-grid capability, the combined storage figures were used.

Figure 12 demonstrates that a substantial amount of realistic FD capacity exists in both the medium- and long-term reference years, with the 2030 capacity of the Highly Flexible and Rapid Electrification scenarios effectively meeting AEMO's projection for DER storage (on a nominal gigawatt basis). Any of the three policy settings that target an increase in electrification of DHW stock alongside measures to support FD result in a significant amount of FD capacity by 2040. If DHW flexibility is targeted over efficiency, there is a realistic potential to increase FD capacity by 40% relative to the Highly Efficient scenario. If both outcomes were pursued alongside rapid electrification, then both objectives could potentially be met.

The opportunity to use DHW as a significant source of FD capacity is largely lost under the BAU scenario. The BAU scenario also limits the functionality of FD DHW as well as the size of the opportunity, because ripple control would likely result in only solar soaking (i.e. *shape* FD) and not play a significant role in providing *shift* FD functionality. The other scenarios demonstrate an increase in self-consumption of renewables through the use of timer and diverter technologies. More importantly, from a grid perspective, these scenarios enable smart and HEMS-enabled DHW to a play a role in providing FD *shift* functionality (while still enabling solar soaking through ripple control).

It is possible that both behind-the-meter storage and coordinated DER storage materialises, in which case the FD capacity provided by DHW

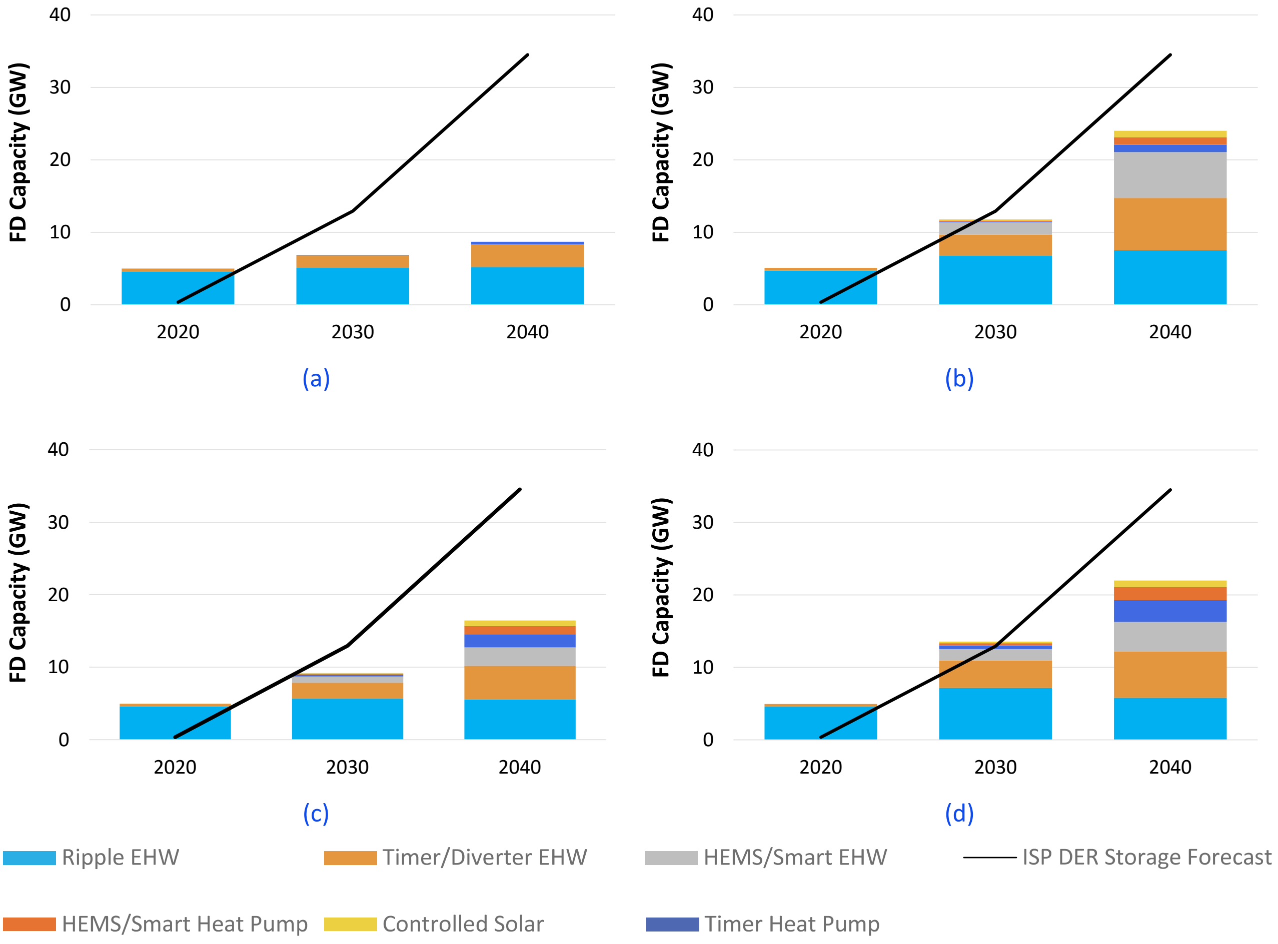


Figure 12. Projected FD capacity across the NEM. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

could displace the need for utility battery storage. The avoided costs of additional utility storage were calculated for the year 2040 to indicate the potential economic benefits of FD-enabled DHW capacity for the grid. It is assumed that each GW of FD-enabled DHW only displaces ~0.44 GW of utility battery storage, which is in line with the results of the high DER scenario performed for ARENA's load flex study (NERA Economic Consulting, 2022). A capital cost of $1369/kW was used for grid battery storage, based on an average of the 2- and 4-hour storage options outlined in NERA's analysis (NERA Economic Consulting, 2022). A summary of the results for 2040 are presented in Table 6.

Section 2.3 highlights the emerging issue of minimum demand caused by the increased uptake of residential solar systems. FD-enabled DHW, particularly resistance heaters, could make a significant contribution to addressing this issue by helping residential consumers self-consume their rooftop solar and by reducing the amount of reverse power flows occurring in distribution networks. As seen in Figure 1, midday demand in South Australia has decreased by an average of approximately 0.75 GW since 2012. Under the Highly Flexible scenario, South Australia's FD capacity potential was 0.5 GW for 2030 and 1.4 GW for 2040 (Figure 46). While flexible DHW alone will not undo the reduction in midday demand caused by PV, it can play a leading role in addressing the issue. The FD capacity results are based on heat pumps drawing 1 kW of power when operated and does not consider that back-up resistance elements could be used to increase minimum demand.

It is difficult to quantify the economic benefit of addressing the minimum demand issue with DHW owing to the multifaceted and localised nature of the problem. On a household level there are cost savings from using cheaper solar power relative to a retail tariff (even when the tariff is discounted as shown in Figure 14), as well as benefits from avoided curtailment where PV export limits are in place. From a DNSP perspective, there are potential savings in avoided network and protection systems upgrades to deal with issues such as reverse power flows. The issue of reverse power flows would be localised to specific sections of the distribution network with high penetration of PV, and thus household consumption and solar generation would need to be modelled on a geographical basis to accurately determine the scope and cost of the problem within a given distribution network. From a system perspective, there could also be significant cost and emission savings from reduced curtailment of large-scale renewables during daylight hours, since renewable generation would not be turned off to allow for generation from coal and gas systems providing inertia to the grid. There are additional system benefits caused by increasing minimum demand that are difficult to quantify, such as increased ease of managing voltage, increased efficacy of emergency frequency control schemes, and higher likelihood of having a stable load for system restart services to successfully enable grid operation after a system outage (AEMO, 2020).

Table 6. Projected FD capacity in 2040.

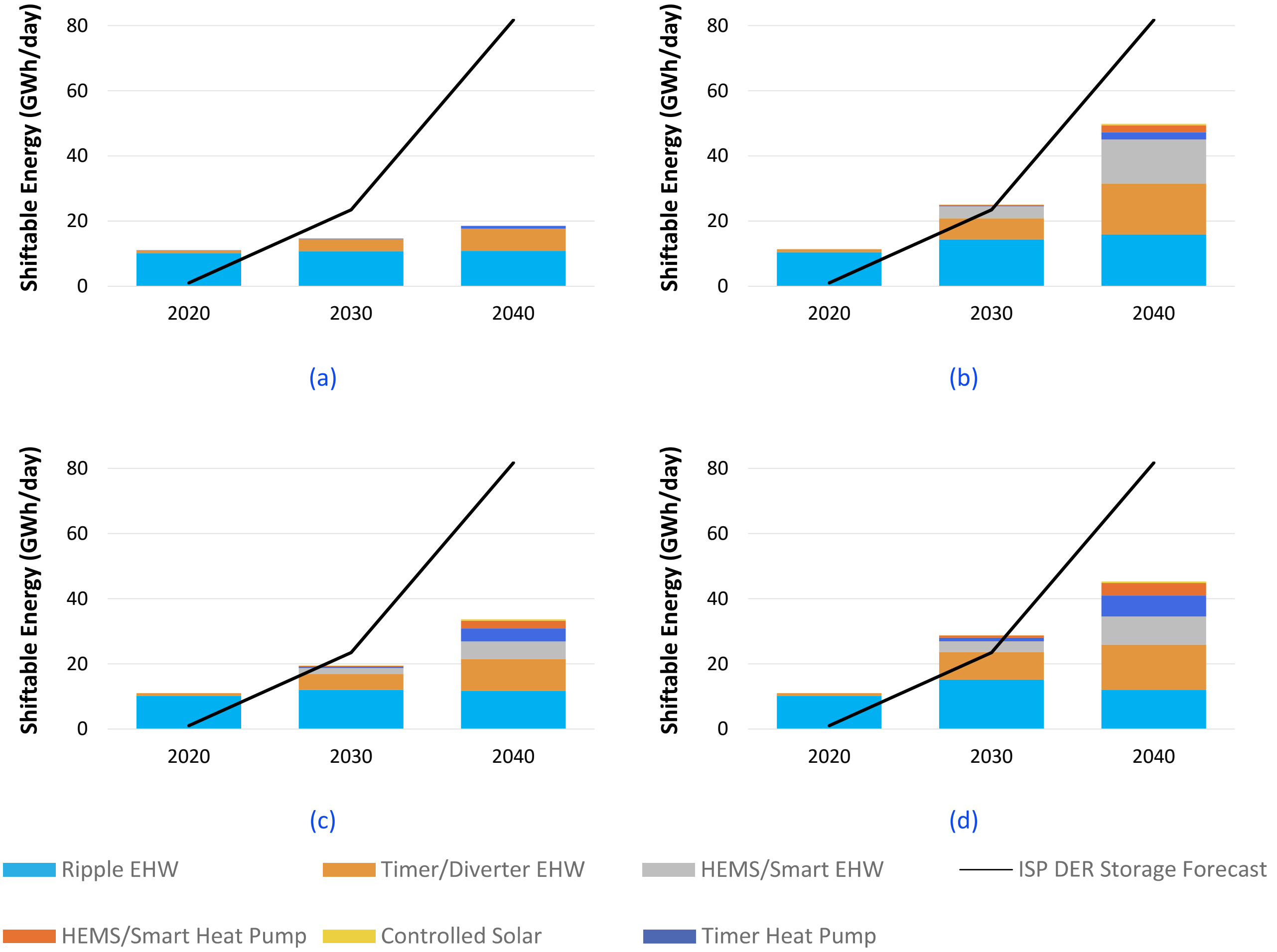
Scenario	FD capacity	Percentage of DER Storage	Avoided grid storage costs
	(GW)	(%)	($ billion)
Business as Usual	9	25	5.4
Highly Flexible	24	70	14.3
Highly Efficient	17	48	10.1
Rapid Electrification	22	64	13.1

3.5 Flexible demand depth

This section discusses the depth of flexible demand capacity, described by the amount of NEM-wide shiftable energy in a given 24-hour period (measured in GWh/day). While FD capacity can be compared to battery storage in terms of absorbing renewable power, this is not the case when considering energy, as DHW cannot dispatch electrical energy at a later time. AEMO’s DER storage figure is still used to provide context to the amount of energy that can be stored in DHW, as absorbing the excess power generated by distributed PV systems can be achieved with either battery storage or DHW.

Two possible methods to determine the amount of shiftable energy provided by FD demand capacity were considered. The first method used determines the nominal amount of shiftable energy by multiplying the rated capacity (in gigawatts) by an average number of operational hours required to heat a storage tank. A deficiency of this method is that it does not consider the amount of hot water used each day. An alternative method is to determine the shiftable energy by considering the amount of hot water used by households. The latter approach was used in the model to more accurately reflect the potential for shiftable energy. The model determines the average daily hot water use of households across each state by considering:

- the hot water demand of household appliances, including showers, basins, sinks, dishwashers and washing machines



(a) (b) (c) (d)

Figure 13. Depth of FD capacity across the NEM. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

- the efficiency of each DHW technology, and the amount of energy required to heat water in each state given the climatic conditions (including losses).

This method approximates the amount of shiftable energy on the basis that energy used to heat water could be sourced from renewables. However, this only captures the *shape* function of FD-enabled DHW. A different modelling approach would be required if load shifting and DR were the primary outcomes of concern, as regular use of hot water would likely reduce the scope of FD services that DHW could provide to DNSPs and third-party operators. This is because increasing hot water consumption reduces the opportunity to allow a storage tank to cool prior to an event when load needs to be increased, as well as reducing the suitable times at which load reduction can occur.

Figure 13 shows similar trends as in Figure 12 when comparing across the four scenarios. This is because both storage capacity and energy storage depth are largely driven by resistance water heaters, which use more energy than heat pump or solar units. When comparing across the capacity and depth results for 2030, DHW provides a larger percentage of AEMO's energy storage forecast relative to the storage capacity forecast in gigawatts. This is for two reasons: AEMO's energy storage forecast assumes an increasing duration of storage hours for batteries, starting with a lower value of ~2 hours (AEMO, 2022) and a large proportion of households are projected to use resistance DHW technology. However, this outcome reverses for the year 2040, as AEMO increases the average duration of battery storage to 2.5 hours (AEMO, 2022), and because heat pumps comprise a larger proportion of DHW stock in 2040 for all but the BAU scenario. This can be seen by comparing results between Table 6 and Table 7.

The Highly Flexible scenario produces 47% more FD depth relative to the Highly Efficient scenario. Thus, if the FD depth provided by the Highly Efficient scenario is not sufficient, policymakers will need to consider the trade-offs between targeting efficiency against higher levels of demand flexibility. To properly assess the trade-offs between these scenarios, both economics and emissions need to be considered, in addition to the modelled FD outcomes. These are discussed in Sections 3.6 and 3.7, respectively.

Table 7. Projected depth of FD potential in 2040.

Scenario	FD depth	Percentage of AEMO forecast
	(GWh)	(%)
Business as Usual	19	23
Highly Flexible	50	61
Highly Efficient	34	41
Rapid Electrification	45	55

3.6 Energy costs

To evaluate the economic impact of differing DHW scenarios, a time series of cost data was constructed based on the cost consumers face through retail tariffs. These costs are derived from the *Gas Price Trends Review 2017* to the COAG Energy Council (Oakley Greenwood, 2017) and the ACCC's latest *Inquiry into the National Electricity Market* report (ACCC, 2022). All costs are expressed in real 2020–21 Australian dollars, and account for both general inflation and specific inflation for electricity and gas, respectively, using quarterly reports from ABS CPI data (ABS, 2022). A significant discount was applied to electric DHW units providing FD services, which was determined by averaging the discounts received by controlled load tariffs across the NEM according to the relevant DNSP price schedule (Roberts *et al.*, 2021). Costs were calculated using the output of modules from the DHW model—e.g. hot water usage, DHW stock and FD uptake.

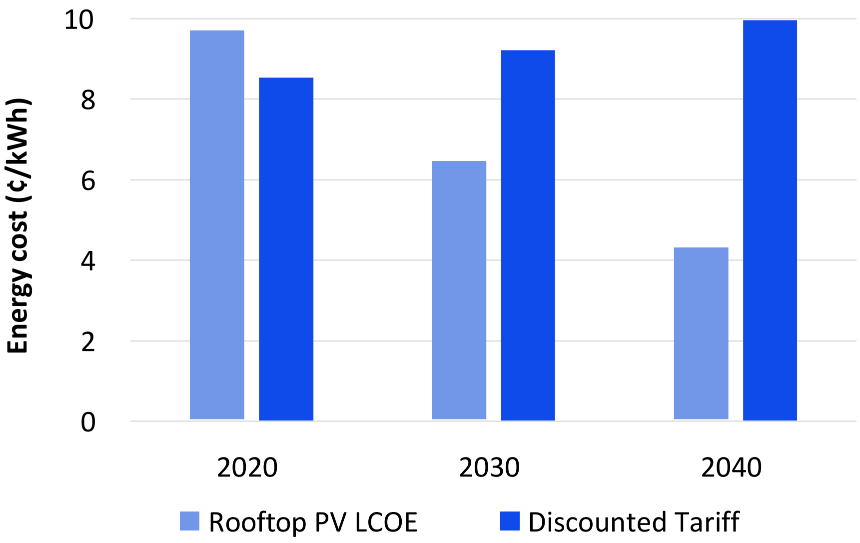
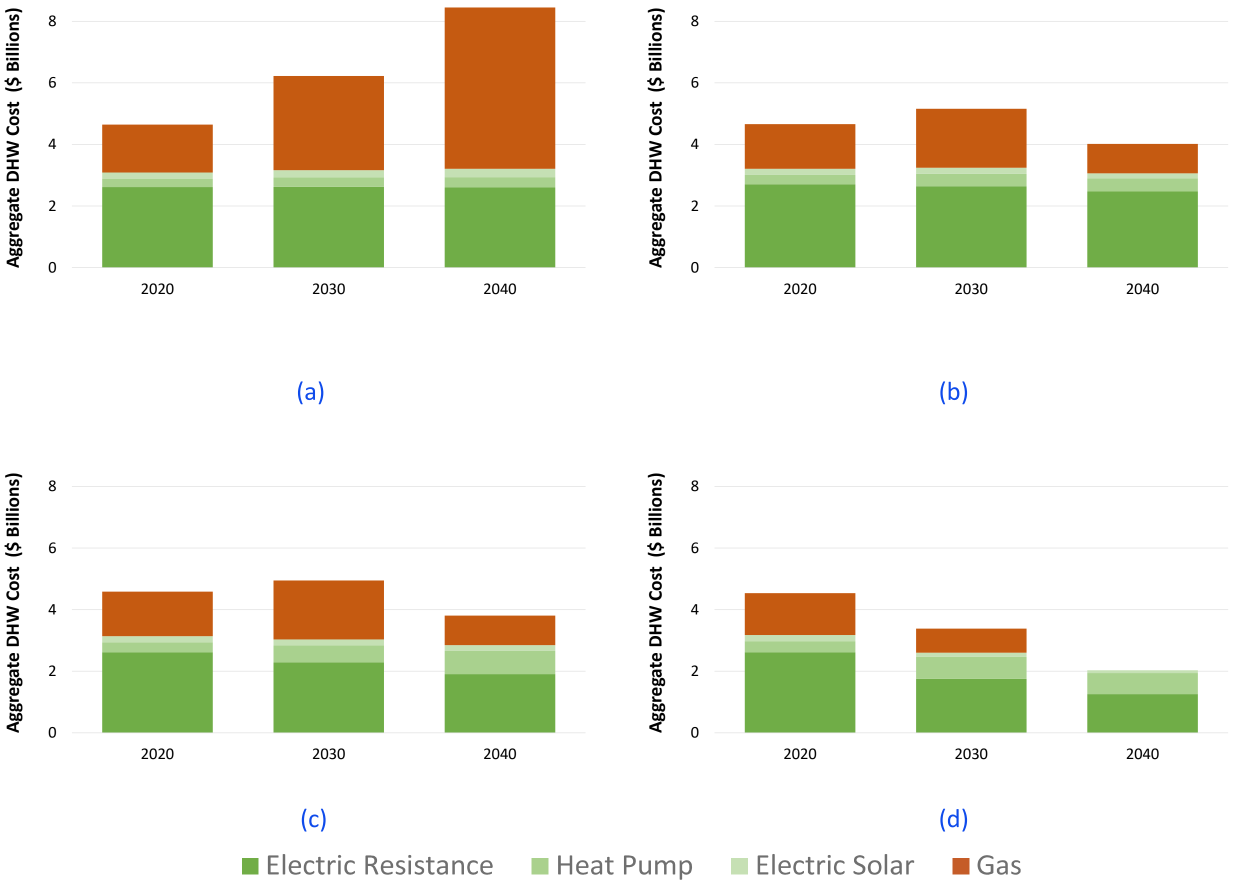


Figure 14. Comparison of electricity costs. Rooftop PV versus discounted tariff from retailer.

Two types of graphs were created to highlight the economic impacts of the DHW scenarios. The macroeconomic perspective (Figure 15) shows aggregate operating costs to consumers across the NEM, while the household graph (Figure 16) shows annual household operating costs broken down by the main types of DHW technology. Capital costs are not included. This methodology somewhat underestimates potential cost savings as customers with rooftop PV would be able to heat their water with cheaper energy. The additional savings these customers would experience is due to the projected difference in energy costs from an electricity retailer’s ‘solar soaker’ tariff and the actual levelised cost of energy (LCOE) for residential solar. The difference between these costs is shown below in Figure 13, with the indicative residential solar LCOE calculated using IRENA data and a 4% per year cost reduction rate (Taylor, 2022). There is confidence that residential solar uptake will continue at pace; however, it is uncertain how common rooftop PV will be among households with differing categories of DHW and if residential solar costs will continually decrease over the 20-year modelling period. For these reasons, the simplified discounted tariff method was used.

Figure 15 highlights that gas poses the biggest risk to increasing consumer costs for DHW heaters. Figure 15(a) shows that under the BAU scenario, consumers across the NEM will be facing an aggregate cost of $8.7 billion for DHW, with gas comprising 63% of aggregate costs. The BAU scenario produces the worst consumer outcomes because of the increasing number of gas units, gas costs rising owing to inflationary pressures, and because there is no mechanism for gas consumers to receive controlled load tariffs or other discounts for providing FD services. Removing gas DHW from the NEM provides consumers with significant savings; both the Highly Flexible and Highly Efficient scenarios save consumers $4.7 billion per annum in gas costs alone by the year 2040. Both these scenarios produce some additional savings owing to discounted electricity tariffs. Interestingly, the Highly Efficient scenario does not provide savings proportional to the reduction in energy consumed, when compared to the Highly Flexible scenario. This is because the savings that would have been made by heat pumps are mitigated by the higher number of consumers receiving a discounted electricity tariff through uptake of FD technology in the Highly Flexible scenario. The Rapid Electrification scenario shows the lowest aggregate costs owing to complete removal of gas by 2040, high levels of FD technology uptake in conjunction with high uptake of heat pumps.



(a) (b) (c) (d)

Figure 15. Aggregate DHW operating costs across the NEM. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Figure 16 highlights that aggregate operating costs are not shared equally among households across the NEM, as increasing gas costs negatively impact some households, while the remainder of households enjoy savings achieved through increased efficiency and discounted tariffs enabled by flexible demand. Although gas users are better off in 2020 than consumers with other DHW technologies, by 2030 they are significantly worse off, with this gap increasing in 2040. Depending on the scenario, in 2040 households with gas DHW have $660–960 higher annual energy bills than heat pump households. Avoiding the BAU scenario also benefits householders with electric DHW technology, as they enjoy cheaper bills through the increased efficiency and uptake of flexible demand.

Figure 16 also highlights the difference in annual heating costs between electric resistance and heat pump households, with heat pumps saving households money relative to resistance heaters for the years 2030 and 2040 across all scenarios. The results shown in Figure 16 indicate that if a household were looking to save on long-term operating costs, they would choose a heat-pump; however, this may not be the ideal economic choice for a household as capital costs, PV system ownership, PV system size, extent of household electrification, and existing DHW technology all impact the benefit of swapping to a heat pump system. The 2020 heat pump figure varies across the scenarios, owing to (1) a lack of historical data available for stock and sales of DHW, (2) the data-fitting process used in the model, and (3) the fact that the cost per household value is quite

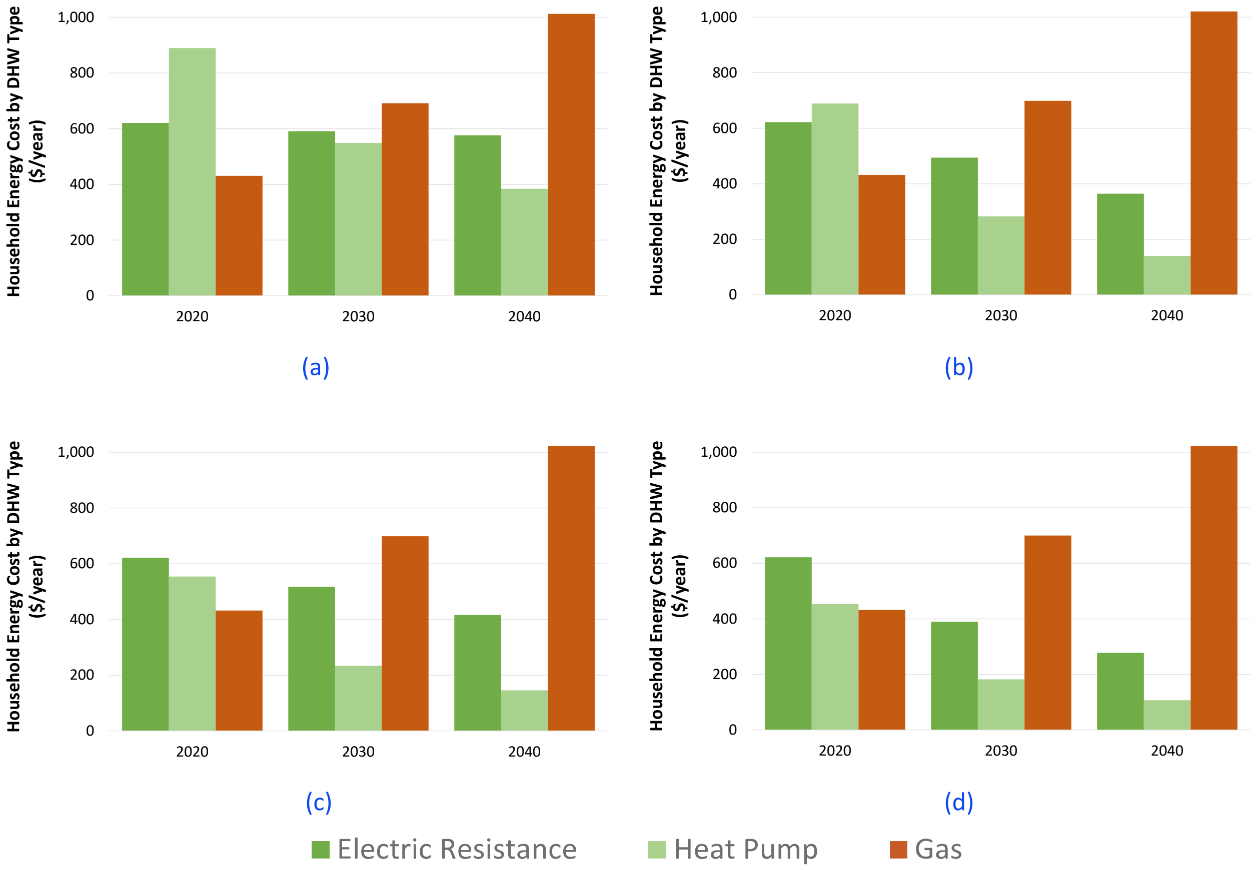


Figure 16. Annual household energy costs segmented by DHW technology type. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

sensitive to the number of households with the relevant technology.

The aggregate costs and cost per household metrics do not consider other economic implications that are relevant to policymakers in the energy space. FD services provided by resistance heaters may provide additional benefits beyond those experienced by electricity retailers and thus not be directly reflected in electricity costs owing to the functioning of the energy market. For example, increased amounts of FD capacity may defer or remove the necessity of DNSPs to upgrade their networks, or defer the need for additional generation to come online. The FD capacity of DHW can also reduce the need for network augmentation by Transmission Network Service Providers (TNSPs).

3.7 Greenhouse gas emissions

Greenhouse gas emissions were calculated by applying emission factors to the consumption of gas and electricity across the NEM. For natural gas, a GHG emissions intensity value of 51.53 kg CO_2-e/GJ was used (DISER, 2020), and assumed to be constant across the modelling period. Electricity emissions were calculated by taking the decarbonisation rate for the NEM under the step change scenario in the ISP (AEMO, 2022) and applying it to the Clean Energy Regulator's state-specific emissions intensities (CER, 2022). The resulting emission factors are displayed below in Table 8. The method used to determine emissions factors for each state uses the assumption that emissions intensity decreases by the same percentage on a year-on-year basis. This method was used as it provides a sufficiently accurate projection of aggregate emissions across the NEM for the reference years. Furthermore, this method also provides a reliable indication of emissions on a state basis, given that states across the NEM have set ambitious emission reduction targets and as the emissions intensity factors listed in Table 8 do not go below that of solar or wind life cycle emissions (Pehl, 2017). The Clean Energy Regulator's Scope 2 emission factors reflect the energy mix in each NEM region, which is influenced by the amount of rooftop solar in each state. Furthermore, AEMO's projection of PV capacity tripling between 2020 and 2040 is factored into the emissions intensities used, as the factors reduce in line with the decarbonisation rate projected in the step change scenario (AEMO, 2022).

Table 8. Emissions intensity on a state basis.

	Emissions intensity		
NEM region	**2020**	**2030**	**2040**
	(g CO_2-e/kWh)		
ACT/NSW/Queensland	810	237	41
South Australia	430	126	22
Tasmania	170	50	9
Victoria	980	286	49

As Tasmania's emission factor reaches the lowest value over the reference period, additional analysis was undertaken to ensure the method used produced reasonable values. Tasmania's emissions intensity factor reduces to a level on par with solar and wind life cycle emissions by 2040, which is ambitious yet achievable, given the available literature and emissions data. For example, Tasmania had an emissions intensity of 29 g CO_2-e/kWh for June 2022.[10] This figure was achieved through ~99% of energy supply being provided by renewable sources, and was determined with the use of 2014 IPCC emissions factors for solar, wind and hydropower. Scope for further emission reductions exists, owing to efficiency improvements in renewable power generation relative to 2014, as well as reduced lifecycle emissions caused by improved manufacturing processes and the increased uptake of low-carbon energy in manufacturing. This analysis holds even when considering that hydropower is the dominant source of energy, as run-of-river hydro and flooded reservoir hydro (excluding emissions from flooded land) has an emissions intensity of less than 5 g CO_2-e/kWh (Raadal *et al.*, 2011).

A result of this method is that the decarbonisation rate is treated as independent from the amount of FD-enabled DHW, even though our modelling indicates substantial potential for FD from DHW. This assumption is justified given the literature available on the topic and AEMO's projections on curtailment. For example, the High DER Uptake State of the World modelled by NERA Economic Consulting found that increased uptake of load flexibility predominantly displaces the need for grid storage while having minor impact on the need for fossil fuel assets in the modelling period 2020–2040 (NERA Economic Consulting, 2022). Furthermore, there is only a marginal benefit that FD-enabled DHW could provide regarding reducing emission if DHW is able to add to overall storage capacity rather than proportionally displace the need for batteries. This can be stated on the basis that AEMO projects that spilled energy will only increase from 7 to 11% across the reference years modelled (AEMO, 2022). AEMO projects that mid-merit gas falls to negligible amounts under the step change scenario by 2040, but up to 7.1 GW of peaking gas and liquid capacity will still be required by this time (AEMO, 2022). If coal is phased out rapidly and DER storage develops in line with AEMO's forecasts, there is the potential for FD-enabled DHW to reduce the regularity of gas peaker operation. This could cause noticeable cost savings for consumers, as well as some additional reductions

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[10] app.electricitymaps.com/zone/AUS-TAS

in emissions (i.e. <11% curtailment of energy by 2040).

Reducing solar curtailment in the short-to-medium term would arguably not reduce emissions, based on a study completed by Hungerford *et al.* (2016), which researched the value of FD-enabled DHW in Australia. This study modelled a NEM with conditions similar to those seen between 2015 and 2020, such that 20% of electricity came from variable renewables. Generator dispatch was modelled at half-hour intervals in this study and was determined by a cost optimisation engine.

Australia’s current OPCL configuration of DHW was compared to an optimised DHW schedule enabled by control of resistance DHW. It was found that solar spill was reduced 30–40% through optimised DHW control. Despite the large reduction in solar curtailment across the NEM, it was found that the optimised DHW schedule slightly increases emissions by 0.01% under the grid conditions modelled. This surprising result occurs because “the overall flattening of the residual load profile also results in a significant shift from OCGT generation to more polluting black coal, resulting in an on-average increase in emissions.” This occurs because the cost optimisation engine dispatches black coal over gas turbines owing to the lower cost of black coal relative to gas. Based on the above literature it was assumed that increasing FD through DHW has minimal impact on overall emissions.

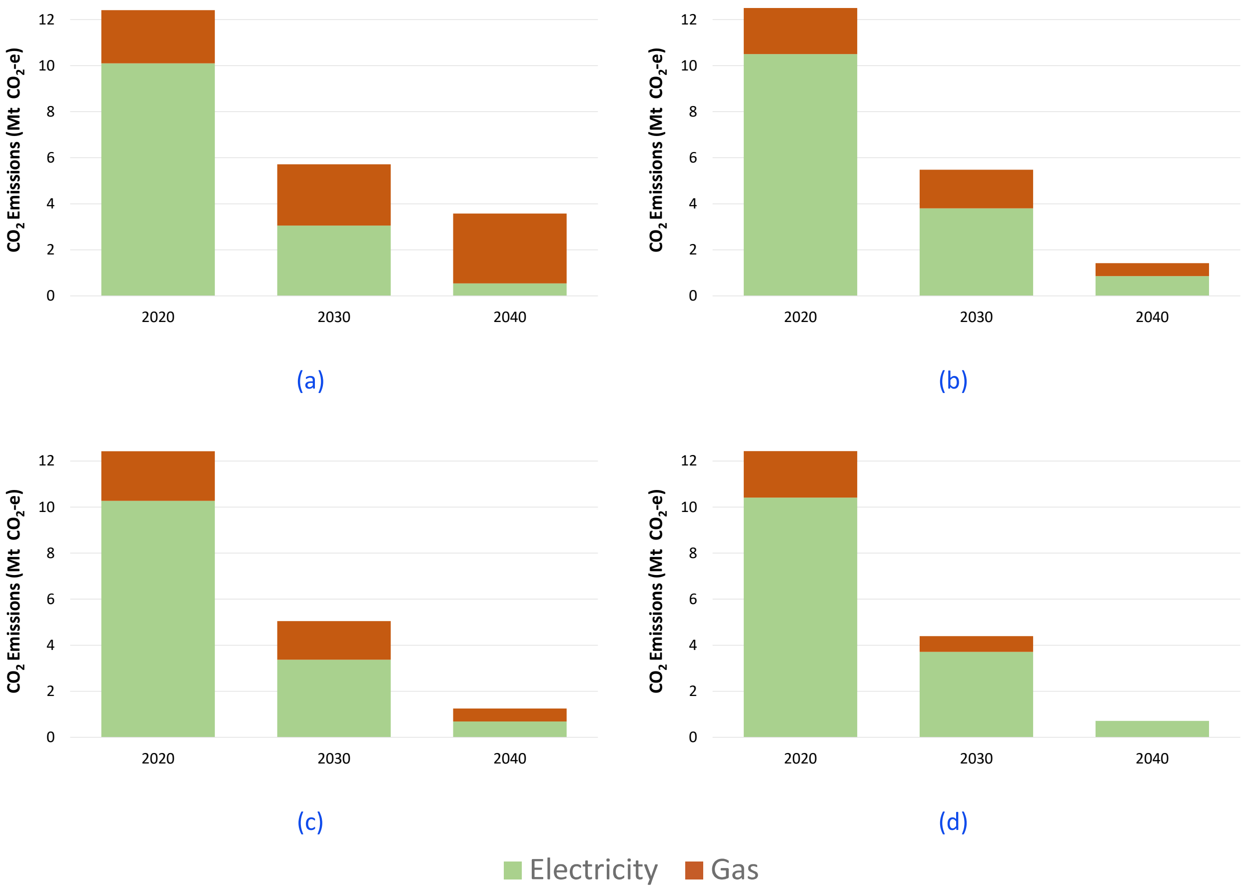

Figure 17. Projected NEM-wide CO_2 Emissions. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

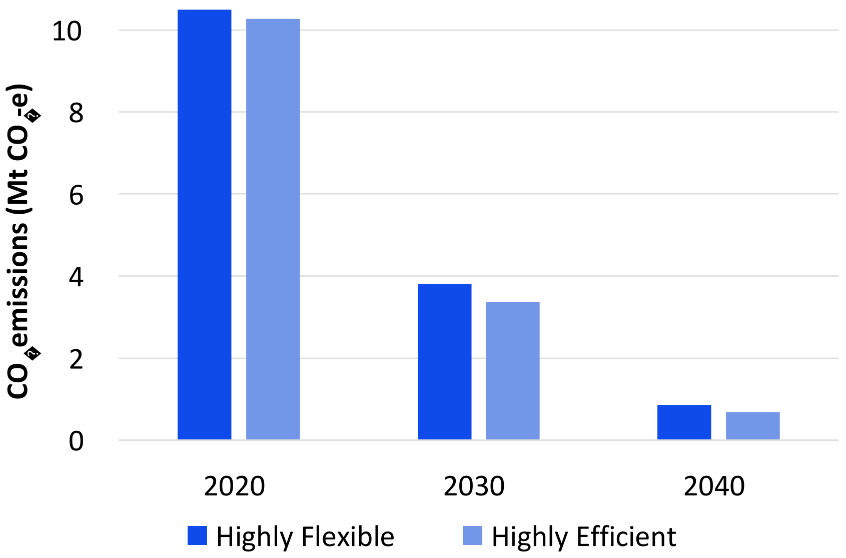

Figure 18. Comparison of electricity emissions between the Highly Flexible and Highly Efficient scenarios.

The results shown in Figure 17 clearly demonstrate that reducing emissions from DHW will predominantly be driven by decarbonisation of the electricity supply, as forecast in AEMO's step change scenario. Figure 17(b) and (c) show very similar emission reduction pathways, indicating that electrification through either resistance heaters or heat pumps will enable decarbonisation of hot water heating in the NEM. Both (b) and (c) show similar emissions pathways owing to the rapid decarbonisation of the NEM outlined in Table 8, so that when heat pumps make up a significant proportion of DHW stock in 2030, the grid has already experienced a 70% reduction in carbon intensity. The Highly Efficient scenario provides marginal improvements regarding electricity emissions, as shown in Figure 18. The high efficiency of heat pumps would have a larger impact on reducing carbon emissions in the event that the NEM decarbonises slower than projected under the step change scenario.

3.8 Comparison of scenarios

The results presented in Sections 3.4–3.7 indicate that all scenarios apart from the BAU case produce beneficial outcomes across the board of outcomes modelled: demand flexibility, reduced energy costs and reduced emissions. The results show that FD outcomes are predominantly met by resistance water heater technology across all four scenarios, with the depth of FD being more sensitive to penetration of resistance heaters than FD capacity. The Highly Flexible and Highly Efficient scenarios produced similar outcomes from a macroeconomic perspective; however, consumers with heat pump DHW units are forecast to save on their annual energy bill relative to those with electric resistance DHW by the year 2040. The emissions modelling indicated that decarbonisation of the NEM is the key driver for reducing emissions intensity of DHW, and that once this occurs gas systems remain the largest obstacle for decarbonising water heating.

Based on these results, there is no clear dichotomy between enabling flexible demand and achieving efficient water heating, but instead a range of future scenarios which achieve both outcomes to varying degrees. The questions policymakers need to address thus become:

1. Is the amount of flexible demand achieved in the Highly Efficient scenario sufficient?
2. If not, to what extent should further flexible demand measures be prioritised over encouraging the uptake of efficient heat pump technology?

As discussed in Section 3.4, AEMO acknowledges there is substantial uncertainty regarding Australia's energy transition development pathway, particularly in the residential sector where aggregate consumer choices could lead to significantly different outcomes for PV, battery and EV uptake. Further complexity is added from a system perspective when considering the extent to which smart control, HEMS and VPP technologies are adopted by households. Figure 19 shows AEMO's storage forecast, in which approximately half of future storage capacity is expected to come from coordinated DER storage (which would be predominantly driven by VPP uptake). As there is less certainty around storage from VPPs, it is a good parameter to consider when considering the amount of storage required from FD-enabled DHW stock.

In a theoretical worst-case scenario for coordinated DER storage, the 18.5 GW forecast for 2040 by AEMO does not materialise and this capacity needs to be replaced by other forms of flexible demand. The Highly Efficient scenario has a realistic potential of 16.5 GW of flexible demand DHW, almost sufficient to cover the contingency of VPP technology not experiencing widespread adoption across the NEM. However, 1 GW of FD in the Highly Efficient scenario is not equivalent to 1 GW of coordinated DER storage, as the majority of FD enabled under this scenario will only be able to provide *shape* FD services rather than shifting demand and other more advanced FD services. The importance of these FD services will increase as the penetration of VRE increases, and thus it may not be optimal to target efficiency measures at the expense of the uptake of smart and HEMS-enabled resistance DHW. Given the numerous uncertainties outlined above, it is prudent to analyse policy options in light of more certain parameters. It is known that enabling FD across electric DHW will significantly decrease curtailment of solar across the NEM, thus assisting DNSPs in managing their networks and providing customers better access to export services. It is not known to what extent VPPs will materialise, the uptake of residential batteries, or how important it will be for FD DHW to provide more advanced FD services. Thus, to minimise trade-offs between the Highly Efficient and Highly Flexible scenarios, short-term policy should focus on enabling FD DHW to perform solar soaking.

As discussed in Section 3.5, the modelled energy storage ability of FD DHW stock is dominated by electric resistance technology, owing to both the FD projections as well as the relatively low efficiency of this technology. Thus, if reduction of PV curtailment during daylight hours was a particular policy objective, this would place a higher importance on enabling FD through resistance water heaters in the short to medium

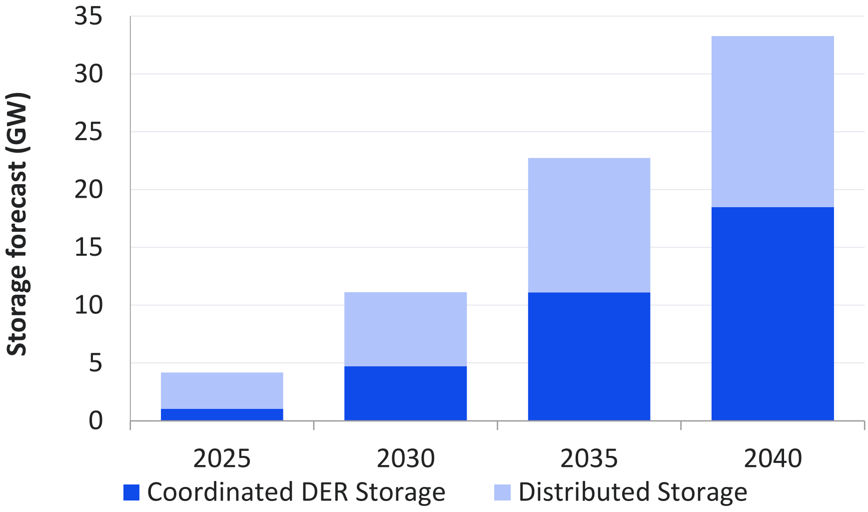

Figure 19. AEMO's DER storage forecast for step change ISP scenario (AEMO, 2022).

term. Solar soaking tariffs and trials to move DNSP-controlled (ripple and timer) DHW to solar hours are yet to be implemented at scale and thus offer low-hanging fruit regarding ways to improve the flexibility of the DHW fleet and soak excess solar energy. A major benefit to solar soaking tariffs and moving DNSP-controlled DHW to solar hours, is that this can be achieved under all scenarios and does not impede other potential mechanisms or development paths. Policies targeting the adoption of timed circuits and diverters for DHW could also be pursued to maximise the storage potential of the electric resistance fleet, given that households installing rooftop PV tend to remove or stop using ripple-controlled electric DHW. In this way, trade-offs between efficiency and flexibility would be minimised, thus enabling the current DHW stock to transition towards a more optimal development pathway without sacrificing the ability to achieve other policy objectives.

4 Barriers and drivers

4.1 Overview of barriers and drivers

The technologies required for improving both the efficiency and flexibility of Australia's DHW are readily available. However, deployment and integration of these technologies are hindered by a range of social, technical, economic, policy and supply chain barriers. This section provides a detailed analysis of these barriers and the related drivers that can support a transition to a more efficient and flexible DHW system.

There have been two major Australian studies into the barriers of enabling domestic FD services:

- CSIRO's *Australian Consumers' Likely Response to Cost Reflective Electricity Pricing* study (Stenner *et al.*, 2015); and
- RACE for 2030's H4 Opportunity Assessment report *Rewarding Flexible Demand: Customer Friendly Cost Reflective Tariffs and Incentives* (Roberts *et al.*, 2021).

CSIRO's study focuses on cost-reflective pricing arrangements such as ToU tariffs and demand charges, while the RACE for 2030 study takes a broader perspective and looks at all aspects of FD. Despite these differences, the two reports converge on an important framework for understanding the barriers to FD services being actualised in Australia:

- availability of FD enabling factors (i.e. relevant tariff structures, technologies etc.)
- household uptake of FD enabling factors
- appropriate behavioural response to incentives and FD enabling factors.

While these three aspects may appear self-evident, it is important to understand how each aspect can prevent the actualisation of FD services in Australia. Not all DNSPs readily provide opportunities for Australian households to access FD-enabling factors. Some have eliminated traditional overnight OPCL tariffs, and there are few trials and schemes enabling FD from DHW. Furthermore, there are currently a limited number of technologies available in the Australian market through which DHW FD can be enabled. Once these initial barriers have been overcome, widespread adoption of FD may be limited by consumers' reluctance to adopt cost-reflective tariffs, the costs associated with FD technologies, or a lack of consumer engagement. These matters are discussed in detail below.

Table 9. Socio-economic factors in cost-reflective tariffs. Source Stenner *et al.* (2015).

Socio-economic factor	Main finding
Income	Lower income households are more comfortable with choosing tariffs with lower risks and complexity; e.g. flat rate, cheaper flat rate with CPP, peak rebate tariffs. Interestingly, higher income households more readily express a preference for flat rate tariffs. Low-income households were discouraged from taking up a cost-reflective tariff when an automation device was included in the offer.
Education	Households with higher education levels[11] expressed a greater willingness to choose a cost-reflective tariff structure over flat rate tariff, while lower income households had a marked preference for flat rate tariffs.
Employment	"Households whose main income earner is only employed part-time are significantly more enthusiastic about *peak time rebates* than are others, and the only ones who generally prefer them to flat rate tariffs." Money-back guarantees to choosing a tariff type also encouraged these households significantly. No other general trends could be drawn across employment categories.
Home ownership	Renters showed a preference for peak-time rebates and real-time pricing over other tariff options including flat rate tariffs.

4.2 Social factors

Decisions by individual householders will ultimately drive uptake of FD-enabling technologies and incentives. It is therefore beneficial to understand the social factors that impact a household's willingness to engage in FD opportunities with electric DHW.

One important social factor is perceived impact on thermal comfort. According to an online survey by Christensen *et al.* (2018) of about 1000 individuals, shower temperature and length were ranked more highly in importance than having clean clothes or dishes. Activating DHW FD therefore requires that impacts on thermal comfort be minimised and householders be suitably informed of potential impacts, particularly those without prior experience with traditional OPCL electric DHW. Similarly, Roberts *et al.* (2021) emphasise the important of consumers maintaining control over their appliances:

> A further factor that significantly influences household's perceived control or loss of control is the possibility to intervene to override remote control of appliances (Buchanan *et al.*, 2016) or to ignore price incentives at any given time (Smale *et al.*, 2017). The provision of a manual override capacity can mitigate concerns (Parkhill *et al.*, 2013), while the absence of such a possibility may be a barrier to user acceptance and engagement. For example, survey results from one part of Ausgrid's hot water control trials showed that 'when offered the option to use an override switch to return to an uninterrupted supply and an incentive, the proportion of the sample willing to switch to controlled load increased to 52% [from 45%]' (Ausgrid, 2016). Ausgrid have noted with respect to the CoolSaver program that the absence of the ability for a customer to override an individual peak event 'was recognised as a possible key barrier to higher customer take-up' (Ausgrid, 2015).

Stenner *et al.* (2015) investigated preference differences across a variety of socio-economic parameters, including income, education, employment and home ownership. Table 9 summarises the main findings of this analysis and provides an indication of how socio-economic factors impact Australian consumer preferences in

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[11] Defined as education beyond a bachelor's degree or graduate diploma.

engaging with FD-enabling factors such as cost-reflective tariff structures. This table highlights variation across social groups in regard to willingness to adopt FD-enabling tariff structures, with several dynamics playing out between factors such as income and education. Social factors also impact a household's ability and willingness to enable electric DHW to participate in FD. For example, while high income households more readily expressed a preference for flat rate tariffs because of their high electrical demand and lower ability to adjust their usage schedule owing to work arrangements, these are the households most readily able to pay for the technology that would enable electric DHW to provide FD services.

In addition to the above variations around preferences and willingness to pay, there is also a lack of trust in FD-enabling factors. For example, customers may exhibit concerns around data and privacy. Distrust from consumers may also act as a social barrier, with many Australians lacking trust across all energy companies whether they be a retailer or DNSP (Roberts *et al.*, 2021). The implications of this distrust for aggregators and third-party companies is not yet well understood.

In the area of DHW, most consumers have only limited understanding of the available technology choices, and the cost-effectiveness of those choices, even before adding an additional layer of complexity through flexible demand. One area identified for improvement is better decision-making tools for consumers, such as those operated by Sustainability Victoria.[12]

4.3 Behavioural and economic factors

Consumers do not always respond perfectly rationally to economic incentives, as demonstrated by only 50% of them taking up traditional OPCL tariffs (Ausgrid, 2016; Ergon Energy & Energex, 2018). As demonstrated by Stenner *et al.* (2015), the success of FD being provided by DHW in Australian households will be dictated largely by consumer behaviour: "the greatest barrier to uptake of cost-reflective pricing appears to be consumers' aversion to making any kind of choice—the status quo bias". When factoring in the response rate of consumers to communications from their energy retailer, their "…calculations suggest that the initial voluntary uptake of cost reflective pricing is unlikely to exceed 5–10% of households" (Stenner *et al.*, 2015).

As discussed in Stenner *et al.* (2015) and Roberts *et al.* (2021), consumers exhibit *status quo* bias towards flat rate tariffs, which have historically been the standard default offer for DNSPs. This bias is entrenched by other aspects of consumer behaviour, such as:

- risk aversion towards higher costs at peak times and other cost-reflective charges; i.e., demand charges, capacity charges, real-time pricing
- uncertainty over economic benefits to be gained by switching to cost-reflective tariffs; i.e. perception of minimal savings to be made, concern of tariff changes not reducing household electricity bills
- risk and uncertainty in households being able to adapt to price signals and shift consumption as required.

Only about 20% of households on ToU tariffs exhibit a significant response to price signals, such

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[12] sustainability.vic.gov.au/energy-efficiency-and-reducing-emissions/save-energy-in-the-home/water-heating/calculate-water-heating-running-costs

that their consumption patterns are reduced at peak times (Currie, 2020). Roberts *et al.* (2021) also found that:

> The highest ranked barrier to DR by retailers and aggregators in Energy Synapse's stakeholder consultation (Energy Synapse, 2020) was "financial payment not attractive enough". In several studies households have expressed doubts that the financial benefits associated with using technologies such as smart meters to achieve demand flexibility would be sufficient to make their engagement worthwhile (Throndsen & Ryghaug, 2015; Balta-Ozkan *et al.*, 2013; Buchanan *et al.*, 2016), and 'running appliances when electricity is cheaper was perceived as pointless if savings were minimal' (Balta-Ozkan *et al.*, 2013). In one phase of Ausgrid's hot water load control trial, not using a lot of electricity and not being convinced that they would save much money were, on average, the two biggest reasons for not being interested in switching to off-peak systems (Ausgrid, 2016). This can present a barrier not only to the uptake of and response to those incentives but will also make it difficult for utilities to provide DR incentives they can afford.

Even if cost-reflective tariffs are implemented on an opt-basis, this will not guarantee changes in household consumption patterns, suggesting that technology and automation are important factors for activating DHW FD. Policymakers must therefore be careful to consider how and which technologies are used to activate FD services. In the short-to-medium term, FD services provided by DHW are most likely to occur through adjusting OPCLs (see Section 2.7.1) to solar hours, households on ToU tariffs using timed circuits to operate DHW at pre-chosen times (2.7.3), and households with rooftop solar using solar diverters (2.7.4).

4.3.1 Capital and operating costs

As shown in Figure 20, the various DHW technologies differ significantly in their capital and operating costs. These calculations are based on the following assumptions:

- Comparative sizing:
  - Flow rate of 26 L/min for instantaneous gas (Rinnai REU-VRM2626WG)
  - Power rating of 19.4 kW for instantaneous electric (Stiebel Eltron DEL18)
  - Tank size of 250–270 L for electric resistance (Rheem 491250), heat pump (Envirosun 250EH1-15) and gas storage (Aquamax G270SS)

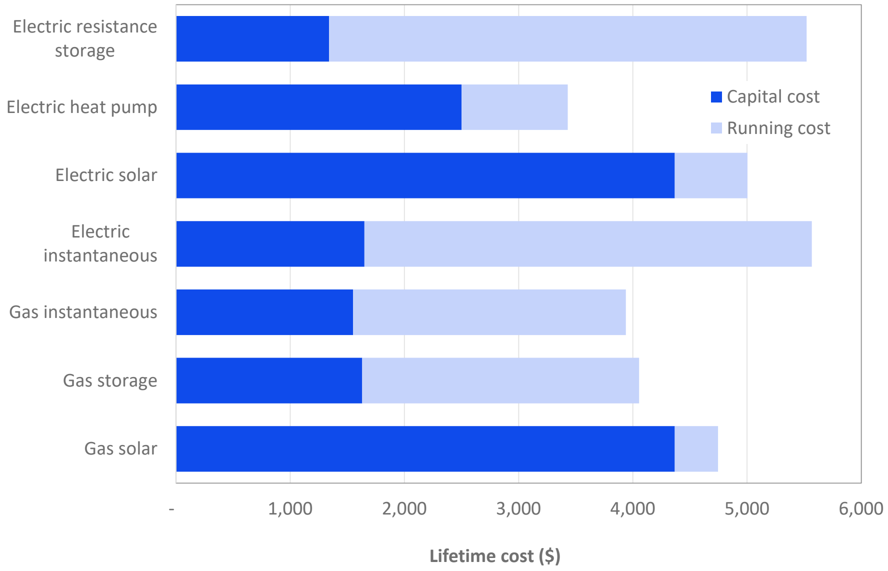

Figure 20. The various DHW technologies differ significantly in their capital and operating costs.

Table 10. Per-unit GHG emissions of the various DHW technologies across the different NEM jurisdictions for 2020 and 2040.

		2020				2040			
Technology	**COP**	**Vic**	**NSW/ ACT/Qld**	**SA**	**Tas**	**Vic**	**NSW/ ACT/Qld**	**SA**	**Tas**
			(g CO_2-e/MJ)				(g CO_2-e/MJ)		
Electric resistance	0.890	306	253	134	53	15	13	7	3
Electric heat pump	3.500	78	64	34	13	4	3	2	1
Electric solar	5.850	47	38	20	8	2	2	1	0
Electric instantaneous	0.950	287	237	126	50	14	12	6	3
Gas instantaneous	0.675	76	76	76	76	76	76	76	76
Gas storage	0.665	77	77	77	77	77	77	77	77
Gas solar	4.250	12	12	12	12	12	12	12	12

  - Tank size of 300 L for solar (Rheem 52L300SS/2L), with capital cost adjusted pro rata by 5/6
- Daily household hot water usage of 125 L
- Electricity cost of $0.27/kWh and gas cost $0.0325/MJ
- Capital costs for supply and installation in NSW (including STC and ESC discounts), taken from Same Day Hot Water Service (samedayhotwaterservice.com.au)
- 13-year system life
- Zero discount rate
- Coefficients of performance per Table 10.

The results presented in Figure 20 show:

- The dominant DHW technologies of electric resistance storage, gas instantaneous and gas storage have the lowest capital costs, with electric resistance storage being the lowest.
- Electric resistance technologies (storage and instantaneous) have the highest operating costs.
- Heat pump and solar DHW technologies have the lowest operating costs, but significantly higher capital costs.
- Heat pumps offer the lowest lifetime cost (with STC and ESC subsidies included).

Consumers understandably place greater significance on up-front costs than future operating costs, which largely explains the popularity of technologies with low capital costs, despite their higher lifetime operating costs, especially compared to heat pump DHW units.

4.3.2 Greenhouse gas emissions

One of the main objectives of government DHW policy is to reduce greenhouse gas emissions. Many consumers are also motivated to reduce their emissions through selecting lower emissions technologies. Table 10 shows a comparison of the various DHW technologies in terms of their per-unit GHG emissions based on emissions intensities for gas and electricity in 2020 and projected intensities for 2040 from Table 8. For gas technologies, a constant emissions factor of 51.53 g CO_2-e/MJ is assumed (DISER, 2020). See also Figure 3.

Table 10 shows that under present grid conditions, the lowest emission DHW technologies are heat pumps and boosted solar. For current emissions factors, gas offers a lower emissions intensity than electric resistance heaters across most of the NEM, although this is not the case for electric solar or heat pumps. Since renewables currently supply ~30% of annual energy in the NEM and are projected to reach 90% before 2040 under the step change scenario, emissions intensities for electric technologies are projected to be substantially less than those of gas technologies by 2040. Emissions from the electric technologies also vary widely by state and are lowest in the states with the highest penetration of renewables, namely SA and Tasmania.

4.3.3 Tariffs and DNSP incentives

Distribution network service providers (DNSPs) own the poles and wires at the distribution stage of the electricity network, while retailers are the interface between residential customers and the rest of the NEM. DNSPs set their own network tariff structures in accordance with AER regulations, which retailers then use when creating retail tariffs. Traditional off-peak controlled DHW has been commonly used to manage peak demand in the NEM, as reflected by the examples detailed in Table 11. Recent years have also seen the emergence of ‘solar soak’ tariffs from SAPN. For a comprehensive list of the retail tariffs available to households in each DNSP area, refer to Appendix 1 of Roberts *et al.* (2021).

Under AEMC market rules, tariff trials (sub-threshold tariffs) are allowed, which enable DNSPs to provide additional tariff structures that were not included in their five-year Tariff Structure Statement. The opportunity to trial tariff structures is also supported by the AER’s decision to increase individual and cumulative thresholds for trials to 1 and 5%, respectively.[13] Table 12 details the tariffs for which DNSPs have sought AER approval.

The tariff trials listed in Table 12 indicate that DNSPs are now dealing with two problems—peak demand and minimum demand (see Section 2.3). These trial tariffs tend to use a peak pricing structure seen in other ToU tariffs. However, owing to the emerging issue of minimum demand during solar hours (see Section 2.3), DNSPs are now looking to offer discounted off-peak rates during daylight hours to minimise problems relating to reverse power flows and voltage rise, which can be caused by excess solar generation. While a problem for DNSPs, minimum demand provides opportunities for households without solar to benefit from lower electricity prices during solar hours. In conjunction with reduced opportunities for households to access traditional overnight OPCL electric DHW, this may incentivise non-solar households to uptake FD-enabling arrangements such as solar soaker ToU tariffs.

Despite the emergence of ‘solar soaker’ and similarly innovative tariff structures, significant barriers to consumer uptake remain. Retailers frequently fail to pass on DNSP tariff structures, for fear of overwhelming their customers with complexity and eroding trust. Solar soaker tariffs on their own are a blunt instrument for incentivising residential customers to shift demand, as they lack the subtlety required to address dynamic events. And as noted in Section 4.1, dynamic price signals are also largely ineffective without automated load control. Emerging solutions combine tariffs with automated ‘peak-smart’ load control of appliances such as ACs and DHW units.

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[13] aer.gov.au/networks-pipelines/network-tariff-reform/tariff-trials

Table 11. Existing network tariffs relevant for DHW.

Company	Tariff name	Time periods	Details
Ausgrid[14]	Controlled Load 1	22:00–07:00	Tank must be ≥250 L.
	Controlled Load 2	20:00–17:00	Tank must be ≥100 L.
Essential Energy[15]	Controlled Load 1	22:00–07:00	Residential customers with consumption <160 MWh pa. Load permanently connected to control load circuit. Primarily for traditional storage DHW systems.
	Controlled Load 2	20:00–07:00 09:00–17:00	Residential customers with consumption <160 MWh pa. Load is permanently connected to control load circuit. Designed for DHW systems requiring a boost during the day, solar DHW, heat pumps, pool pumps, slab heating.
Ergon & Energex[16]	Tariff 31	22:00–07:00	Tariff is for electric resistance DHW systems ≥250 L that only need to reheat at night. Power available for minimum of 8 h/day. Uses ripple control.
	Tariff 33	20:00–16:00	Tariff is mostly used for pool pumps, electric resistance DHW systems ≥125 L, heat pump DHW systems ≥270 L and solar DHW systems ≥160 L. Power available minimum 18 h/day. Uses ripple control.
SAPN[17]	Controlled load Residential (Legacy)	23:00–07:00 10:00–15:00	Legacy tariff closed to new customers. Timer on meters used for this tariff were manually set by SAPN.
	Controlled load Residential	Solar Sponge: 09:30–15:30 Off-Peak: 23:30–06:30 Peak 6:30–09.30, 15:30–23:30	The exact timing of DHW operation is managed by a timer, which can be adjusted by the retailer.
CitiPower, Powercor and United Energy[18]	Dedicated Circuit	22:00–07:00	For single phase homes with a resistive controlled load <30 A for twin and single element storage or electric boosted solar hot water storage. Heat pump and instantaneous hot water are not approved.

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[14] Ausgrid (2016)

[15] Essential Energy, Controlled Load Fact Sheet.

[16] ergon.com.au/retail/residential/tariffs-and-prices/economy-tariffs

[17] SAPN, 2020–25 Tariff Structure Statement Part A.

[18] CitiPower (2021). Tariff structure statement 2021–2026.

Table 12. DNSP tariff trials.[19]

Company	Trial name	Time periods	Details
Essential Energy[20]	Peak Time Rebate	Fixed price with rebate for peak events	Peak events may be up to four hours, and may occur up to 15 times per year. Second option with export charge will include charge for export 10:00–15:00.
	Sun Soaker	Off-peak 10:00–15:00, shoulder and peak pricing	No export charge. Relies on usual ToU peak pricing to discourage peak demand consumption.
	Sun Soaker with critical peak pricing (CPP)	Off-peak 10:00–15:00, all other times rate	No export charge. CPP events may be up to 4 h and may occur up to 15 times per year. Customers will face increased costs during these events.
Endeavour Energy	Off Peak Plus Program	Flexible	Installation of IntelliHub control device. Tariff is suitable for DHW applications and EVs. Trial will enable self-consumption of solar.
SAPN[21]	Electrify	Peak: 17:00–21:00 Solar Sponge: 10:00–15:00 Off peak at other times	Designed for customers with flexible appliances, including EVs and DHW, and can optimise usage outside peak demand periods.
CitiPower, Powercor and United Energy[22]	Residential Daytime Saver	Peak: 16:00–21:00 Solar Sponge: 10:00–15:00 Shoulder at other times	Intention is to provide free electricity during solar sponge window. Tariff designed to encourage those who do not have solar to shift their loads to daylight hours.

4.3.4 Efficiency versus flexibility

There is an obvious trade-off between the demand flexibility of resistance DHW and the efficiency of alternatives, notably heat pumps. As shown in Table 10, electric resistance is currently the most greenhouse-intensive technology option across most of NEM. Recognising this, past and current policies and market trends have driven a decline in resistance water heaters, a trend that future policies may only amplify. Given other barriers, generous tariffs or other significant incentives are required to drive uptake of flexible resistance DHW.

Table 13 compares uncontrolled (Tariff 11) versus controlled (Tariffs 31 and 33) load tariffs available from Queensland DNSPs,[23] in addition to the solar feed-in tariff.[24] The solar feed-in tariff represents a discount of 61.8% compared to the standard uncontrolled tariff. This is roughly comparable with the tariff discount required to reach lifetime

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[19] AusNet is not currently offering any off-peak tariffs for residential customers, as their dedicated circuit tariffs are closed to new entrants. Furthermore, they do not offer a tariff that encourages consumption during solar hours nor a tariff that would charge PV owners for exporting to the grid. According to the AER website, AusNet is not currently trialling any tariffs. Hence the Mallacoota trial cited in Table 4 is presumed to have occurred under legacy dedicated circuit tariffs and did not rely on customers being incentivised to adopt a new technology. Jemena has also closed their dedicated circuit tariff structure to new customers.

[20] Essential Energy (2021), Letter to AER 'Intention to introduce sub-threshold tariffs for the remainder of the 2019-24 regulatory period', https://www.aer.gov.au/networks-pipelines/network-tariff-reform/tariff-trials. Note: these are options which may be trialled.

[21] SAPN, Tariff Trial – Electrify, https://www.aer.gov.au/networks-pipelines/network-tariff-reform/tariff-trials

[22] CitiPower, Trial tariff notification 2022–23.

[23] ergon.com.au/retail/residential/tariffs-and-prices/economy-tariffs

[24] ergon.com.au/retail/residential/tariffs-and-prices/solar-feed-in-tariff

cost parity between resistance and heat pump DHW units of ~65%, calculated from the figures presented in Figure 20. Together, these results demonstrate that current controlled load tariff discounts of <30% are inadequate for incentivising activation of FD through resistance DHW, versus improving efficiency of DHW through uptake of heat pumps.

Table 13. Tariffs available in Queensland from 1 July 2022.

Queensland tariffs	Rate	Discount
	($/kWh)	(%)
Tariff 11	0.24349	–
Tariff 31	0.17266	29.1
Tariff 33	0.19140	21.4
Solar feed-in	0.09300	61.8

4.4 Regulation and policy factors

4.4.1 Standards

In Australia, domestic storage water heaters are governed by several standards, including:

- *AS 1056-1991 Storage water heaters – Part 1: General requirements*
- *AS 1361-1995 Electric heat-exchange water heaters – Part 1: For domestic applications*
- *AS/NZS 4234:2021 Heated water systems – Calculation of energy consumption*
- *AS/NZS 4692.1:2005 4692.1:2005 Electric water heaters – Part 1: Energy, consumption, performance and general requirements*
- *AS/NZS 4692.2:2005 Electric water heaters – Part 2: Minimum Energy Performance Standard (MEPS) requirements and energy labelling.*

Both in Australia and internationally, Minimum Energy Performance Standards (MEPS) are a key policy tool for addressing residential energy efficiency and carbon emissions. In Australia, water heaters are currently governed by Greenhouse and Energy Minimum Standards (Electric Water Heaters) Determination, dated 25 October 2012. This GEMS determination refers to the MEPS defined in *AS/NZS 4692 Electric water heaters*, which came into effect in 2005. This standard supersedes the previous standard AS 1056. Heat pump water heaters were also previously covered by AS 1361.

Resistance heating is a simple technology with little opportunity for direct performance improvement. The main effect of AS/NZ 4692 is to define an upper threshold for standing losses, which result from dissipation of heat from stored hot water into the surrounding environment. Heat loss value limits for electric storage water heaters both before (AS 1056.1) and after (AS 4692) MEPS 1999 are shown in Table 14. Heat loss values from 1985 to 1999 were not regulated, but many products on the market would have met the specified levels. In 2005, the MEPS levels for small water heaters were strengthened. While there are some small variations across models, it can be assumed that all models only just comply with regulated MEPS levels.

An obvious pathway for improving energy efficiency of storage heaters is to improve regulated MEPS levels, thereby reducing standing losses for new units. The standing losses of existing units could also be reduced relatively inexpensively through retrofitting insulating jackets.

Reducing operating temperatures of storage heaters below typical values of 60°C would also significantly reduce standing losses, though this would limit demand flexibility owing to the need to maintain temperatures to reduce the risk of infection from *Legionella* bacteria. *Legionella* can survive temperatures greater than 45°C but is unable to multiply, and is killed by temperatures of 65°C for about 2 minutes, 60°C for 32 minutes and 55°C for 6 hours. A feasible option to balance storage losses with *Legionella* growth is therefore to maintain a DHW storage tank at 50–55°C with periodic increases to 60°C.

Table 14. Heat loss value limits for electric storage water heaters to AS 1056 and AS 4692.

Hot water delivery capacity	Heat loss 1985–99			Heat loss 1999–2004			Heat loss 2005–present		
(L)	(kWh/day)	(MJ/day)	(W)	(kWh/day)	(MJ/day)	(W)	(kWh/day)	(MJ/day)	(W)
25	1.70	6.12	71	1.40	5.04	58	0.98	3.53	41
50	1.95	7.02	81	1.70	6.12	71	1.19	4.28	50
80	2.10	7.56	88	1.47	5.29	61	1.47	5.29	61
125	2.50	9.00	104	1.75	6.30	73	1.75	6.30	73
160	2.80	10.08	117	1.96	7.06	82	1.96	7.06	82
250	3.40	12.24	142	2.38	8.57	99	2.38	8.57	99
315	3.80	13.68	158	2.66	9.58	111	2.66	9.58	111
400	4.10	14.76	171	2.87	10.33	120	2.87	10.33	120

Unlike reverse cycle ACs, there is no MEPS (beyond storage) or energy rating label for heat pump water heaters. This is another policy gap that could easily be addressed.

The standard *AS/NZS 4234:2021 Heated water systems – Calculation of energy consumption* sets out a method for evaluating the annual energy performance of water heaters using a combination of test results for component performance and mathematical models to determine the standardised annual supplementary energy use. The standard was updated in 2021 from its earlier 2008 version. It applies to electric and gas storage water heaters, electric and gas instantaneous water heaters, solar water heaters (with or without boosters) and air source heat pump water heaters.

4.4.2 AS/NZS 4755

The newly developed standard *AS/NZS 4755.1:2017 – Demand Response Capabilities and Supporting Technologies for Electrical Products* provides a demand response framework and requirements for Demand Response Enabling Devices (DREDs). The standard sets out four demand response modes for storage water heaters, as listed in Table 15. DRM 1 and 4 are effectively full off and on modes, respectively, while DRM 2 and 3 are lower power modes involving 40–80% of full demand. Only DRM 1 (no heating) is mandatory, and would require no additional metering. Fully incentivising adoption of DREDs would require activation of at least DRM 4 in combination with some tariff or other incentive, plus additional metering.

AS/NZS 4755 is not mandatory for new storage water heaters, and doing so would likely impose additional costs on manufacturers. A lower cost option is to require new water heaters to have a physical DRED-compatible connection to facilitate fitting a DRED for AS/NZS 4755 compliance. An advantage of this approach is that is maintains flexibility in communications protocols and other DRED variables that are not yet standardised.

Table 15. Water heater demand response modes, AS/NZS 4755.

Operational Instruction (OI)	Demand response mode (DRM)	Description of operation in this mode	Mandatory for conformance to AS 4755.2?
OI 1	DRM 1	No electric heating of water (whether by resistive heating element, heat pump or any other electrical device).	Yes
OI 2	DRM 2	(a) The water heater shall continue to be capable of heating water during the demand response event; and (b) When heating water, the energy consumed shall be between 40 and 60% of reference value.	No
OI 3	DRM 3	(a) The water heater shall continue to be capable of heating water during the demand response event; and (b) When heating water, the energy consumed shall be between 60 % and 80 % of reference value.	No
OI 4	DRM 4	The water heater initiates a period of higher storage mode operation, which continues until the DR event terminates or the required level of heat storage under this mode of operation is reached (whichever occurs first).	No

4.4.3 National Trajectory for Low Energy Buildings

The National Trajectory for Low Energy Buildings is a national plan that aims to achieve zero energy and carbon-ready commercial and residential buildings in Australia. It is a key initiative to address Australia's 40% energy productivity improvement target by 2030 under the National Energy Productivity Plan (NEPP). The Trajectory identifies a suite of policies divided into three core areas. For residential buildings, these policies are:

- COAG Energy Council (2019a). Trajectory for Low Energy Buildings – residential initiatives (energy.gov.au/government-priorities/buildings/residential-buildings)
- COAG Energy Council (2018). *Report for Achieving Low Energy Homes.*
- COAG Energy Council (2019b). *Report for Achieving Low Energy Existing Homes.*
- COAG Energy Council (2019c). *Addendum to the Trajectory for Low Energy Buildings—Existing Buildings.*

The National Trajectory policy framework intersects with various elements of domestic energy efficiency and decarbonisation efforts, including DHW, at both federal and state levels.

The Trajectory Addendum (COAG Energy Council, 2019c) is the second stage of the trajectory and provides a suite of initiatives to improve the energy efficiency of existing buildings in Australia. Among the initiatives it proposes, the following are relevant to DHW:

- developing information, training and energy rating tools for households and businesses to enable greater understanding of energy efficiency options and applications
- developing and expanding target building policies, including:
  - disclosure of energy performance
  - minimum energy efficiency standards for rental properties
- identifying and developing supporting measures, including:
  - specific measures for strata titled buildings
  - appliance standards and labelling
  - specific measures for vulnerable households
  - a national dataset and collection process for existing homes.

4.4.4 NatHERS, BASIX and the National Construction Code

Australia’s residential building standards are governed by the National Construction Code (NCC).[25] In August 2022, Australia’s Building Ministers agreed to lift energy standards of new homes through adoption of NCC 2022. A streamlined pathway is provided for meeting the energy efficiency requirements of NCC 2022 via the Nationwide House Energy Rating Scheme (NatHERS), which has been upgraded to rate the energy performance for the whole home, including major appliances, solar panels and batteries, in addition to the star rating for the building shell.

NCC 2022 requires new homes and apartments to achieve the equivalent of ‘7 stars’ NatHERS thermal performance, while a new annual energy use budget has been introduced for the first time. This budget applies to homes’ major appliances, including hot water systems. NCC 2022 was adopted by all Australian states and territories on 1 May 2023 (with a transition period to 1 October 2023 for some provisions).

NCC 2022 establishes that, to reduce greenhouse gas emissions, a heated water service must be capable of efficiently using energy, and obtain its heating energy from either a ‘low greenhouse gas intensity energy source’, on-site renewable energy, or reclaimed heat (NCC, 2022a). For the first option, the energy source must have a greenhouse gas intensity of no more than 100 g CO_2-e/MJ of thermal energy load (NCC, 2022b). However, this NCC provision is overridden by various state-based plumbing codes.

Assuming an efficiency of 0.89 and the latest NGER emissions factors (CER,2022), the emissions intensity of resistive water heating from grid electricity is up to 300 g/MJ CO_2-e, for Victoria (see Section 4.3.2). This provision therefore effectively rules out installation of resistive water heaters for those homes without on-site solar in all states except Tasmania (50 g/MJ). Importantly, NCC 2022 provides no disincentives for installing gas water heaters, which have an emissions intensity of around 76 g/MJ. A heat pump water heater with a COP of 3.5 has an emissions intensity of between 13 g/MJ (Tasmania) and 76 g/MJ (Victoria), without on-site solar, and is therefore permitted.

NatHERS is being expanded to include ‘whole-of-home’ assessments to support the proposed National Construction Code (NCC) energy efficiency requirements for residential buildings in 2022. The Whole of Home energy assessment features energy performance of household appliances such as heating and cooling, hot water, lighting, pool/spa and on-site energy generation and storage (Department of the Environment and Energy, 2022a).

NSW operates BASIX, a parallel system to NatHERS that has recently been updated to align with 7-star NatHERS. The NSW Sustainable Buildings SEPP and Regulation amendments will begin on 1 October 2023. They will not apply to homes in the north coast climate zone and apartment buildings lower than six storeys, as the energy bill savings are deemed not to offset higher construction costs for those developments. Furthermore, non-residential developments will be required to report on embodied-emissions measurement, energy standards for large commercial developments will need to be verified once occupied with residual emissions offset, and ‘certain developments will need to be all electric or capable of converting by 2035. Similar requirements are likely to be required for new residential buildings in coming years, with implications for gas water heating and its electrification.

The ACT government has announced plans to phase out the use of fossil gas by 2045, with the

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[25] ncc.abcb.gov.au/editions-national-construction-code

recent release of a paper modelling the transition to full electrification of homes and businesses (RenewEconomy, 2022).

4.4.5 Small-scale Technology Certificates

Australia has been operating a scheme of tradable renewable energy certificates (RECs) for over 20 years. RECs are widely used for purchasing of renewable energy, for greenhouse gas reporting and for various government mandates. Small-scale Technology Certificates (STCs) are a form of REC created by rooftop PV systems, solar water heaters and heat pump water heaters, at the time of installation. One STC is equivalent to a megawatt-hour (MWh) of electricity displaced by an eligible system, with the number of STCs created deemed over a period of several years. The deeming period is now the number of years from the installation year until the planned scheme end date of 31 December 2030 (e.g. eight years for systems installed in 2023).

STCs provide a financial incentive to encourage the installation of solar and heat pump water heaters. The number of STCs for which a system is eligible will depend on the size of the model and the postcode where it is installed, corresponding to one of four (solar) or five (heat pump) climate zones. For example, a typical solar or heat pump water heater with a 300 L tank is eligible for about three STCs per deeming year, with a market value as of November 2022 of about $40 each (or $1080 total in 2022).[26]

4.4.6 State-based ‘white label’ schemes

In addition to the systems of STCs, several Australian states operate tradeable energy savings certificate schemes. Eligible scheme participants can register equipment upgrades that improve energy efficiency to create these certificates. Each certificate represents 1 MWh of notionally saved electricity.

The two main schemes in operation are the NSW Energy Savings Scheme (ESS), which creates Energy Savings Certificates (ESCs), and the Victorian Energy Upgrades (VEU) scheme, which creates Victorian Energy Efficiency Certificates (VEECs). South Australia also operates the Retailer Energy Productivity Scheme (REPS).

Solar and heat pump water heaters were included in the NSW ESS in April 2022. Under the scheme, replacement of existing electric resistance or gas water heaters with solar or heat pump heaters are eligible upgrades under the Home Energy Efficiency Retrofits (HEER) method. This method requires a minimum customer co-payment of $30 (+ GST). Accredited systems installers can create ESCs (together with STCs) and use these to offer their customers a discount. As of September 2022, ESCs trade at about $34 each.[26] Assuming replacement of a 300 L electric resistance unit with a typical solar or heat pump unit creates 30 ESCs, the financial incentive provided by the ESS is about $1020. Combined with STCs, the total available financial incentive is about $2100 in 2022, declining to $1980 in 2023). This combination of STCs and ESSs is sufficient to fully cover the costs of supplying and installing some heat pump water heaters, resulting in some suppliers offering full system replacements for only $33.

Under the VEU, eligible water heating activities include replacing electric resistance DHW units with gas, solar or heat pump units. The VEET Regulations introduced a six-month transitional period for water heating activities, with new activity requirements and new greenhouse gas equations for water heating activities applying from 10 June 2019. VEECs currently trade at about $72 each.[26]

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[26] demandmanager.com.au/certificate-prices

4.5 Supply chains

Supply chains have a major impact on the availability and adoption of various technologies, including those related to DHW. During our stakeholder interviews, we presented and confirmed the illustration of Australia's DHW supply chain presented in Figure 21. While there is some local manufacturing carried out in Australia, most of it is conducted overseas. Domestic water heaters are distributed locally through local brand subsidiaries/owners and manufacturers.

4.5.1 Replacement pathways

Domestic water heaters typically last at least 10 years, so their replacement is a relatively infrequent event for most homeowners. As quoted by one of our stakeholders, when a householder discovers their DHW unit is broken, they are "typically cold, wet and naked." The urgency of replacing a broken unit usually means property owners rely heavily on the network of local plumbers and related system installers, and frequently follow the path of least resistance, such as like-for-like replacement using whatever the installer has readily available. According to BIS (2008), when a water heater fails, 46% of home occupants contact a plumber, 15% a hot water specialist, 15% an energy retailer and 2% a builder. Only about 18% go to the types of retailers or specialised stores that would normally be the first point of contact for the purchase of other large appliances. Any efforts to change the mix of DHW technologies, either to increase efficiency and/or flexibility, needs to address these issues, through measures such as performance standards, incentives to replace units before their end of life, or switching DHW from an appliance-ownership to a service-delivery model (see Section 5).

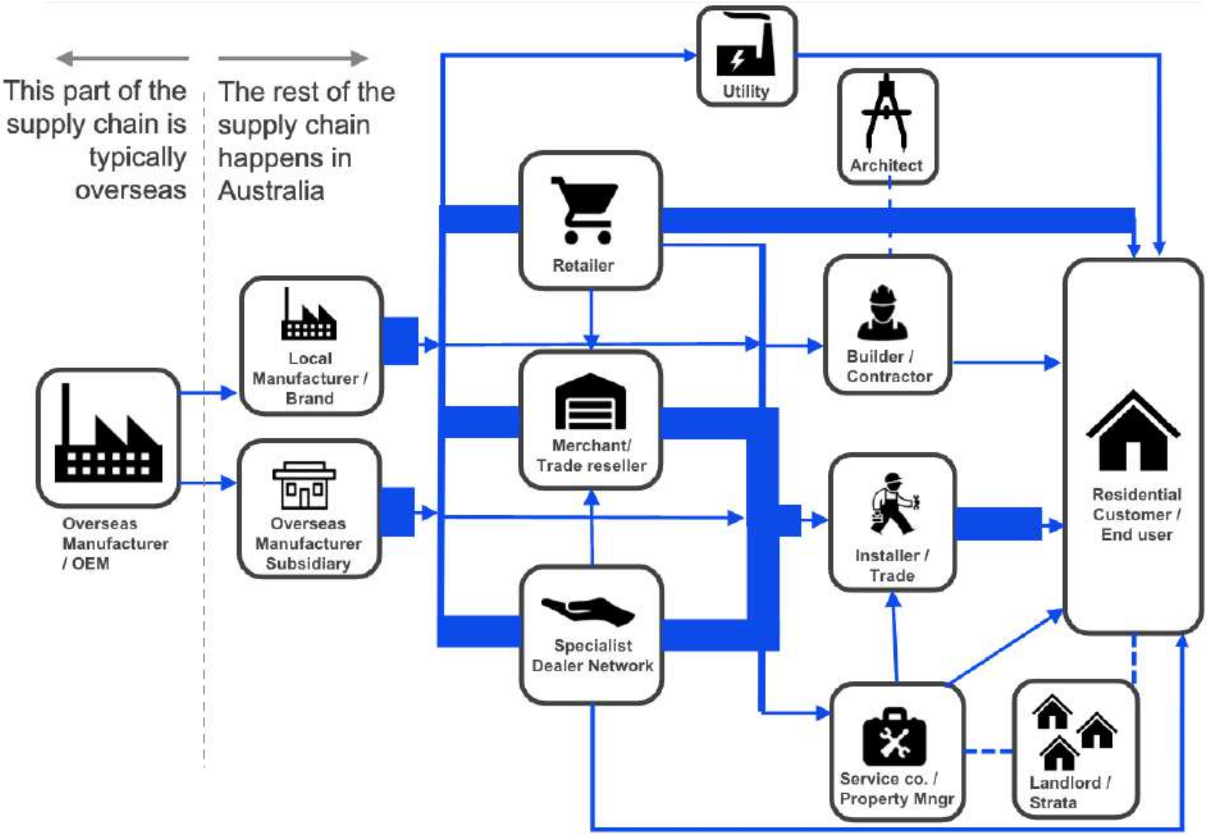

Figure 21. A representation of the Australian domestic hot water supply chain.

4.5.2 Workforce readiness

Widespread adoption of more efficient and/or more flexible DHW technology requires a sufficiently trained workforce of an appropriate size for implementation. Installation of FD-enabled electric DHW may require both plumber and electricians. Government statistics on plumbers are positive, with the workforce being younger than the average Australian worker and a future growth projection of 8.6% within the next five years (Jobs & Skills, 2022a). Furthermore, general plumbers (code: 334111) have the required skills to work with DHW and make up a majority of plumbers in Australia. Results for electricians are similar (Jobs & Skills, 2022b). Hence over the short-to-medium term, there is expected to be a sufficient workforce of plumbers and electricians to enable rollout of FD via electric DHW. However, system installers need appropriate incentives and information to better inform consumers, to enable consumers to make better decisions about the most efficient, least cost and least greenhouse-intensive DHW technology options.

4.5.3 Supply chain disruptions

Recent shortages of semiconductor chips have impacted a wide variety of industries, including companies in Australia that provide services such as residential energy monitoring, HEMS, and appliance control, and has impacted component costs and order lead times. Rheem, for example, has experienced issues in the rollout of their Active Hot Water Control trial (ARENA, 2022).

4.5.4 Local manufacturing supply chains

Without intervention, policy and other incentives that result in rapid and widespread adoption of heat pump DHW across Australia are likely to expose bottlenecks in existing supply chains. This problem is exacerbated by the increasing demand for heat pumps from other parts of the world, such as Europe and the USA, looking to rapidly transition to a more efficient energy system.

There is some local manufacturing of heat pump units, meaning there are building blocks for a strong local industry to help drive transition across the country.

There is anecdotal evidence that low-cost hot water heat pumps can fail prematurely, potentially creating negative sentiment among installers and customers and a reluctance to purchase or work with the technology. While this issue did not emerge specifically from our stakeholder interviews, more could be done to understand the basis for such reports and identify the underlying reasons (such as the products themselves, their installation or other factors).

4.5.5 Alternative flexible demand delivery models

There are various alternative potential business models for delivering flexible DHW. DHW units are typically sold like an appliance akin to a washing machine or other white good. Activating flexible demand therefore relies on a home-owning energy consumer to engage with the complexities of the energy system to activate and then flexibly operate their DHW system. While emerging technologies can facilitate this process, many energy consumers are not sufficiently engaged to bother. They would rather pay a little more for the convenience of not having to think about energy markets.

An alternative business model is to sell hot water as a service, rather than an appliance, using heat pump or electric resistance technology. The service provider would own the DHW unit and would agree to replace or service it as required. They would guarantee a certain level of supply quality (minimum litres per day, for example) and in return would be free to provide flexible demand services to a DNSP. Consumers would benefit from cheaper hot water and no maintenance costs, while DNSPs and service providers would also benefit economically.

Rather than negotiate with individual consumers, aggregators such as Wattwatchers are looking to activate demand flexibility through DHW and other variable loads by accessing property managers for social housing and community housing.

4.6 Electrification

There is a growing consensus that electrification is an important element in decarbonising residential energy use. Natural gas is both a fossil fuel and rich in methane, itself a potent greenhouse gas. Carbon-neutral alternatives to natural gas, such as biogas or synthetic methane, are not yet commercially viable at scale, while combustion of gas inside homes for cooking and heating produces indoor air pollutants such as nitrous oxides. Gas distribution networks connect around 5 million Australian households to natural gas (Energy Networks, 2017). Almost all this gas is used for one of three purposes: cooking, water heating and space heating. Switching from natural gas to electricity for these three applications, combined with decarbonisation of the electricity system through increasing use of renewables, provides a technically feasible and potentially rapid pathway for residential energy decarbonisation.

While electrification can be seen as a means to an end (decarbonisation and lower energy bills), it has been pushed in recent years as an end in itself, as espoused by Rewiring Australia (rewiringaustralia.org) with their call to 'electrify everything'. My Efficient Electric Home (MEEH), a popular Australian public Facebook group with about 70,000 members, espouses a similar electrification narrative. This narrative is only likely to grow in coming years and accelerate the push to replace gas water heaters with efficient electric units, notably heat pumps.

While the technologies that enable electrification are readily available (reverse cycle AC, induction stoves and heat pump water heaters), there are additional barriers to widespread electrification. One is that multiple trades are often required. This is the case when replacing a gas stove with an electric induction stove, for example. While most plumbers are qualified to wire-up a replacement electric water heater, replacing a gas heater with an electric heater may present additional challenges requiring an electrician. Removing this barrier might involve reviewing what additional qualifications plumbers might need to effect DHW electrification, particularly with a focus on FD.

Another barrier to electrification is the cost of disconnecting from gas, to avoid any ongoing standing charges. There is currently significant inconsistency in pricing, with some customers in NSW being charged up to $1150 by Jemena to disconnect their gas meter, while others are disconnected for free. Full gas disconnection is currently an uncommon and ad hoc activity. A move to more widespread electrification would likely require government intervention to ensure greater coordination, transparency, affordability and fairness for energy consumers pushing to reduce their GHG emissions.

4.7 Summary of main drivers and barriers

The main drivers and barriers identified in this section are summarised below in Table 16 and Table 17.

Table 16. Summary of main drivers and barriers for three focus DHW technologies.

	Electric resistance storage		Heat pump		Instantaneous gas	
	Drivers	**Barriers**	**Drivers**	**Barriers**	**Drivers**	**Barriers**
Social	• Traditional and familiar product.		• Newer technology – appeals to early adopters. • 'Electrify everything'.	• Lack of consumer understanding. • Potentially noisy.	• Unlimited supply of hot water.	
Technical	• Simple and reliable. • Only available option for some homes. • Options to reduce losses.	• May require separate circuit with high current rating (~3.6 kW). • Low self-consumption potential for some states/ climates.	• Efficient option for all electric homes.	• Outdoor installation not suitable for some apartments etc.	• Reliable. • Compact and unobtrusive units.	
Economic	• Cheap to install. • Off-peak and flex tariffs. • Self-consumption by PV system owners.	• Very high running costs using grid electricity.	• Higher efficiency and lower running costs. • Self-consumption by PV system owners. • Off-peak and flex tariffs.	• Higher capital cost than other options. • Declining STC value.	• Cheap to install and operate.	• High and rising gas prices.
Policy		• Discouraged by some policies (e.g. NCC, SA policy). • Lack of policy and standards enabling uptake of FD	• Government incentives through STCs and state White Label schemes. • Energy efficiency, NCC, NatHERS etc.	• Declining STC value. • No MEPS. • Policies favour gas.	• Lack of policy to transition away from gas. • NCC threshold of 100 g CO_2-e/MJ.	• NCC provision for net zero pathway in large developments. • Other policies (e.g. ACT).
Supply chain	• Like-for-like replacement when units fail. • Existing supply chain infrastructure.			• Nascent local industry. • Potential lack of supply capacity volume. • Anecdotal evidence of variable quality of installation and products.	• Like-for-like replacement when units fail. • Existing supply chain infrastructure.	
Environmental	• Reduced solar curtailment.	• High GHG emissions when powered by grid electricity.	• Alternative to gas with net zero pathway.			• Fossil fuel with no immediate substitution pathway. • Gateway for gas home heating and cooking, with detrimental health outcomes.

Table 17. Summary of main drivers and barriers for activating DHW flexible demand.

	Drivers	Barriers
Social	• Existing familiarity with off-peak DHW. • Growing understanding.	• Lack of trust and understanding. • Retailer inertia. • Confusing marketplace. • Consumer complacency.
Technical	• Availability of enabling technologies—ripple control, smart meters, HEMS, solar diverters, existing fleet of electric storage DHW units. • Potential for integration with batteries and other storage technologies.	• Requires additional hardware/rewiring, method for metering (DRM4). • Lack of single product solution. • Lower flexible demand capacity of heat pumps without resistive elements due to high efficiency • Small tanks for apartments.
Economic	• Solar soak tariffs. • Self-consumption. • Network benefits (avoided emergency load shedding, upgrade deferrals).	• Resistance DHW expensive to operate. • Tariffs inadequate.
Policy	• AS 4755.	• Policies largely focus on energy efficiency, not flexibility. • Policies that facilitate gas DHW. • Market rules limit value of FD.
Supply chain	• Integration of DRM into new units. • Solar/heat pump units with resistive elements.	• Like-for-like replacement when units fail. • Concentrated supply chain lacking innovation.
Environmental	• Increased penetration of renewables.	

5 Recommendations

The pathways, steps, and enablers needed to decarbonise and increase the flexibility of water heating energy demand are complex and hindered by multiple barriers. These include the fragmented nature of the water heater market and its supply chains, disjointed and outdated policy frameworks, as well as the physical constraints and technical complexities associated with retrofitting more efficient or flexible electric water heaters in Australian homes.

There is a compelling case for a more coherent and updated approach to policy for residential water heating, particularly given the context of climate change and high energy prices. Electrifying water heating provides major opportunities to reduce energy use and carbon emissions, protect against future energy price rises, and tap into a major source of energy storage to support integration of renewable energy in the grid. Addressing the barriers that are slowing the uptake of more flexible and efficient heating options will likely result in improved outcomes for customers, while supporting federal and state targets for energy efficiency, renewable energy and net-zero emissions. This will require an integrated approach to improving customer knowledge and awareness, developing and upskill supply chains, investing in research and development (R&D), and encouraging innovation and new business models.

5.1 A system transformation approach

Following completion of the research phase of this project, a collaborative sense-making workshop, developed around a system transformation model (illustrated in Figure 22) was employed to review the main findings and to map solution pathways and next steps. In this model, the current system is represented by a set of **system drivers**, which are forces outside the system we cannot control, **business-as-usual** elements, which are mostly things we want to change, and **innovations**, which are things we can keep or build on as part of the system transformation. Moving to the **transformed system** therefore requires a number of **actors** and **levers** to work in concert. A detailed examination of the sense-making workshop procedure and outcomes is contained in Appendix C—System transformation.

5.2 Key recommendations

Almost 30 individual recommendations emerged from the research, which were categorised under five key headings: supply chains, policy, innovation and business models, R&D, and customers. For each recommendation, one of three timeframes for action was applied: short (S), medium (M) or long (L). In addition, a traffic light system was used to evaluate each recommendation with respect to impact the action would have, how easy it would be to implement, and ultimately if it should be a priority.

A summary of the priority recommendations is provided below. The full list of available levers is shown in Table 18.

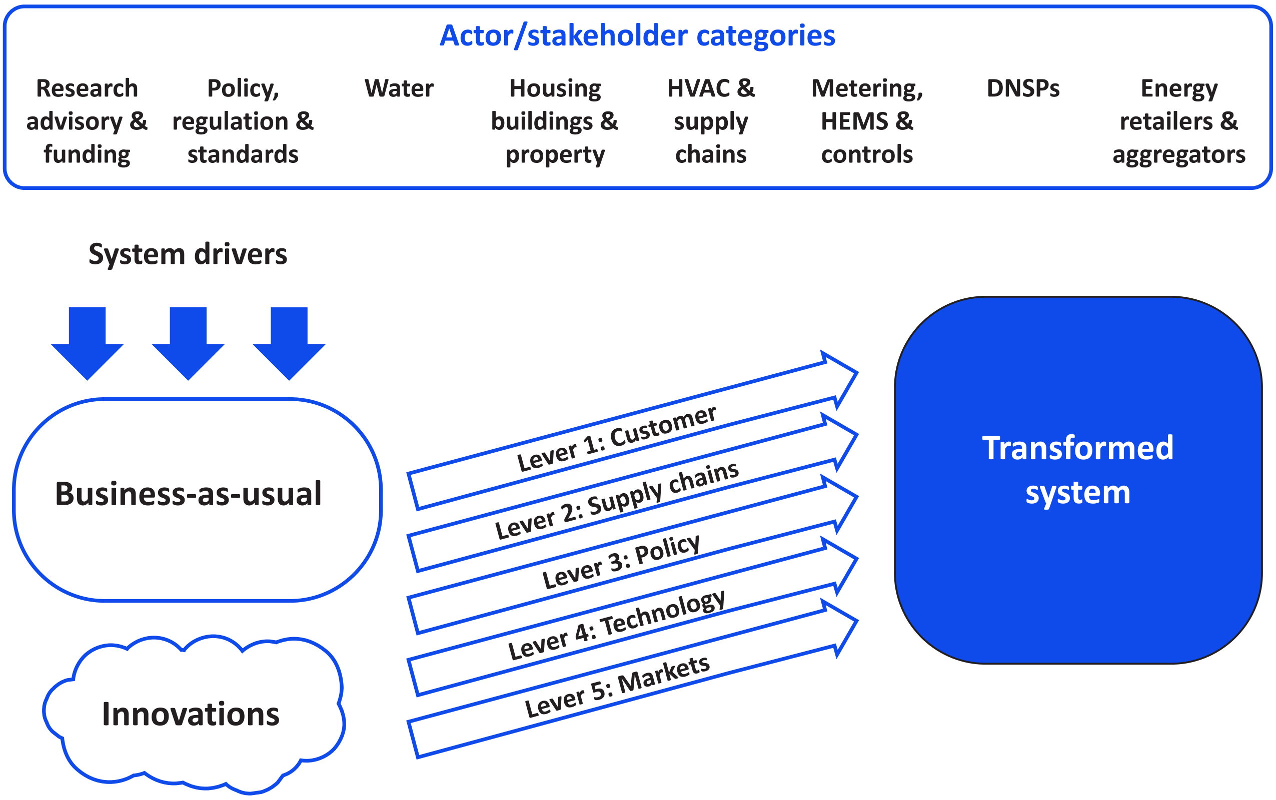

Figure 22. The system transformation model used for this project.

Policy

Convene a roundtable to discuss the project findings, inviting key stakeholders. A roundtable would ensure the project's findings are widely disseminated and acted on, which requires the cooperation of multiple stakeholders. This is a relatively easy measure that could be implemented quickly. The stakeholder map in Figure 23 shows categories and examples of stakeholders that could be invited to this roundtable.

Develop a national strategy for flexible DHW that accounts for state differences, supporting efficiency where possible and the uptake of FD-enabled resistance heaters. There is a clear lack of a coherent national policy on domestic water heating. A national strategy for flexible DHW would have significant impact. It should account for differences between states, while seeking to balance efficiency and flexibility through a rapid transition away from gas.

Policy reforms to remove perverse incentives against heat pumps in new homes. New homes represent the lowest hanging fruit for policy reform. Policy settings should future-proof new homes to smooth the transition to net zero emissions, which means installing electric instead of gas heaters. This could be addressed through the 2025 update to the National Construction Code, through updating state-based plumbing codes, and by tightening GEMS and MEPS for water heaters.

Strengthen Greenhouse and Energy Minimum Standards (GEMS) and Minimum Energy Performance Standards (MEPS) for DHW. The efficiency of new water heaters can be significantly improved by strengthening MEPS to (1) increase tank insulation to reduce standing losses and (2) improve heat pump performance. GEMS and MEPS can also be used to phase out gas water heating.

Develop energy rating and quality performance standards for heat pump DHW. While all domestic reverse cycle air conditioners sold in Australia must carry an energy performance rating label, heat pump water heaters do not. Addressing this anomaly would incentivise manufacturers to improve unit performance.

Expand and clarify Demand Management Innovation Allowance (DMIA) scope. This measure would incentivise capital and operating expenditure for rollout of projects enabling *shape* and *shift* FD resistance DHW through existing and emerging technologies.

Innovation and business models

Retailer programs that support flexible hot water while reducing customer churn. This may include hot-water-as-a-service and leasing models. New entrant retailers with a higher appetite for risk may be particularly interested in trialling new business models. Trials should also ensure a social research element to understand customer behaviour and perceptions to flexible DHW. Trials and research based on lessons from around the world on business model innovation for water heaters may also help foster innovation in this area.

R&D

Detailed cost benefit analysis of policy options. A logical follow up to this study is to conduct detailed cost benefit analysis of some of the policy options proposed, in part to provide an evidence base to support decisions by policymakers.

Fund research focussing on constrained sections of network and conducting DMIA calculations. This measure could help better demonstrate the advantages of flexible DHW to the Australian Energy Regulator, and encourage them to push back against DNSPs seeking to upgrade their networks without first showing cause on how demand-side measures such as more efficient and flexible DHW can defer or reduce the need for such upgrades.

Support better data collection across electricity networks to better understand the role and opportunities for flexible DHW. More, better quality and more accessible data would likely improve understanding and facilitate opportunities for flexible DWH for multiple stakeholders across the system, including DNSPs, regulators and aggregators.

Pilot DHW flexibility projects with the support of the AER. This measure would reveal costs and benefits to consumers as well as other stakeholders, and could be linked with trials under the innovation and business model recommendations.

Support innovative tariff trials. This would likely lead to better reporting and open publication of trial results to help build suitable incentives and business models to activate flexible DHW.

Customers

Support improved customer education and awareness. This measure could leverage existing consumer awareness programs and information resources while partnering with trusted organisations.

Better decision-making tools for customers. This could be developed with trusted consumer organisations, as an output from a standalone research project, or as a deliverable from the recommended pilot projects.

Table 18. Identified levers for transition, and their categories, timeframes, impact, ease and priority. S = short term (1–2 years), M = medium term (3–4 years), L = long term (5+ years). Green = high, amber = medium, red = low

Category	Lever	Who?	Time-frame	Impact	Ease	Priority
Supply chains	Investigate ways in which DNSPs or other system actors could take on responsibility for delivering hot water as a service, and owning DHW units	State governments, DNSPs, water utilities	S	🟨	🟩	🟩
	Bulk buy and installation/swap-out of quality heat pump DHW units		M	🟩	🟥	🟥
	Bulk buy and rollout of DREDs or other FD-enabling technologies		M	🟩	🟥	🟥
	Invest in development of local industry for heat pumps, DHW components (e.g. storage tanks) and FD-enabling technologies	Federal, state governments	L	🟨	🟨	🟨
	Supply chain development through education, training, skills		L	🟩	🟨	🟨
Policy	Convene a workshop with regulators, policymakers, consumer groups (from energy, water, built environment) to discuss the project findings—refer to Figure 23	ARENA and ISF	S	🟩	🟩	🟩
	Develop national strategy for flexible DHW that accounts for state differences—supporting efficiency where possible and the uptake of FD-enabled resistance heaters	Federal Government (supported by states through COAG)	S	🟩	🟨	🟩
	Gas policy reforms to accelerate phase out of gas DHW (with priority for new buildings)		M	🟩	🟨	🟩
	Policy reforms to remove perverse incentives against heat pumps in new homes		M	🟩	🟩	🟩
	Strengthen Greenhouse and Energy Minimum Standards (GEMS) and Minimum Energy Performance Standards (MEPS) for DHW	Federal Government (DCCEEW) and Standards Australia	S	🟩	🟨	🟩
	Develop energy rating and quality performance standards for heat pump DHW		S	🟨	🟨	🟩
	Expand and clarify Demand Management Innovation Allowance (DMIA) scope—better encourage capital and operating expenditure for rollout of projects enabling *shape* and *shift* FD resistance DHW through existing and emerging technologies	ENCRC (AEMO, AER, AEMC)	S	🟨	🟩	🟩
	Expand and clarify Demand Management Incentive Scheme (DMIS) scope—increase ease for DHW projects to be considered through flexibility around 'demand management proposal' and relevant indicators of management (e.g. kWh instead of just kVA/year)		S	🟨	🟩	🟩
	Convene a workshop with regulators, policymakers, consumer groups (from energy, water, built environment) to discuss project findings—refer to stakeholder map in Figure 23	ARENA and ISF	S	🟨	🟩	🟩
	Widespread rollout of DREDs or other FD-enabling technologies	State governments, DNSPs	L	🟩	🟨	🟨
	Policies to support accelerated smart meter rollout with focus on activating flexible DHW	State governments	L	🟨	🟨	🟨
	Government program for honest brokerage of flexible DHW (e.g. proposed Victorian government-owned energy retailer)	State governments	M	🟨	🟨	🟨
Innovation & business models	Investigate ways of making the DMIS easier to access	ENCRC	S	🟨	🟨	🟨
	Support inclusion of hot water in water utilities' existing water efficiency schemes for strata buildings (c.f. NT Power and Water)	State governments, water utilities	S	🟨	🟩	🟩
	Retailer programs that support flexible hot water while reducing customer churn—may include hot water as a service and leasing models	ARENA (CfP targeting energy retailers)	M	🟨	🟨	🟨
	Support for smart meter business models that provide useful data for energy retailers	ARENA, DNSPs, state governments	M	🟨	🟩	🟨
	Support for aggregator business models that activate flexible DHW		M	🟨	🟩	🟨
R&D	Detailed cost benefit analysis of policy options	ARENA, RACE for 2030	S	🟨	🟩	🟩
	Fund research focussing on constrained sections of network and conducting DMIS calculations (with aim of demonstrating advantages of flexible DHW to AER)		S	🟩	🟨	🟩
	Support better data collection across electricity networks to better understand the role and opportunities for flexible DHW		M	🟨	🟨	🟩
	Support innovative tariff trials, with better reporting and open publication of trial results		S	🟩	🟨	🟩
	Pilot DHW flex projects with support of AER	ARENA, RACE for 2030, AER	S	🟩	🟨	🟩
Customers	Support improved customer education and awareness	Governments, ARENA, ECA, Choice	M	🟨	🟩	🟩
	Better decision-making tools for customers		S	🟨	🟩	🟩

5.3 Stakeholder map

The following stakeholder map shows categories and examples of stakeholders that could be invited to a roundtable to discuss the project findings. Such a roundtable would ensure the project's findings are widely disseminated and acted on, which requires the cooperation of multiple stakeholders.

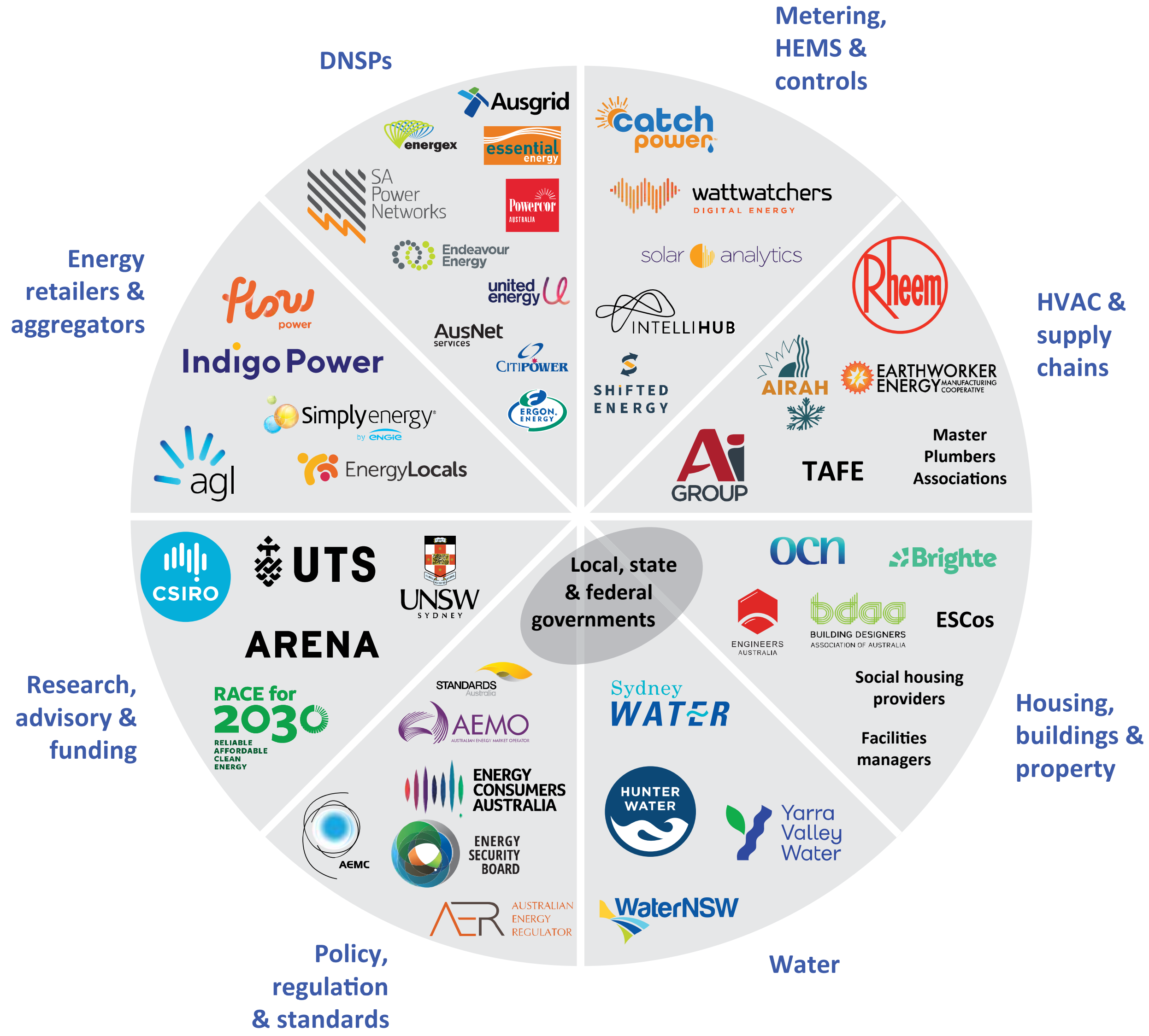

Figure 23. Indicative stakeholder map for roundtable discussion.

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Appendix A—Model details

Sales forecasts

The **Business as Usual** scenario assumes no new policies or market factors to drive uptake of electric DHW. Sales forecasts are based purely on projections of hindcast trends, which differ substantially by state. This leads to a growth in gas DHW sales across much of the NEM, with instantaneous gas DHW sales dominating in the ACT, SA and Victoria.

The **Highly Flexible** and **Highly Efficient** scenarios assume a combination of policy and market incentives are implemented to electrify the water heater fleet. These include: gradual phaseout of gas DHW sales by 2040 caused by direct government policy or through improved GHG emissions standards, and financial incentives/policy settings to encourage customers to replace existing gas hot water units with electric units, leading to shorter gas DHW lifetimes (discussed further in section 6.1.2). The difference between scenarios **Highly Flexible** and **Highly Efficient** is the relevant growth in sales of electric DHW technology, such that one of these technologies dominates the replacement of gas DHW during the gas phaseout. The **Highly Flexible** scenario was created by applying the maximum realistic growth rate to electric resistance technology sales on a state-by-state basis, this is because each state has had a different trajectory in regard to their removal of electric resistance units. The **Highly Efficient** scenario was developed in a similar fashion, such that heat pump technology experienced the maximum realistic growth possible on a state-by-state basis, with heat pump sales capped to 75% as an upper bound for the year 2050. The figure of 75% was chosen based on several factors such as the proportion of households which are apartments, historical trends in the growth of apartment dwellings, and accounting for a portion of buildings which would not be suited for heat pump technology.

The **Rapid Electrification** scenario represents the maximum possible policy ambition in terms of electrification of household loads, decarbonisation, uptake of efficient technologies, and uptake of flexible demand technology. Although this scenario is highly ambitious, the sales forecast was constructed in a similar fashion to the **Highly Efficient** scenario such that heat pump DHW experiences the maximum possible growth across each state. Heat pump DHW sales dominates sales across the ACT, NSW, SA and VIC under the **Rapid Electrification** scenario and reaches 30 to 40 percent of sales in Queensland and Tasmania by 2050 (where electric resistance has historically dominated the DHW market by a significant margin). What distinguishes the **Rapid Electrification** and the **Highly Efficient** scenarios is the combination of policy and market incentives. Policies include no gas DHW sales after 2025, and accelerated financial incentives/policy settings to encourage customers to replace existing gas with electric DHW, leading to a further shortening of gas unit lifetimes (discussed further in Section 6.1.2).

See Appendix B for charts of the sales forecasts for each scenario and state or territory.

Unit lifetimes

Throughout the stock model, equipment unit lifetimes are determined by assuming a zero decay rate for an initial period, followed by a decay rate that follows a cumulative Weibull distribution function, as illustrated in Figure 24.That is, the decay rate δ is given by:

$$\delta(y,p,\alpha,\beta) = 1 - e^{-[(y-p)/\beta]^{\alpha}}$$

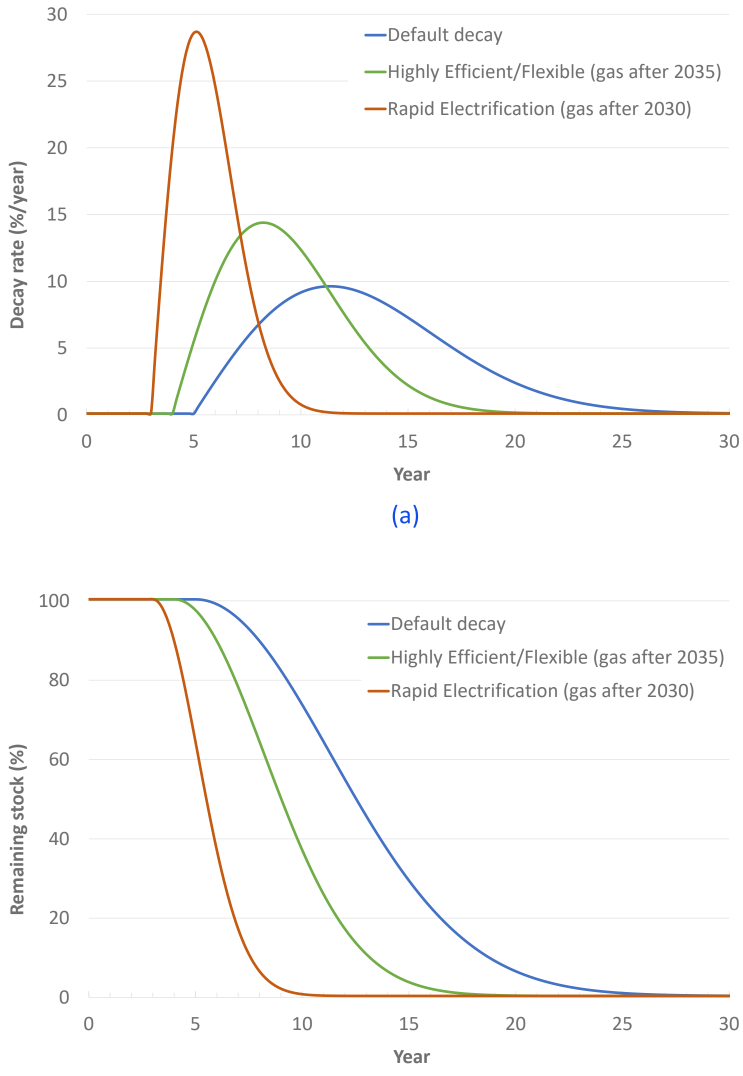
where,

y = year
p = initial period of zero decay
α, β = Weibull parameters

Storage water heaters typically carry warranties of 5–10 years. According to Wilkenfeld (2009), based on analysis of data from BIS Shrapnel, the average lifetimes of electric storage water heaters is about 13 years. Using these figures as a guide, for water heaters the default parameter values used for all scenarios are p = 5 years, α = 2 and β = 9, giving a mean lifetime of 13.0 years.

For the Highly Flexible and Highly Efficient scenarios, accelerated decay is assumed for gas water heaters from 2035 onwards using parameter values p = 4 years, α = 2 and β = 6, giving a mean lifetime of 9.3 years, with a 10-year transition period between the two decay functions from 2025 to 2035. For the Rapid Electrification scenario, accelerated decay is assumed for gas water heaters from 2030 onwards using parameter values p = 3 years, α = 2 and β = 3, giving a mean lifetime of 5.7 years, with a five-year transition period between the two decay functions from 2025 to 2030.

The resulting decay rates and remaining stock functions are illustrated below in Figure 24.



(a)

(b)

Figure 24. (a) Decay rate and (b) remaining stock of water heaters versus years after purchase. Default decay rate applied under all scenarios. Accelerated decay rates applied only to gas units after 2035 or 2030, depending on scenario (see Section 3.2).

Methodology for modelling FD potential

Owing to discrepancies in the penetration, maturity and technical ease of FD-enabling technologies, a technology-specific approach was taken to forecast future FD capacity. The technology specific breakdown across differing categories of FD took place within a simplified guiding framework of maximum possible FD uptake across the three types of electric DHW (resistance, heat pump, solar). Each of the four scenarios was given maximum thresholds for FD uptake: 60% by 2050 for the Business as Usual scenario, 100% by 2045 for the Highly Efficient scenario, 100% by 2050 for the Highly Flexible scenario, and 100% by 2035 for the Rapid Electrification scenario. The maximum FD penetration for each type of electric DHW is shown in Figure 25.

A maximum uptake value of 40% in the year 2020 was set owing to the penetration of ripple technology in NSW and Queensland. The FD uptake threshold was defined by the linear trend from this starting value to the relevant uptake value set out by each scenario.

The NEM regions were classified into two categories: ripple or time-based controlled, with NSW and Queensland being the only ripple control states. In NSW and Queensland, resistance heaters start with 100% of the possible uptake of FD in 2020 (i.e. 40% of total resistance heaters used ripple technology) while heat pumps and solar start with 0% of the maximum possible uptake (40%). This provides an accurate reflection of the current situation. From 2025 onwards, growth is seen in the uptake of FD technologies for heat pumps and electric solar heaters, while resistance technologies continue to match the maximum linear trend shown in Figure 25. Heat pumps reach the maximum potential in the early 2040s. This was done to capture a range of factors, such as the lack of maturity for the relevant control technologies, possible higher upfront costs of heat pumps, the complexities of controlling heat pumps when not operating with a resistive element, and the reduced benefits/incentives of solar soaking caused by lower load. Controlled solar reaches only 50% of the maximum potential by 2050 owing to the lack of solar soak opportunities and the complexities involved in aligning boosting periods with irregular periods of excess renewables (i.e. wind power in the early morning and evenings). From 2025 onwards, the share of technologies enabling FD in resistance heaters changes to reflect the potential growth in diverters and smart/HEMS heaters.

A similar approach is taken for the other states, with the main difference being that resistance

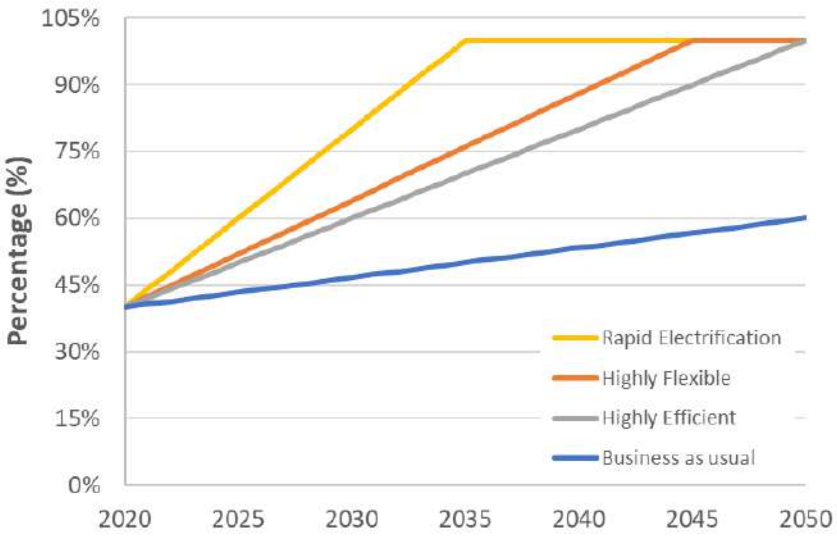


Figure 25. Assumed maximum possible uptake of FD technology in model.

Table 19. Estimated share of new houses with a gas connection by state. Source: Foster & Harrington, 2022, p. 241.

State/territory	2020 existing total gas connections	New houses with mains gas	Expected trend in gas connections
	(%)	(%)	
New South Wales	47	87	Increasing
Victoria	81	70	Decreasing
Queensland	11	0	Decreasing
South Australia	59	87	Increasing
Western Australia	71	100	Increasing
Tasmania	6	18	Increasing
Northern Territory	3	2	Stable (est.)
Australian Capital Territory	65	42	Decreasing

heaters in those states do not start with the full potential defined by the linear trend. This is due to factors such as the truck roll required to change timers and clocks to solar soak periods and the limited number of trials which have taken place to enable these changes.

The proportion of FD-enabling technology used for resistance heaters and heat pumps reflects what were deemed to be realistic ratios given the limited amount of market information on FD-enabling technologies. These proportions were varied in line with the relevant scenarios, as well as to reflect the specific state circumstances (i.e. ripple or time-based resistance heater control).

Water heater data

For the years 1994–2014, long-term data for residential water heater ownership by type is sourced from the series of Australian Bureau of Statistics surveys *ABS4602.0 Environmental Issues: Energy Use and Conservation* (ABS, 2014). The ABS has not undertaken any relevant surveys since 2014. The only other source of data on household water heaters in recent years is by BIS Oxford Economics (2018, 2020), which is based on national surveys of about 4000–5000 households. These provide detailed data on the installed share of DHW technologies across NSW, Victoria, Queensland, SA and WA and for the years 2014, 2016, 2018 and 2020. The BIS data was used to establish trends in the ABS data for each of the main water heater types over time.

Solar and air source heat pump sales data is available from the Small-scale Renewable Energy Scheme. Heat pumps were only included from 2005, with historical rates of installation considered to be lower. Heat pump performance has also improved significantly in recent years.

Appendix B—Detailed model results

The following figures show the sales, stock, flexible demand potential, flexible demand depth, greenhouse gas emissions and operating costs of Section 3 for each NEM state or territory. Chart colours are as per the corresponding figures in Section 3.

Australian Capital Territory

Sales

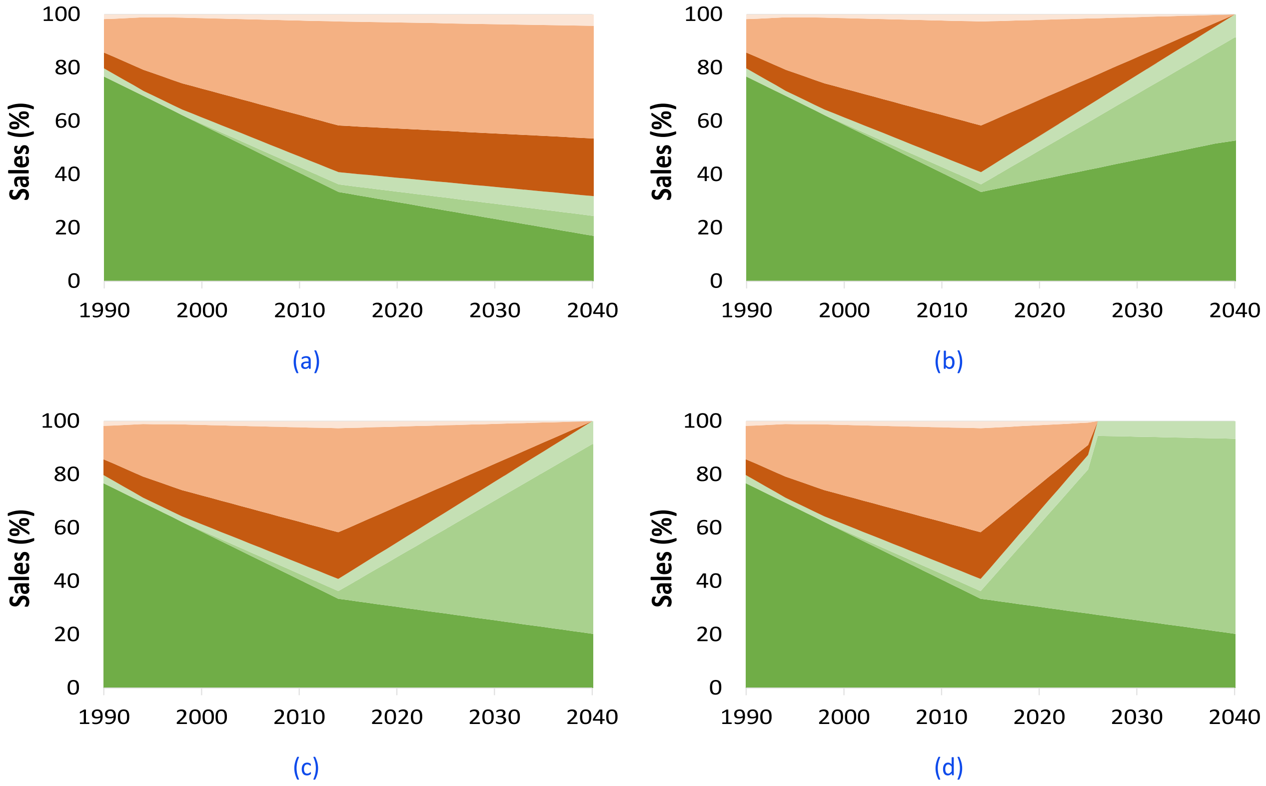


Figure 26. Projected DHW sales for the ACT. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Stock

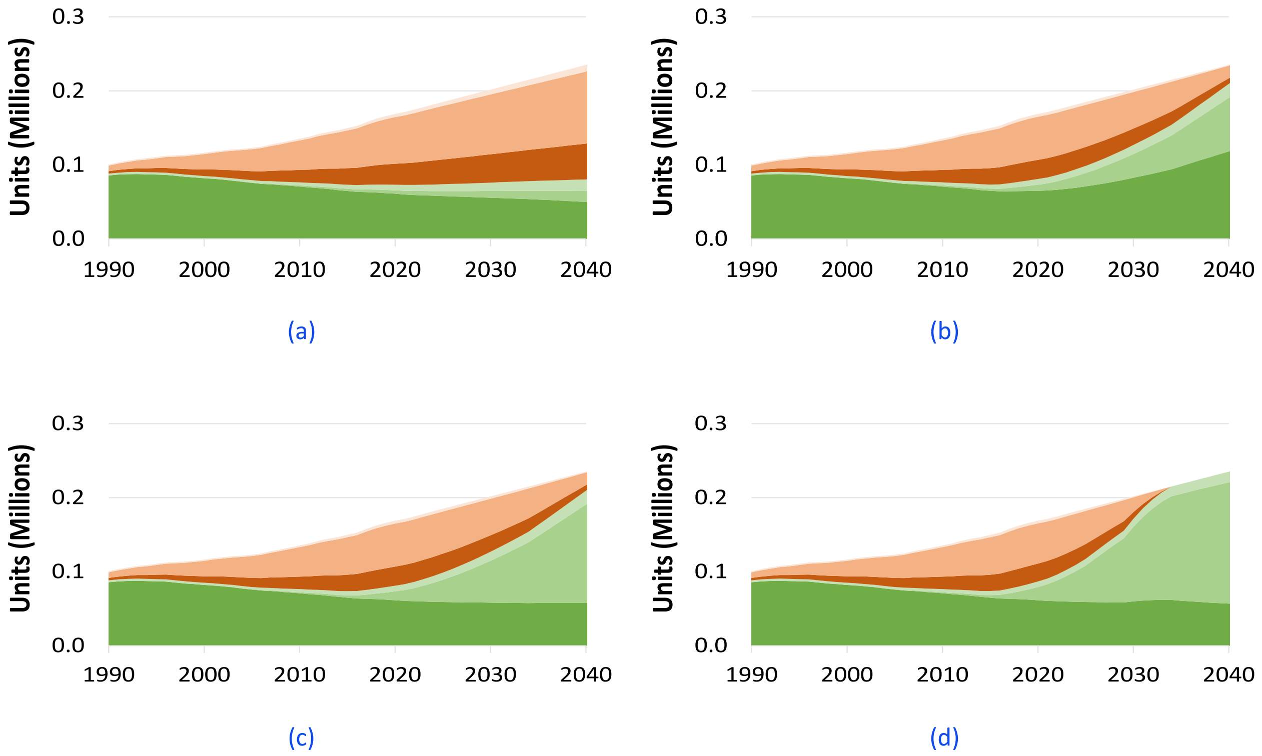
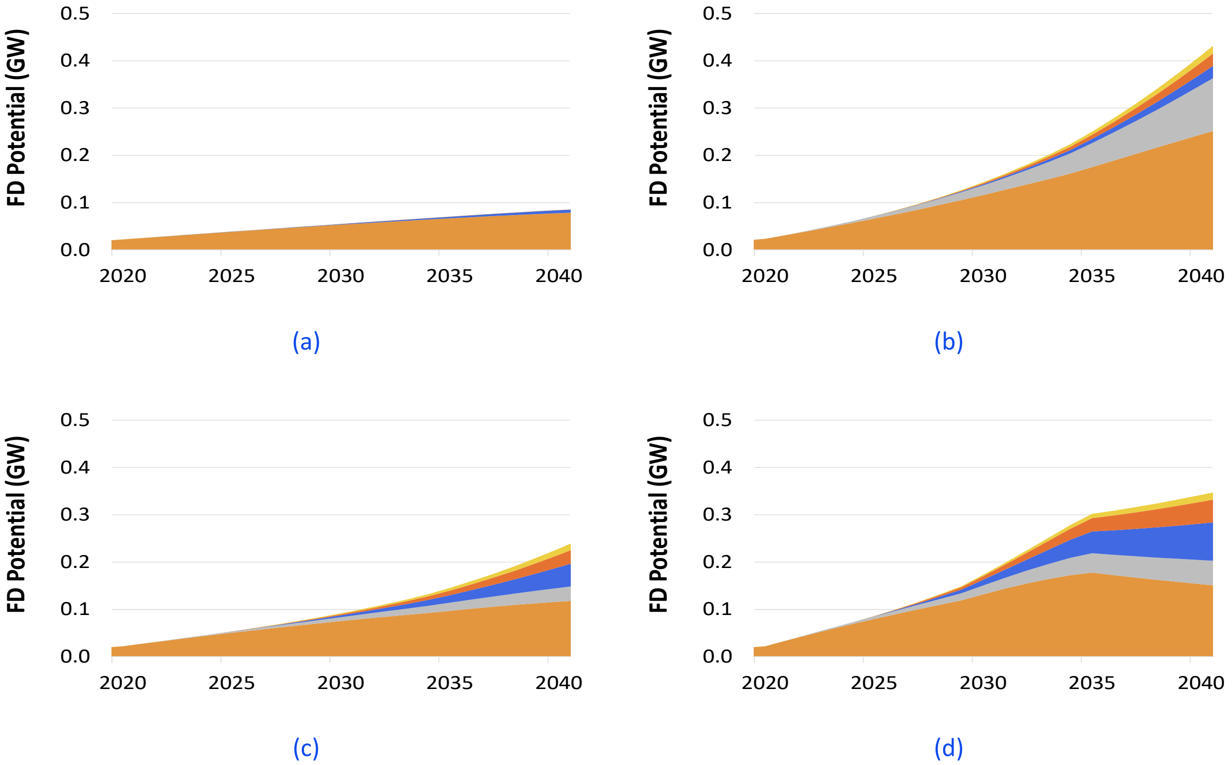


Figure 27. Projected DHW stock for the ACT. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

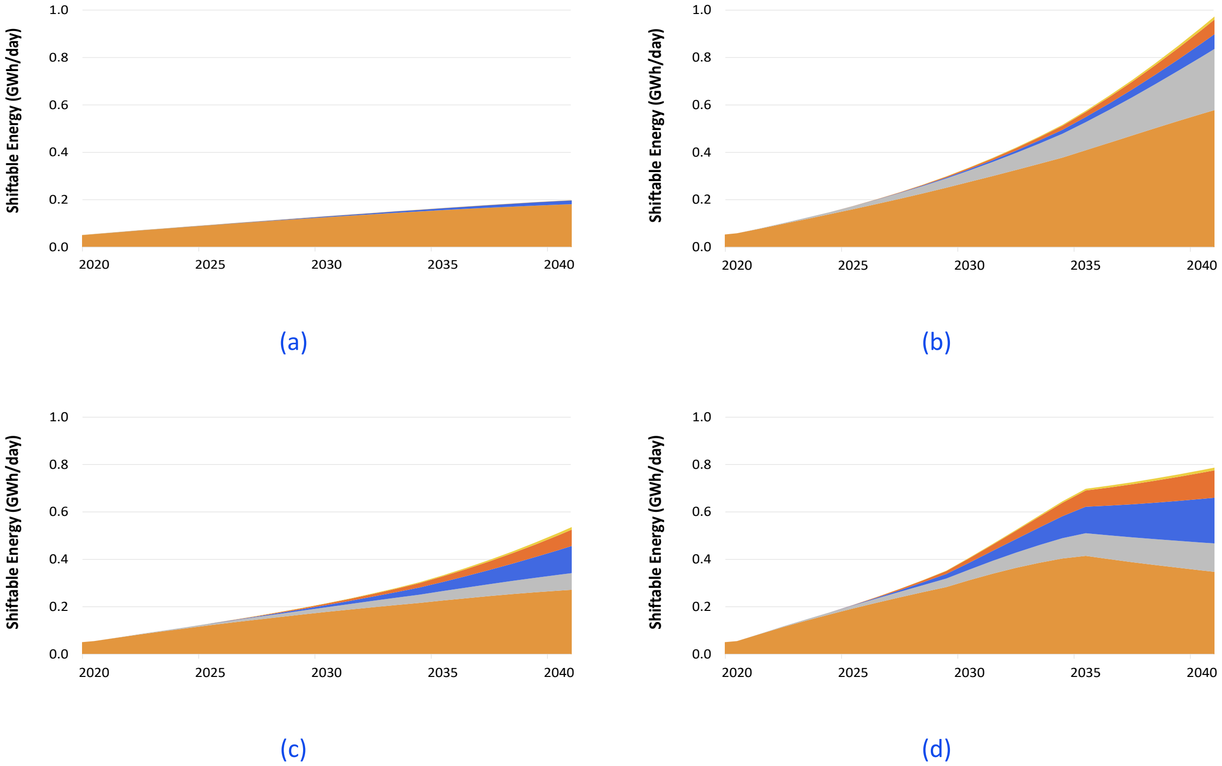
Flexible demand potential



(a) (b) (c) (d)

Figure 28. Projected flexible demand potential from DHW for the ACT. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

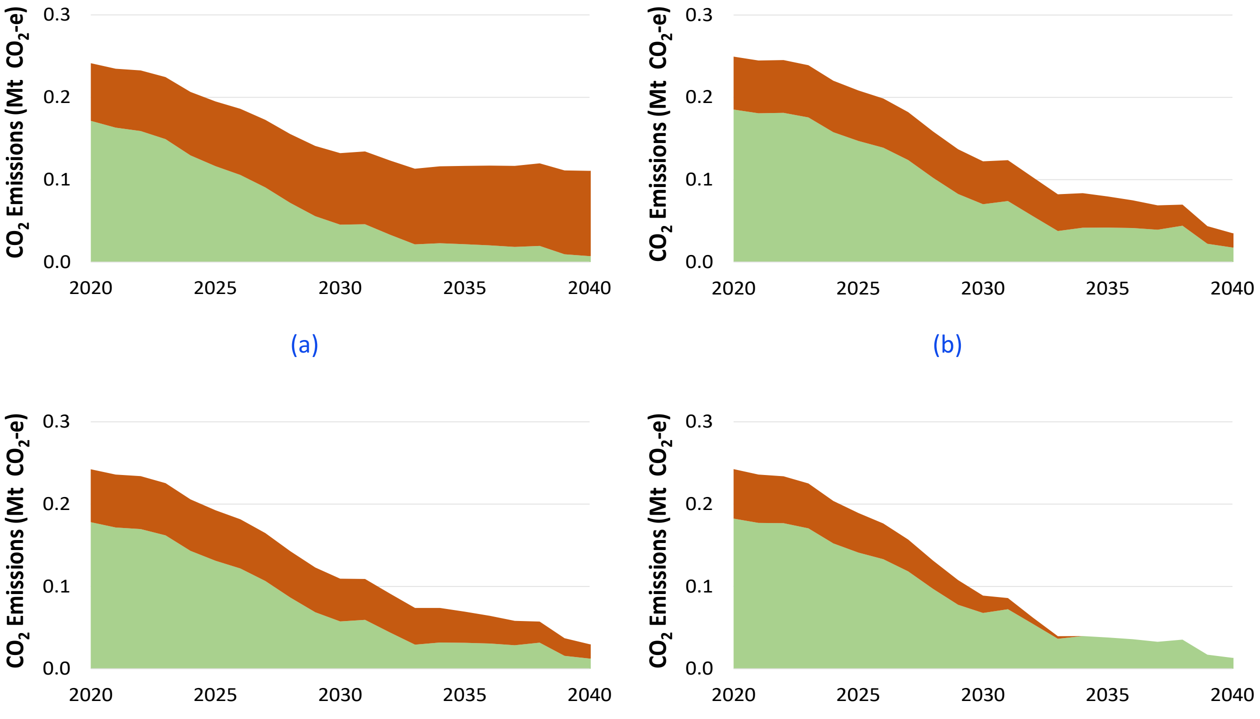
Flexible demand depth



(a) (b) (c) (d)

Figure 29. Projected flexible demand depth from DHW for the ACT. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Greenhouse gas emissions



(a)

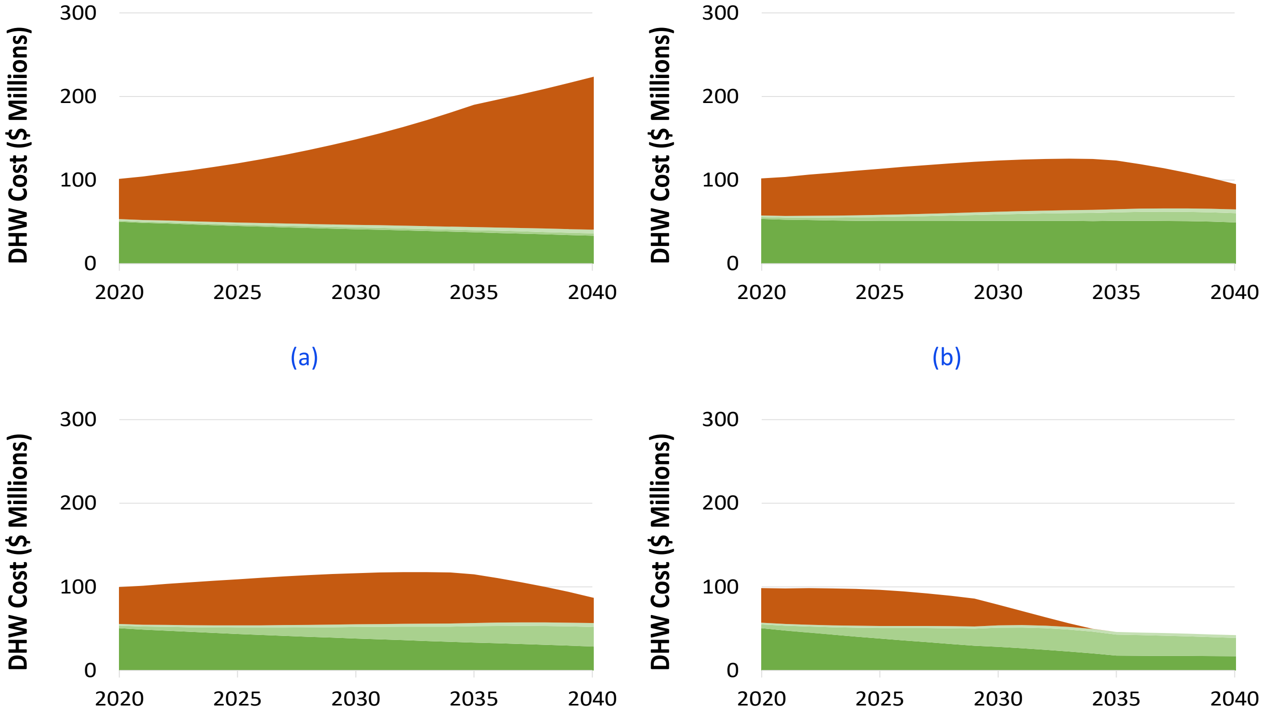
(b)

(c)

(d)

Figure 30. Projected greenhouse gas emissions from DHW for the ACT. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Operating costs



(a)

(b)

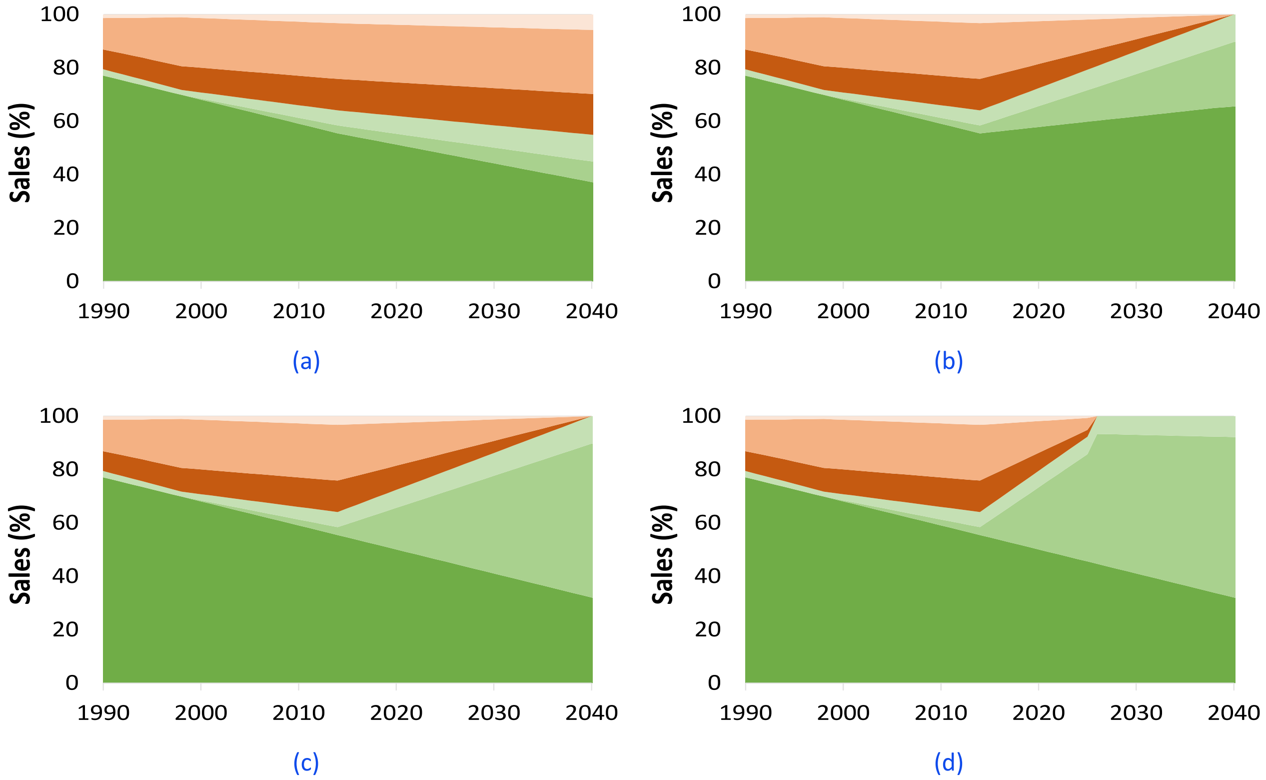
(c)

(d)

Figure 31. Projected total retail operating costs of DHW for the ACT. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

New South Wales

Sales

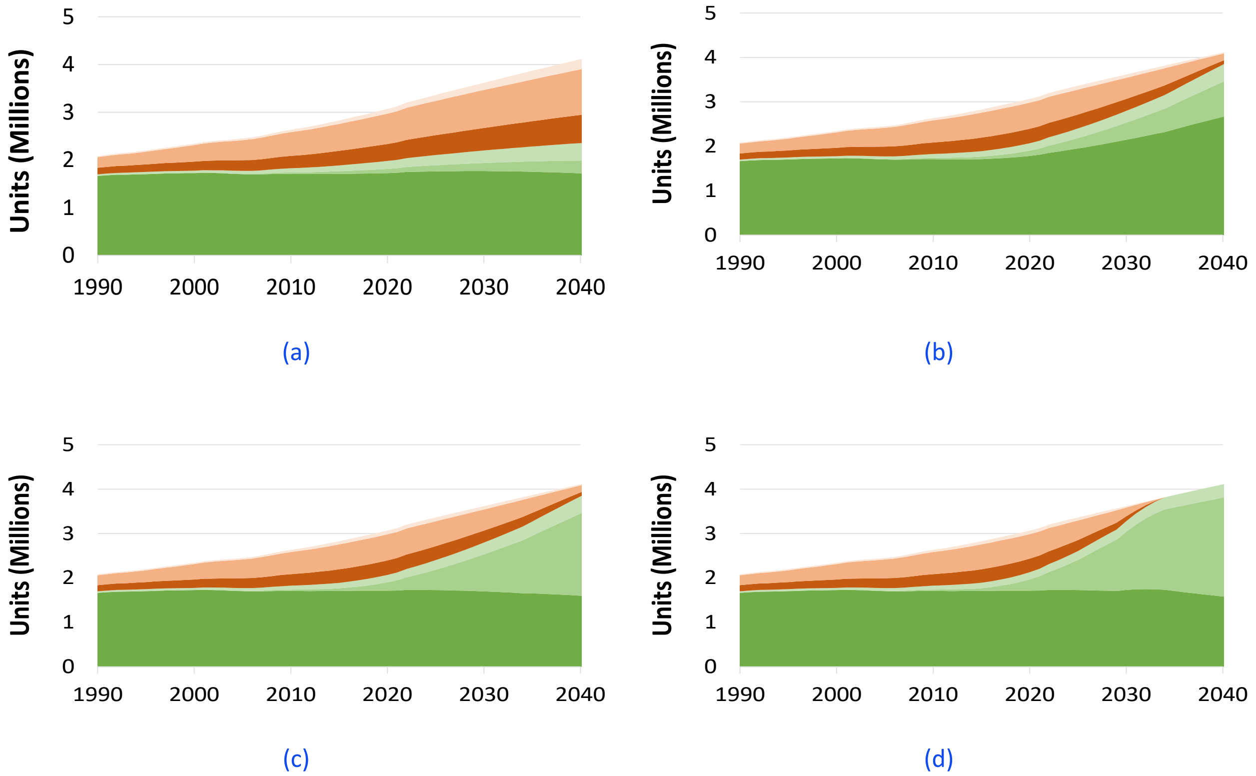


(a) (b)

(c) (d)

Figure 32. Projected DHW sales for NSW. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Stock

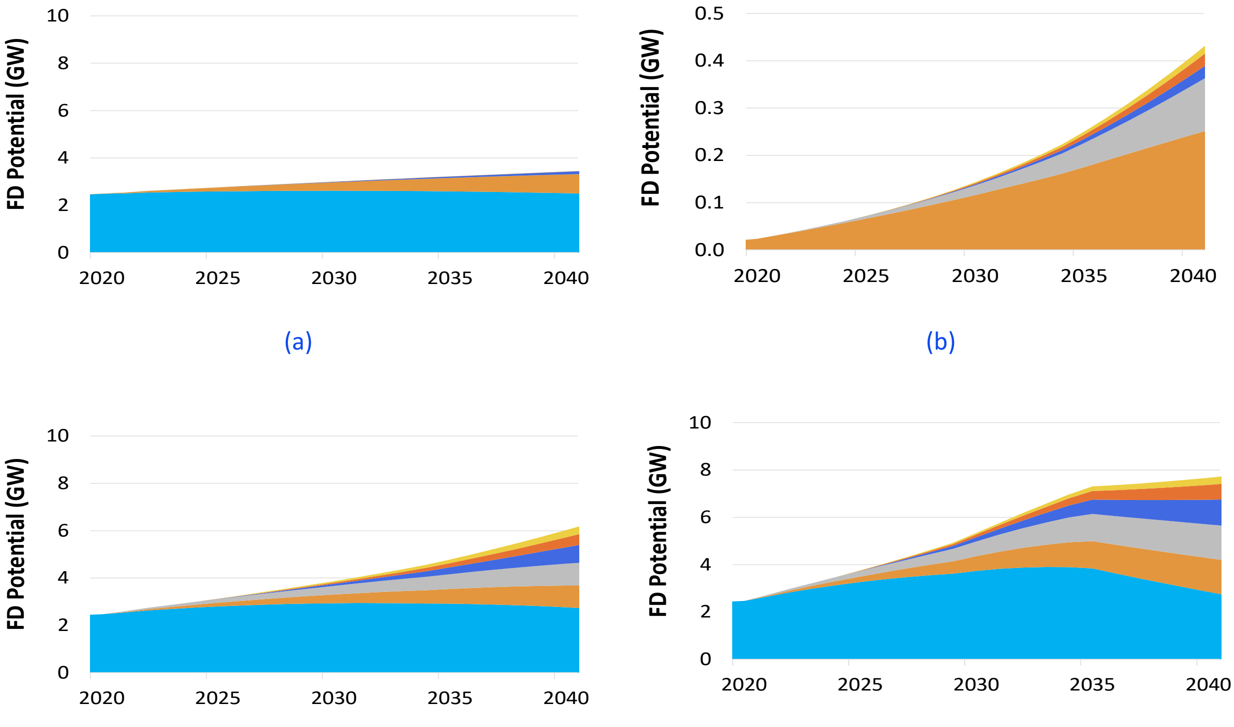


(a) (b)

(c) (d)

Figure 33. Projected DHW stock for NSW. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Flexible demand potential

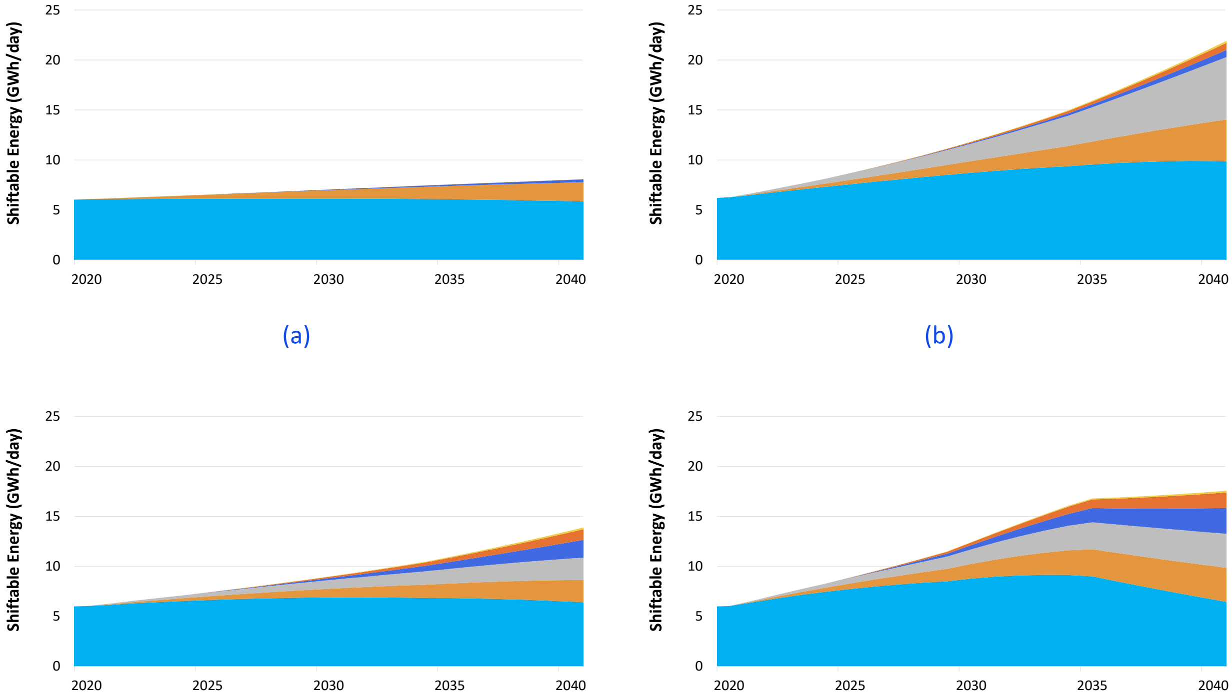


(a) (b)

(c) (d)

Figure 34. Projected flexible demand potential from DHW for NSW. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Flexible demand depth

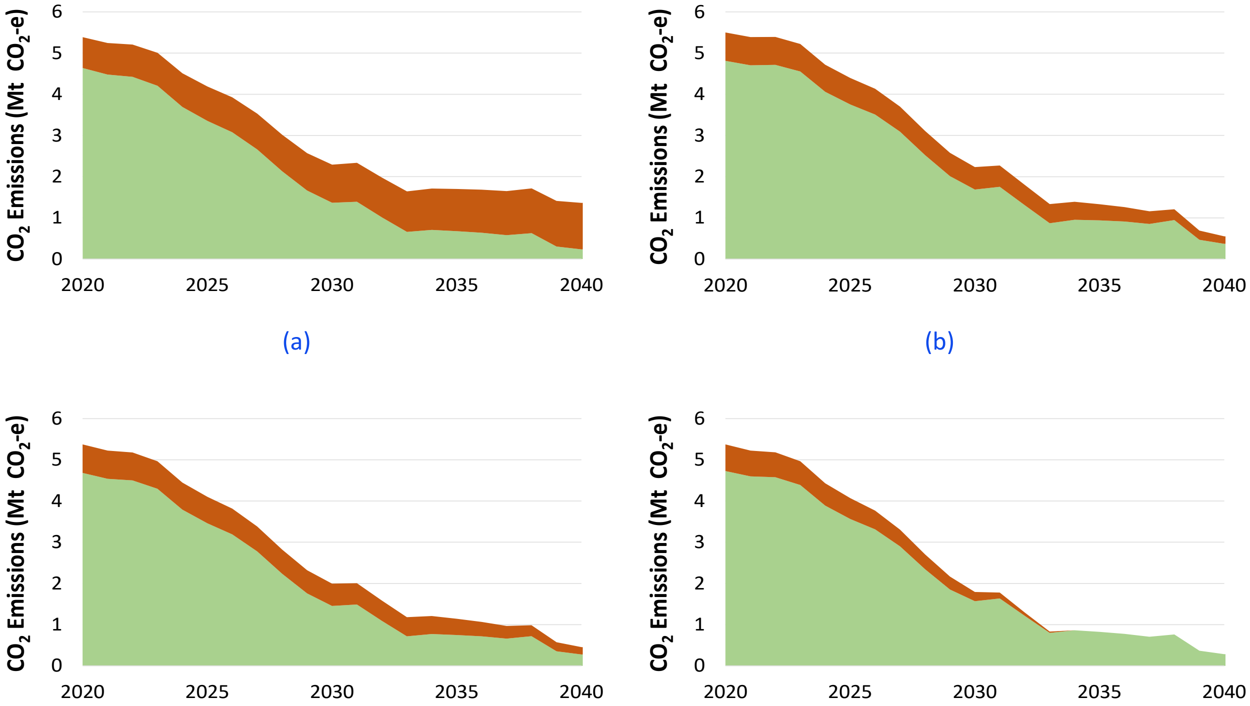


(a) (b)

(c) (d)

Figure 35. Projected flexible demand depth from DHW for NSW. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Greenhouse gas emissions



(a)

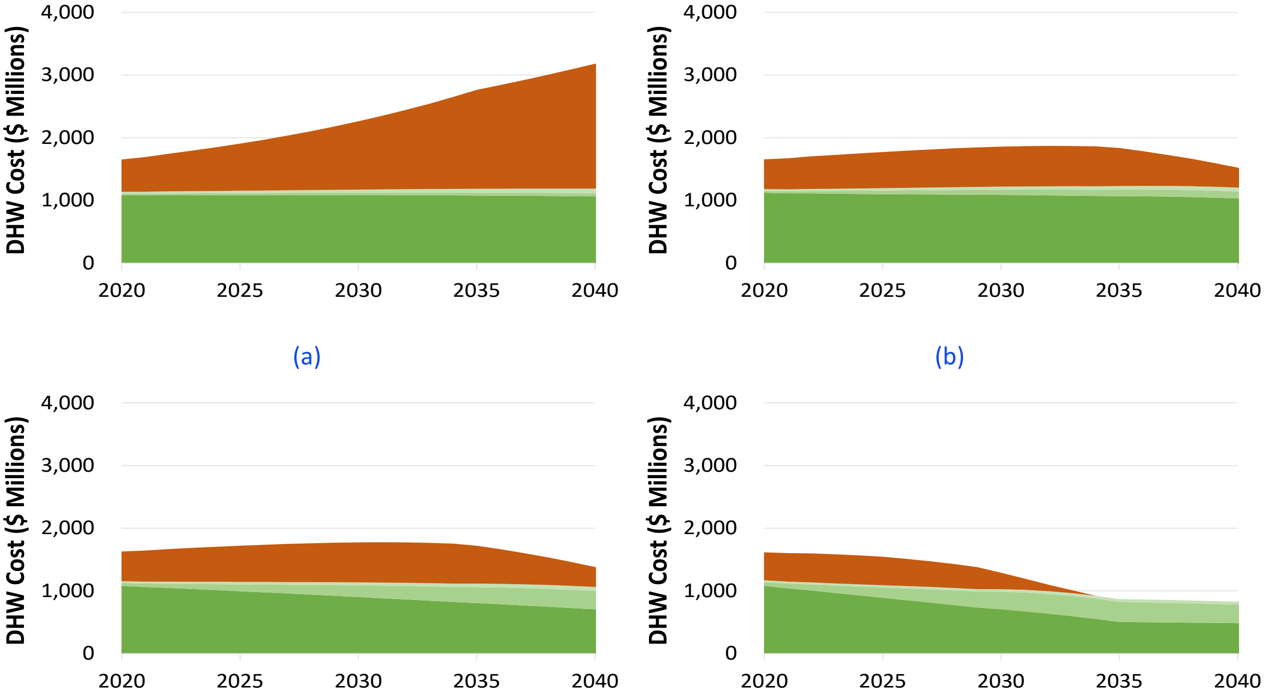
(b)

(c)

(d)

Figure 36. Projected greenhouse gas emissions from DHW for NSW. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Operating costs



(a)

(b)

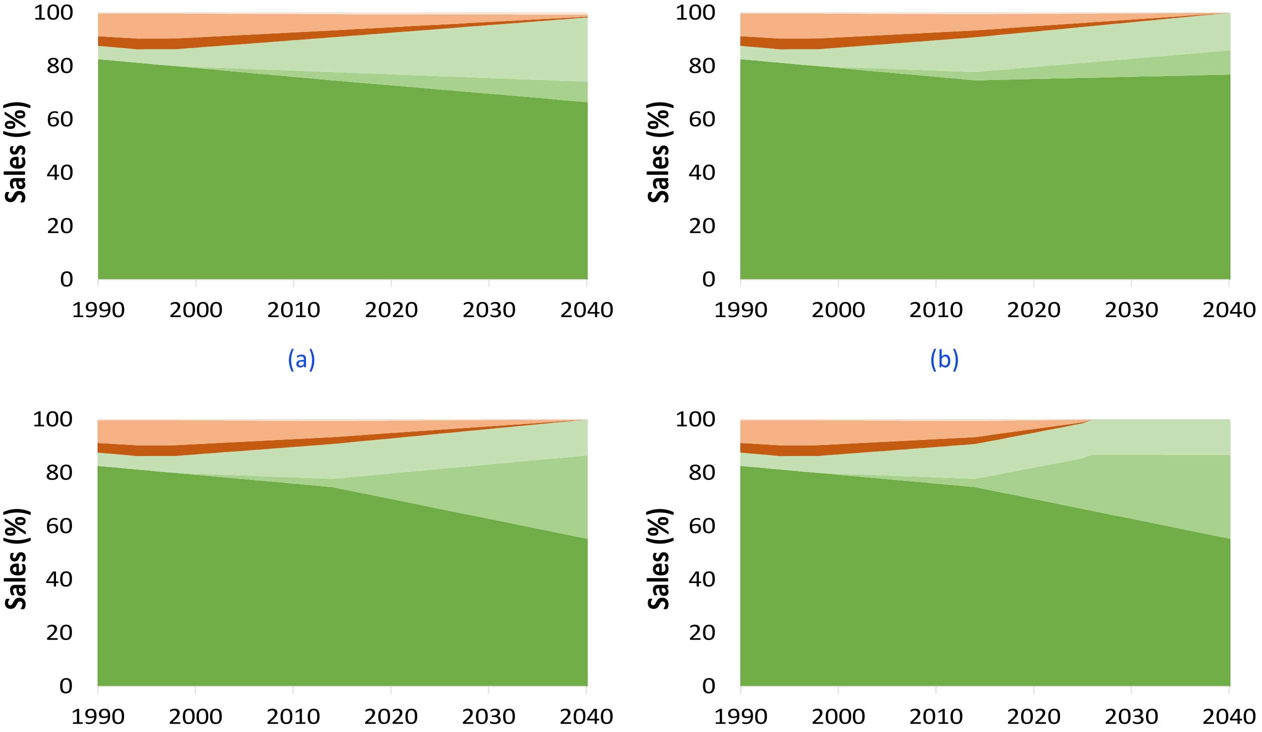
(c)

(d)

Figure 37. Projected total retail operating costs of DHW for NSW. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Queensland

Sales



(a)

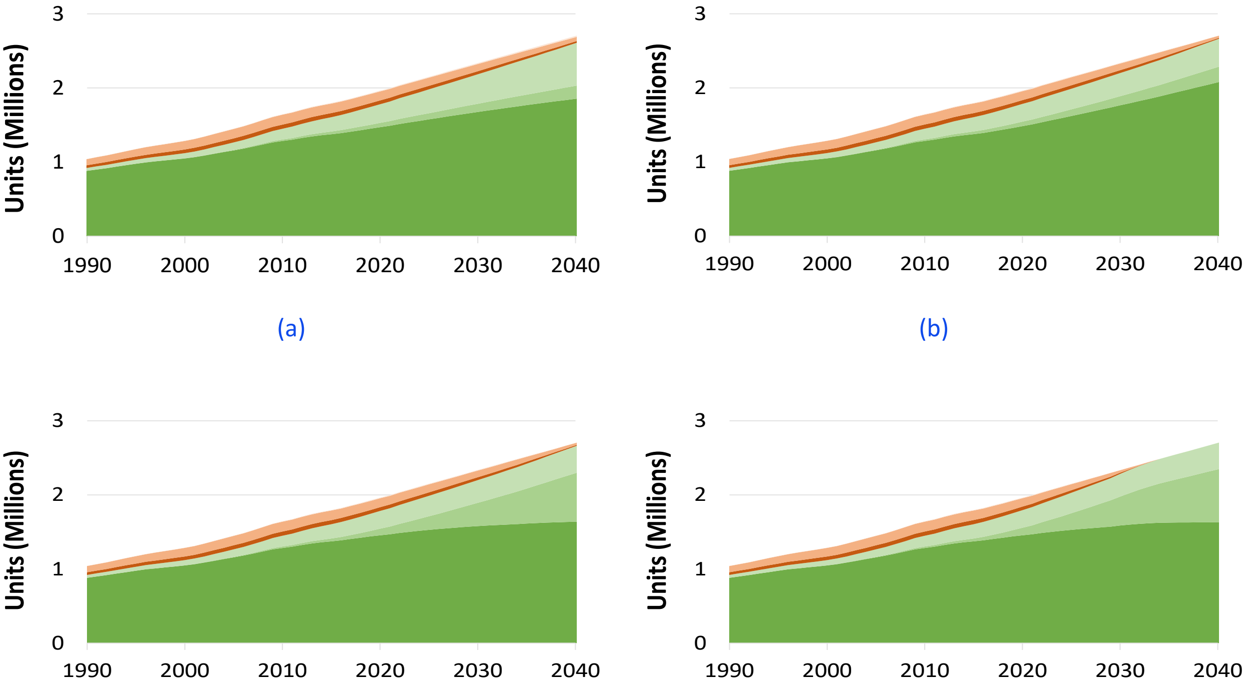
(b)

(c)

(d)

Figure 38. Projected DHW sales for Queensland. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Stock



(a)

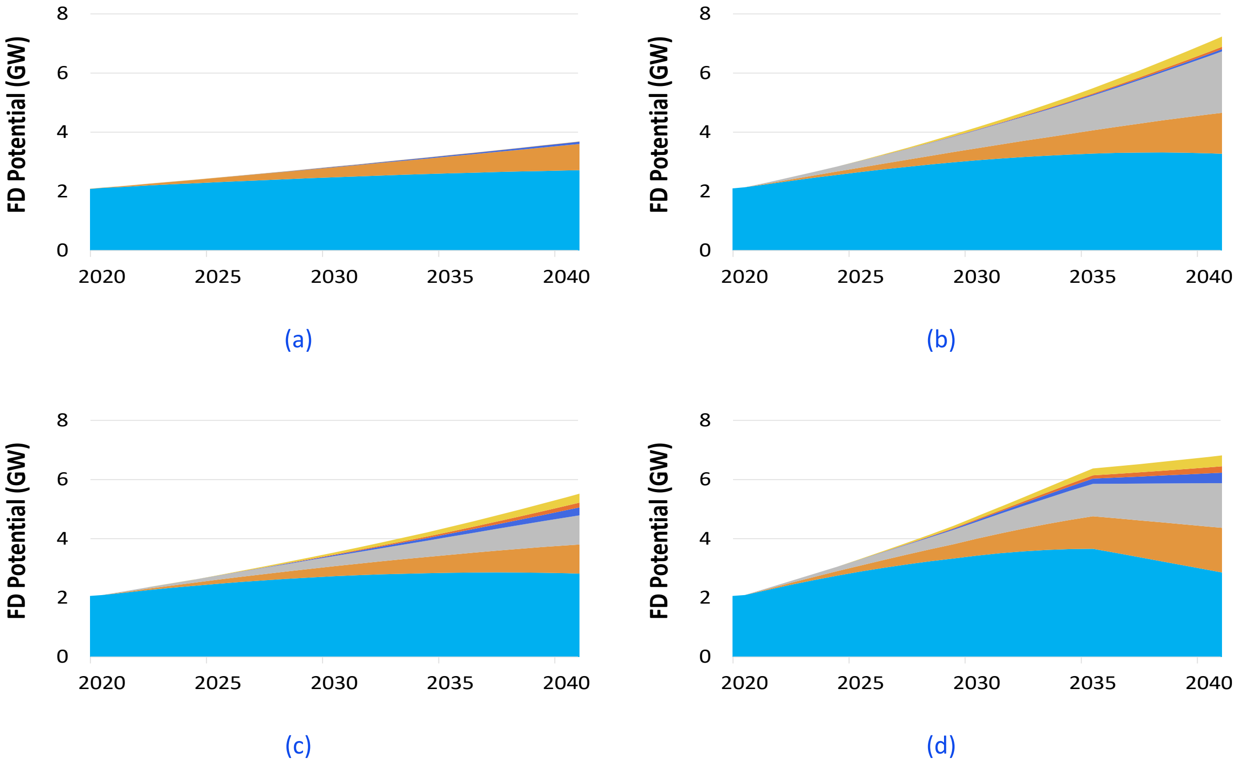
(b)

(c)

(d)

Figure 39. Projected DHW stock for Queensland. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

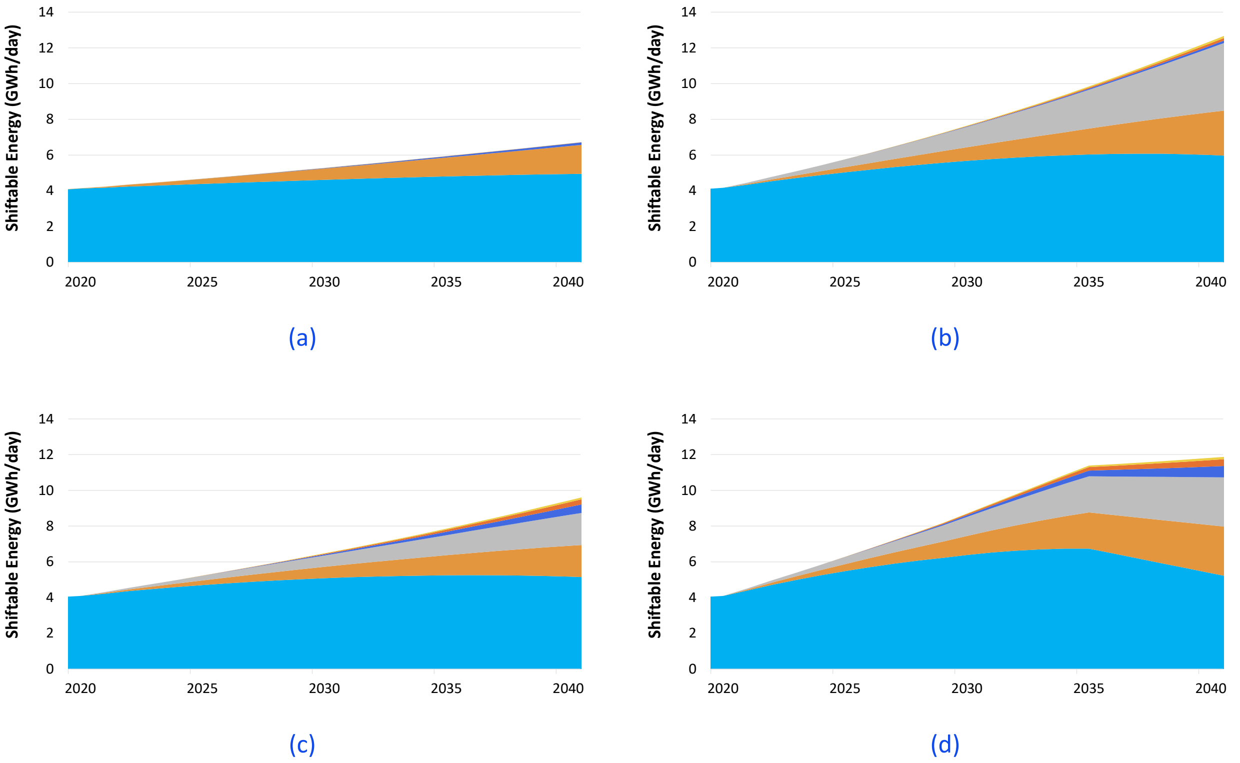
Flexible demand potential



(a) (b) (c) (d)

Figure 40. Projected flexible demand potential from DHW for the ACT. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Flexible demand depth



(a) (b) (c) (d)

Figure 41. Projected flexible demand depth from DHW for Queensland. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Greenhouse gas emissions

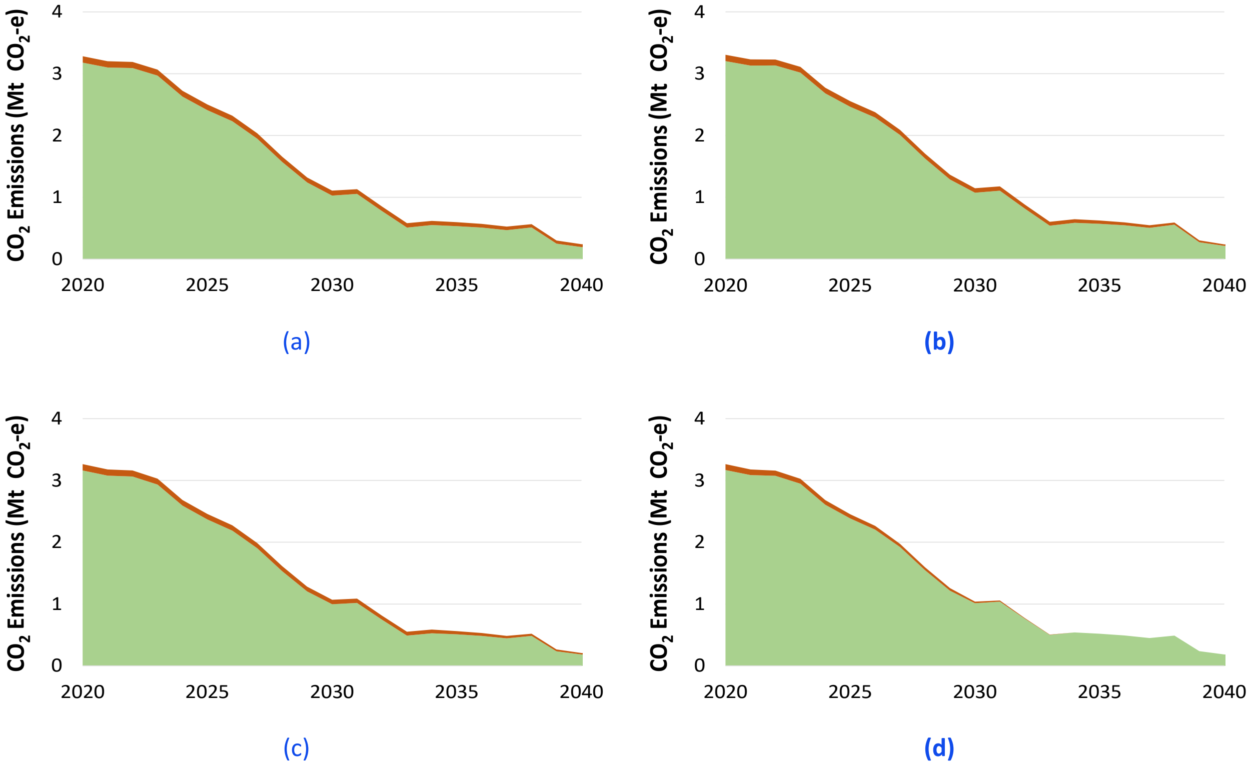


Figure 42. Projected greenhouse gas emissions from DHW for Queensland. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Operating costs

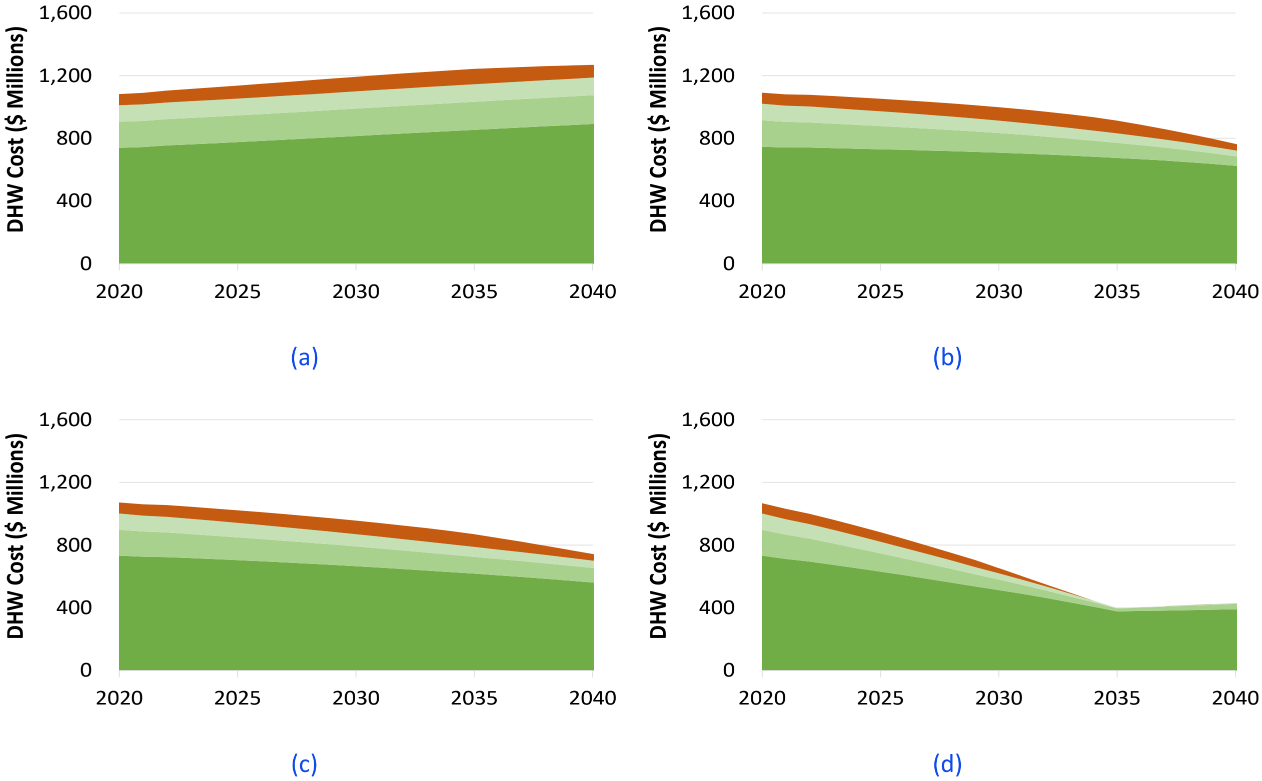
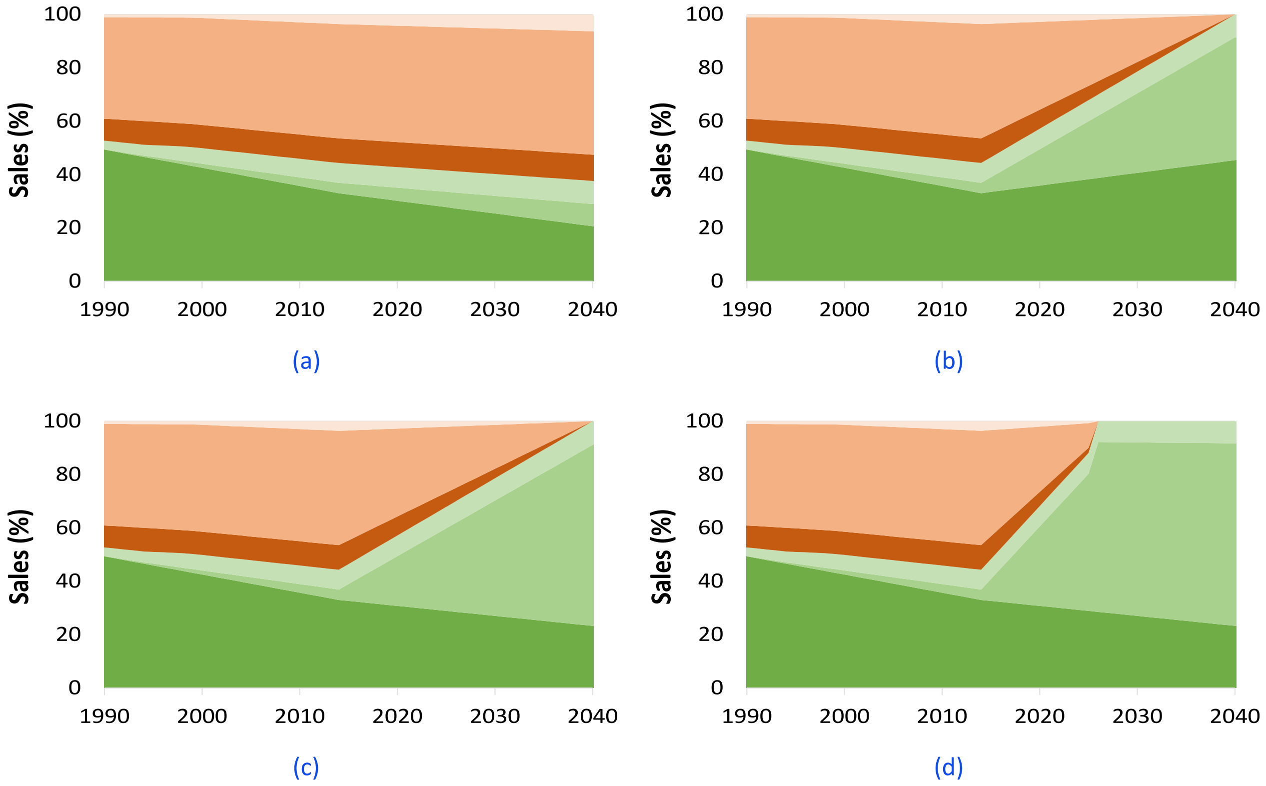


Figure 43. Projected total retail operating costs of DHW for Queensland. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

South Australia

Sales

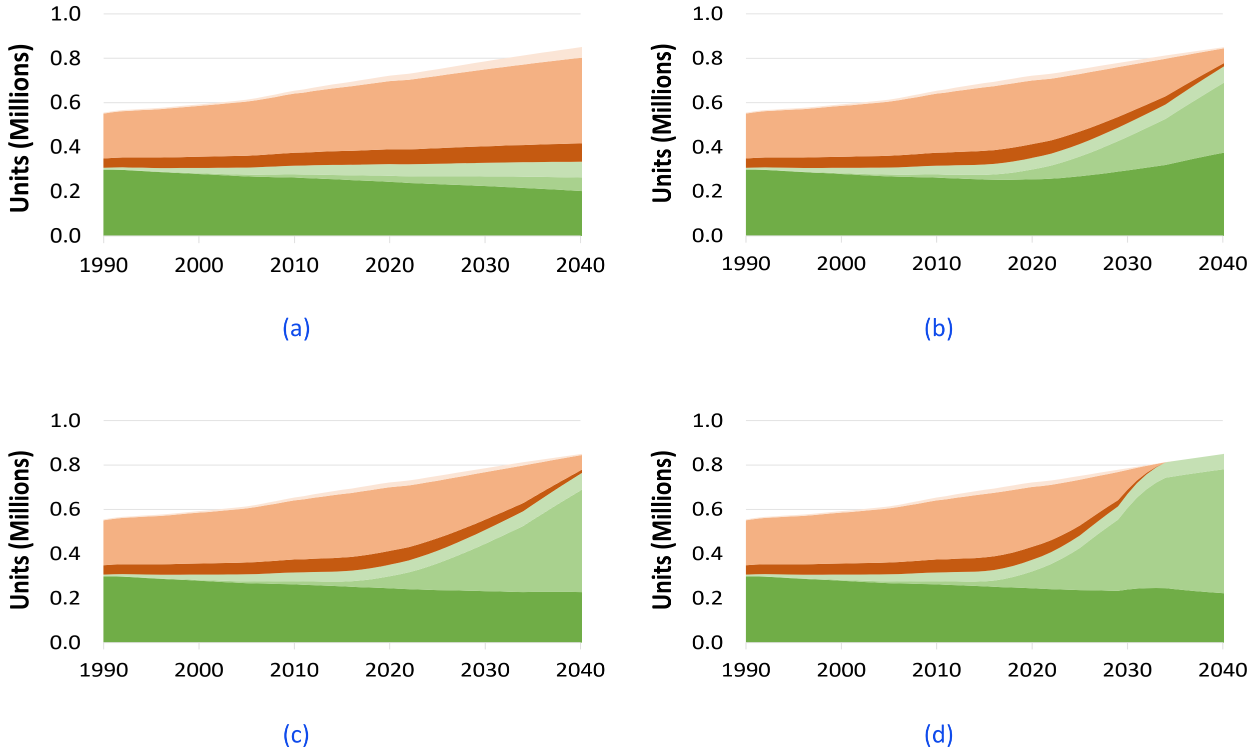


(a) (b)

(c) (d)

Figure 44. Projected DHW sales for South Australia. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Stock

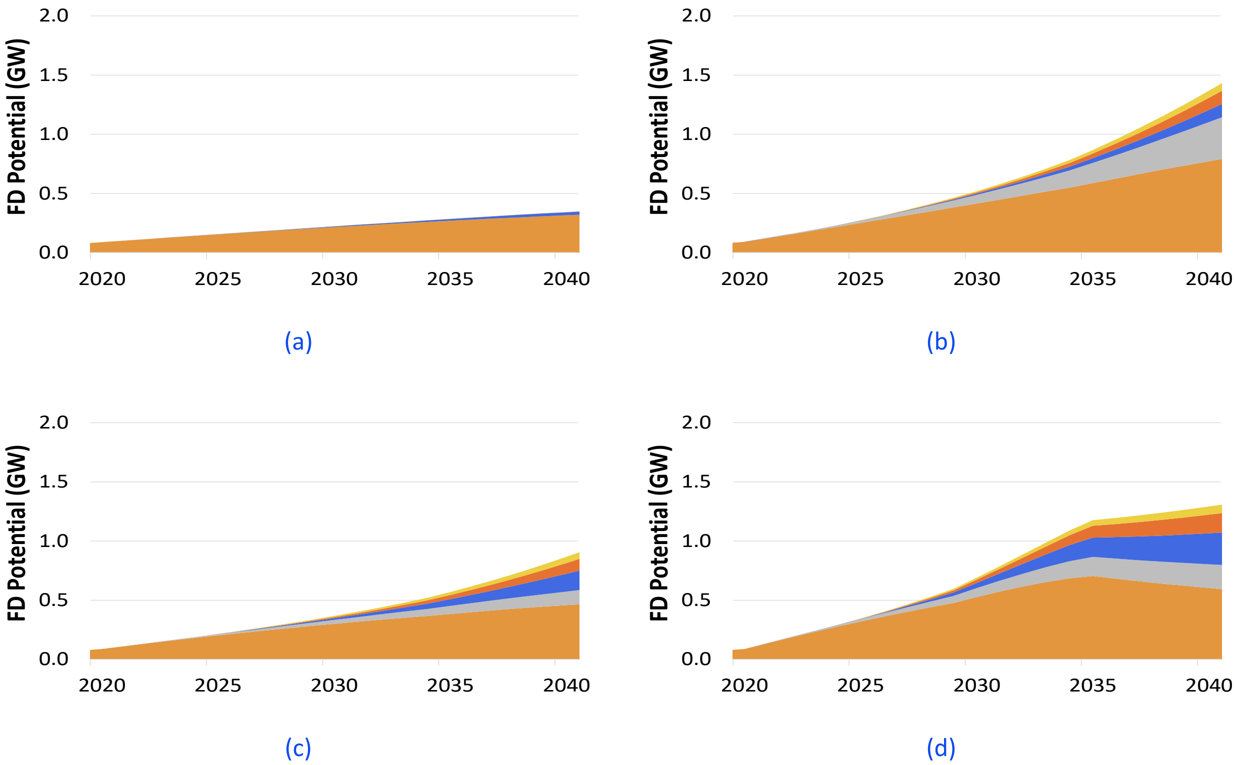


(a) (b)

(c) (d)

Figure 45. Projected DHW stock for South Australia. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

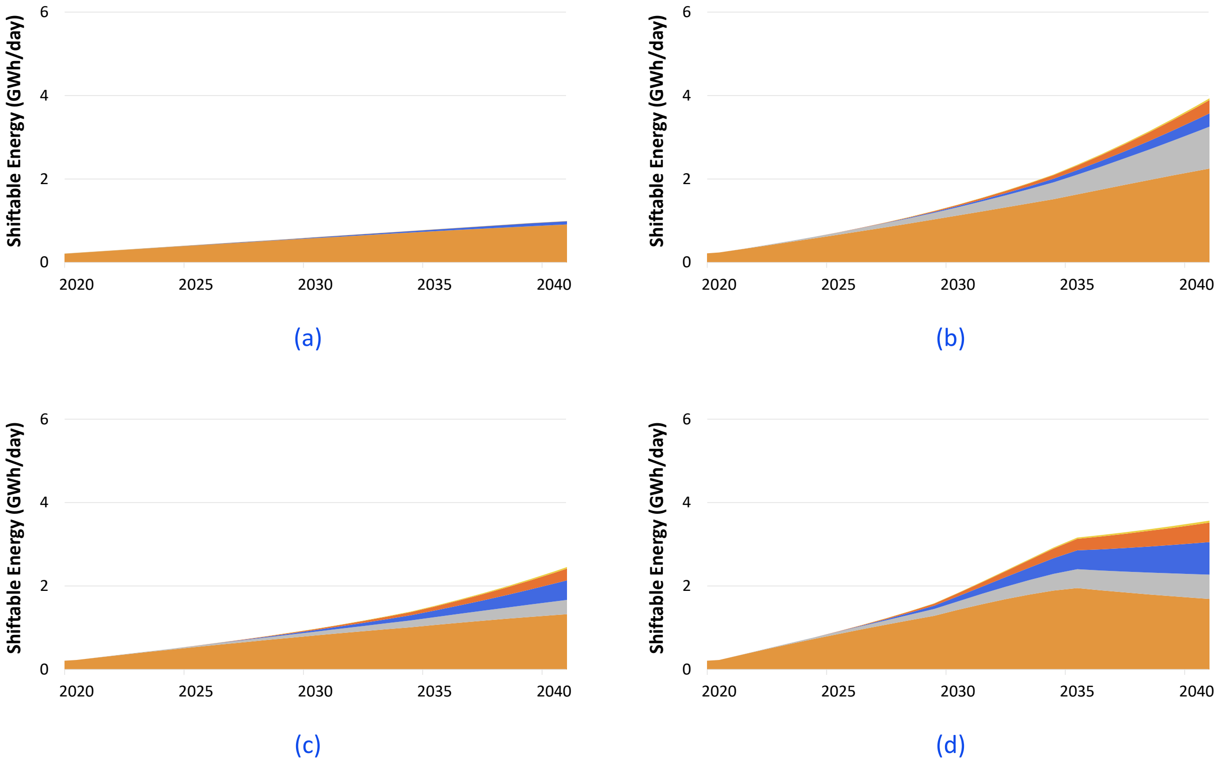
Flexible demand potential



(a) (b) (c) (d)

Figure 46. Projected flexible demand potential from DHW for South Australia. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

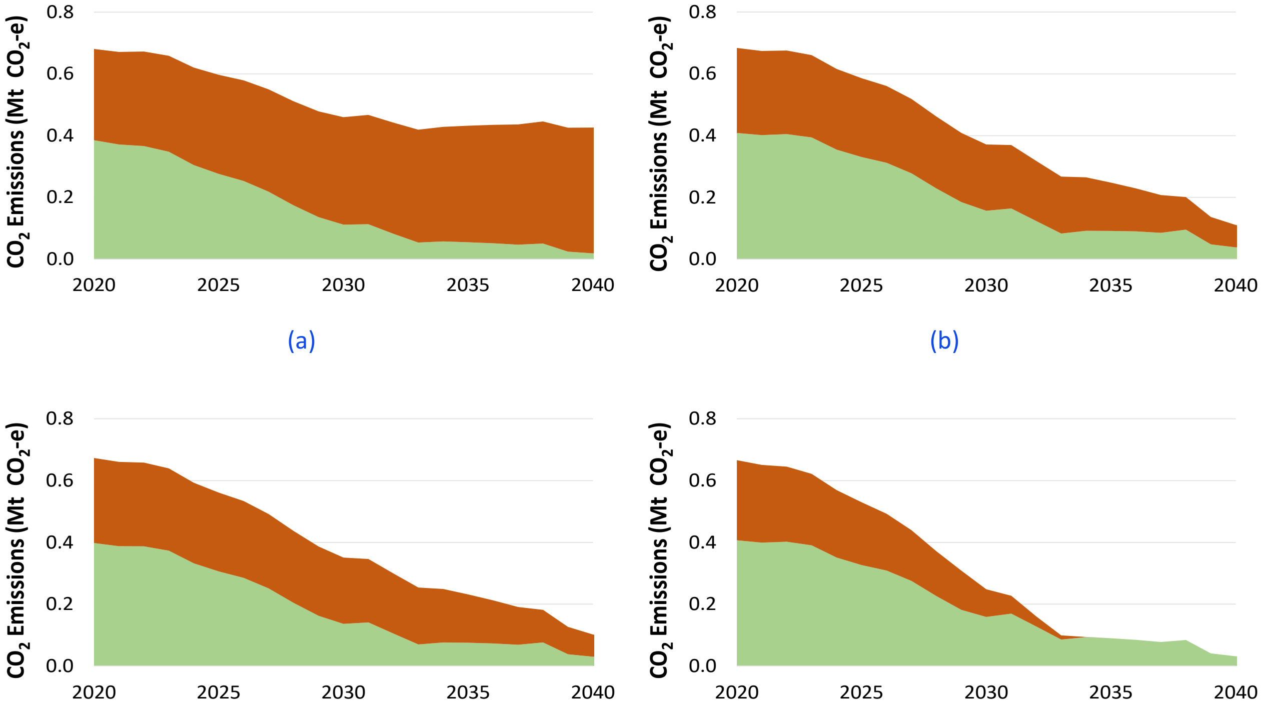
Flexible demand depth



(a) (b) (c) (d)

Figure 47. Projected flexible demand depth from DHW for South Australia. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Greenhouse gas emissions

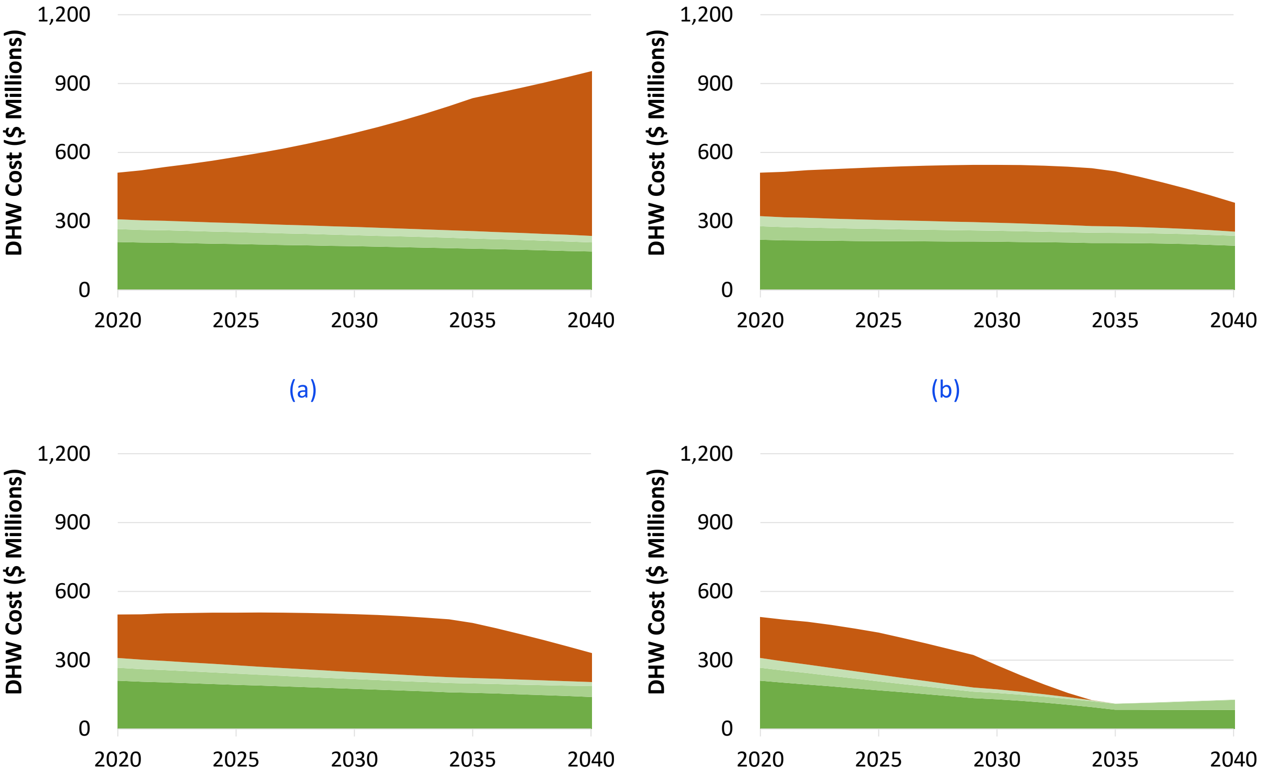


(a) (b)

(c) (d)

Figure 48. Projected greenhouse gas emissions from DHW for South Australia. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Operating costs



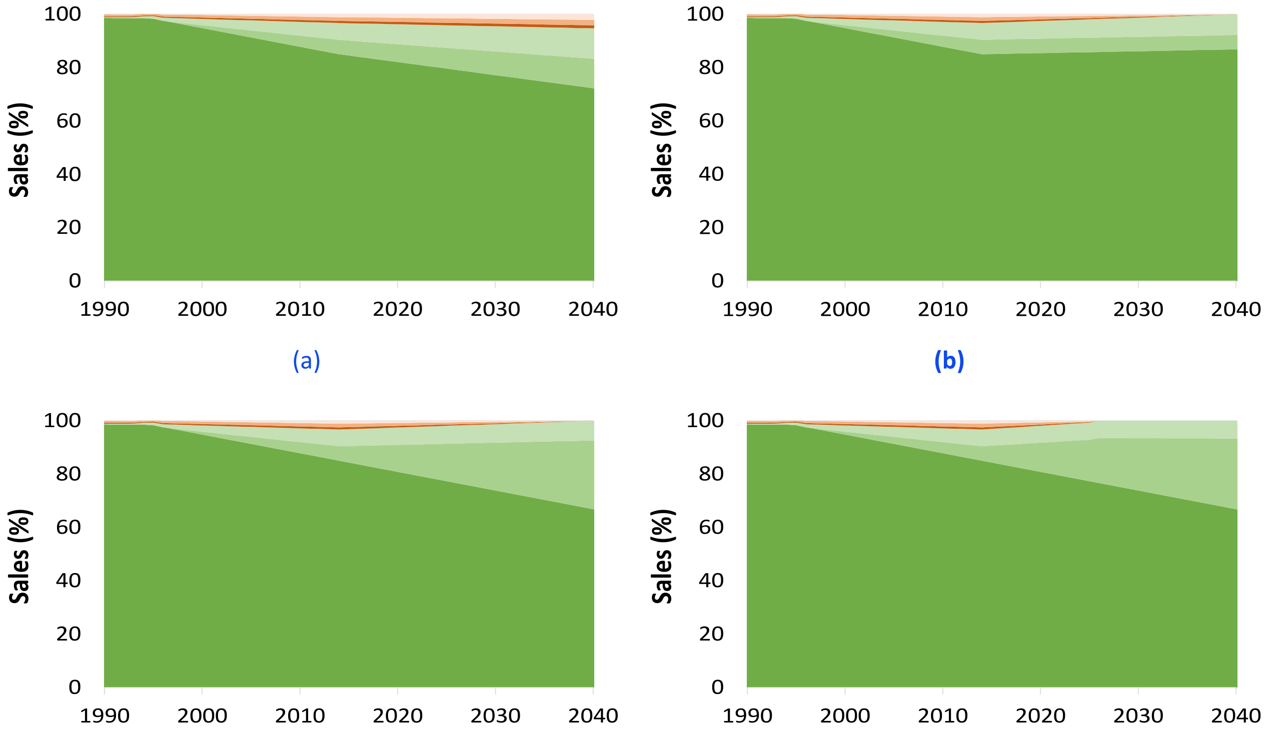
(a) (b)

(c) (d)

Figure 49. Projected total retail operating costs of DHW for South Australia. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Tasmania

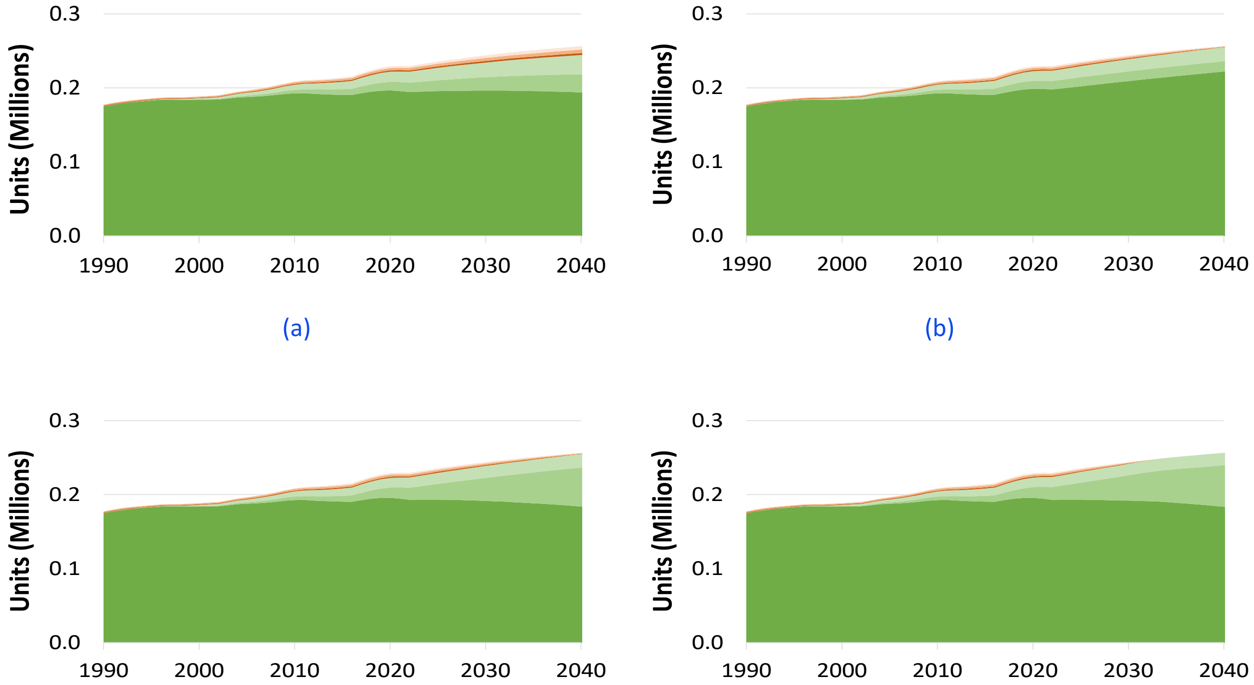
Sales



(a) (b) (c) (d)

Figure 50. Projected DHW sales for Tasmania. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

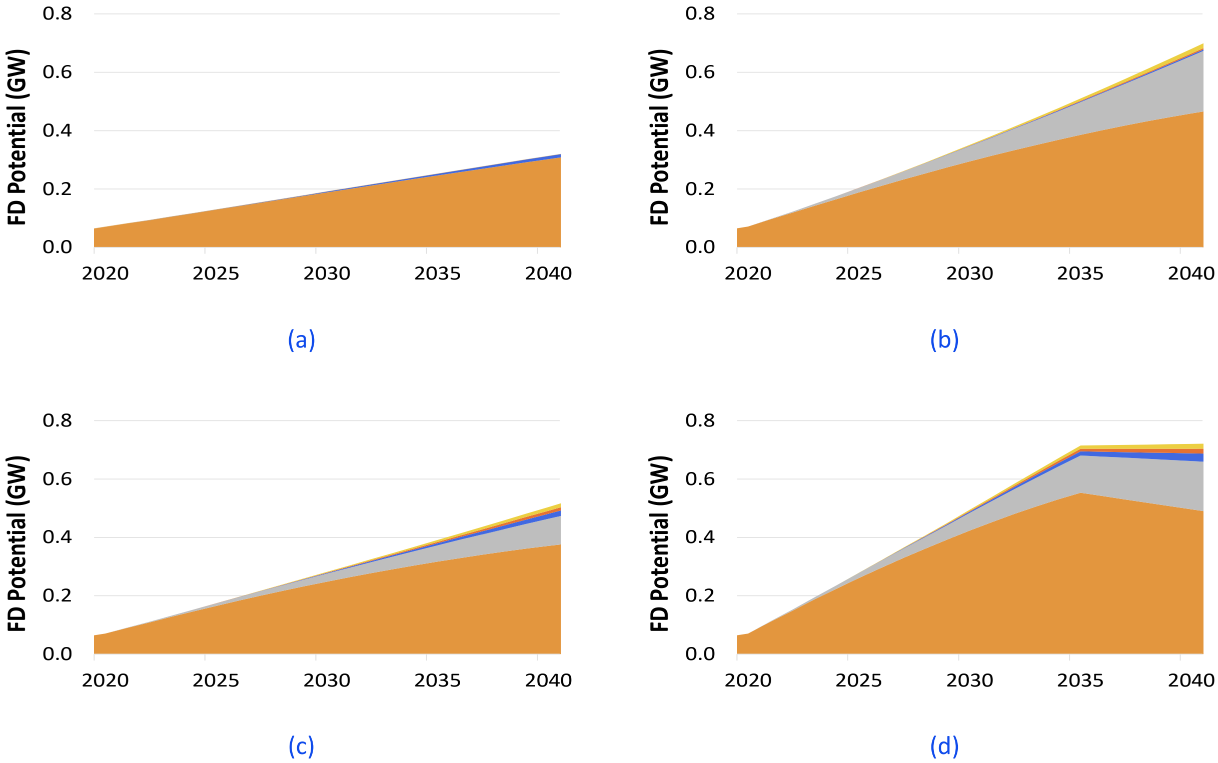
Stock



(a) (b) (c) (d)

Figure 51. Projected DHW stock for Tasmania. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Flexible demand potential



(a)

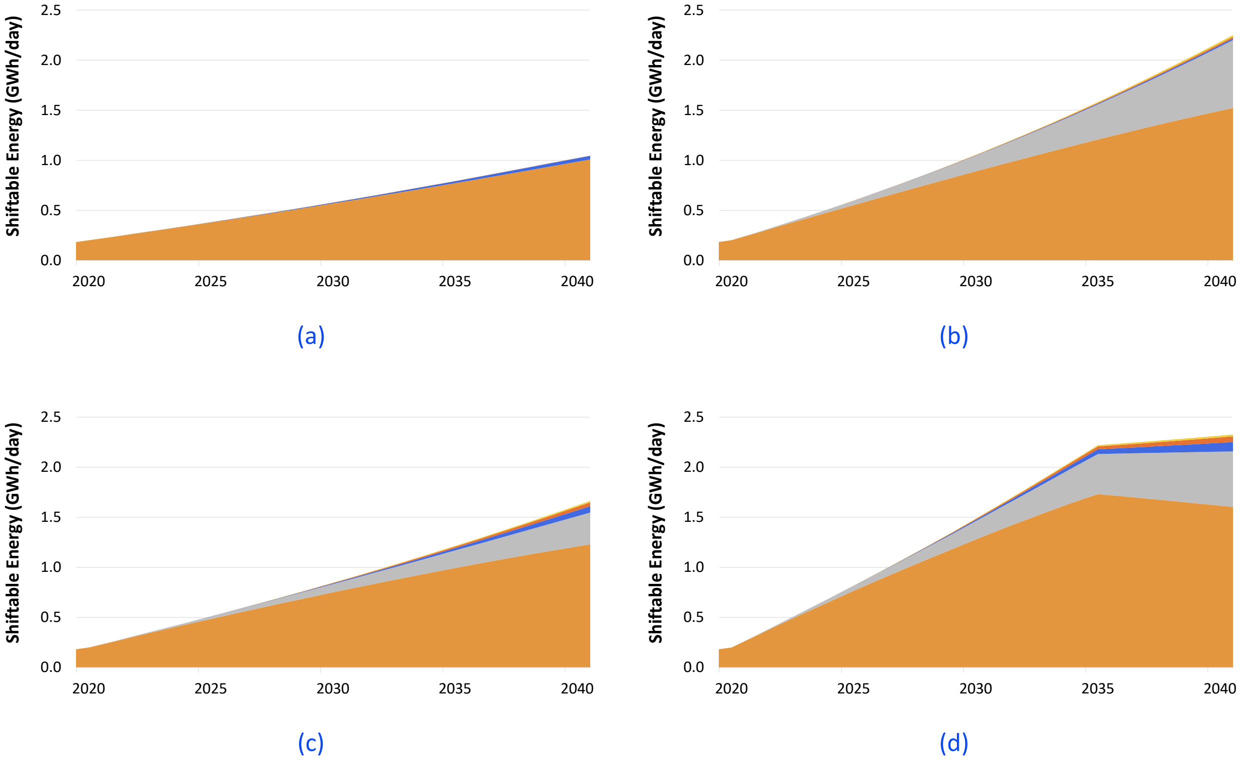
(b)

(c)

(d)

Figure 52. Projected flexible demand potential from DHW for Tasmania. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Flexible demand depth



(a)

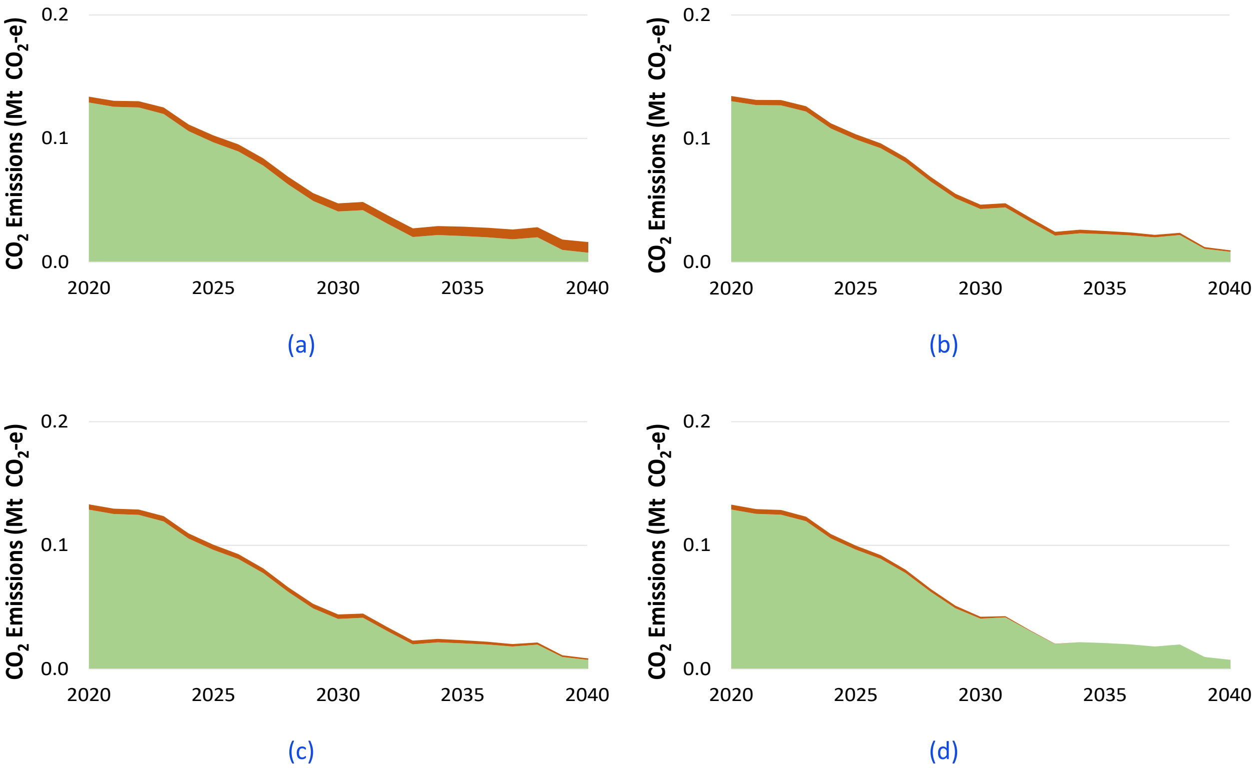
(b)

(c)

(d)

Figure 53. Projected flexible demand depth from DHW for Tasmania. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

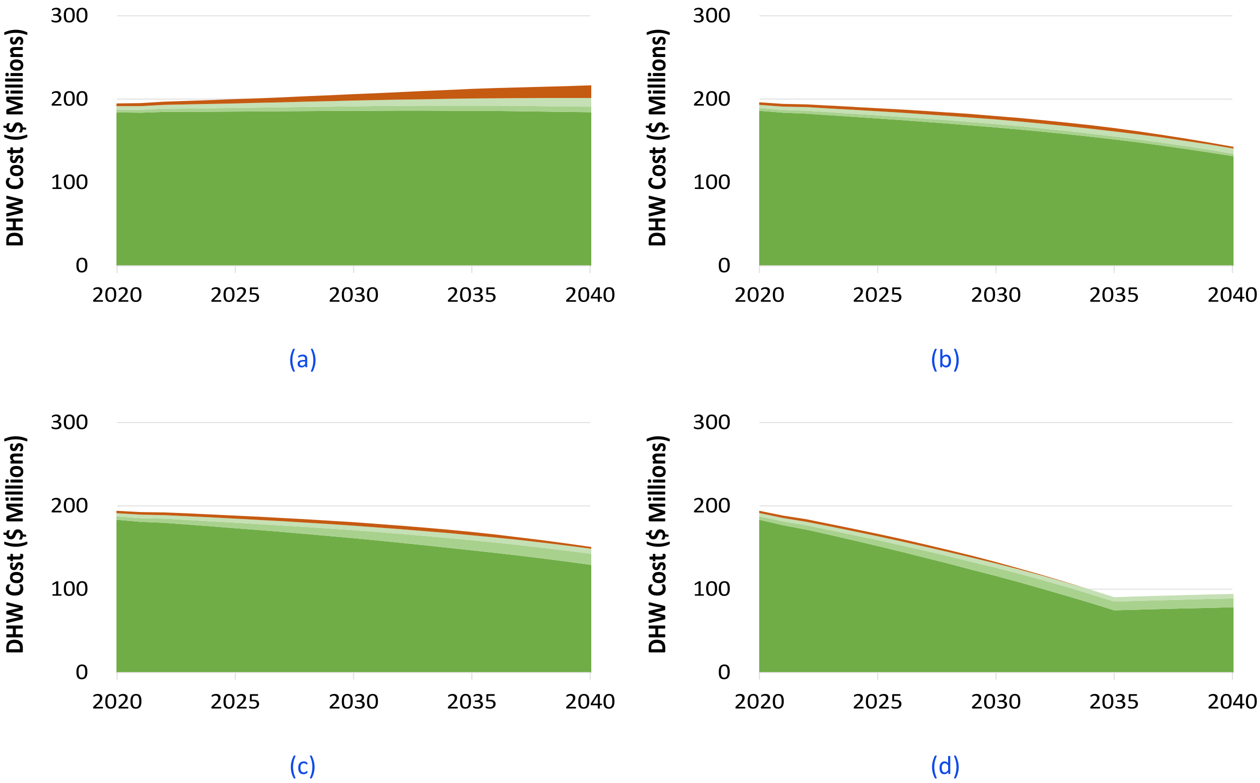
Greenhouse gas emissions



(a) (b) (c) (d)

Figure 54. Projected greenhouse gas emissions from DHW for Tasmania. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Operating costs



(a) (b) (c) (d)

Figure 55. Projected total retail operating costs of DHW for Tasmania. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Victoria

Sales

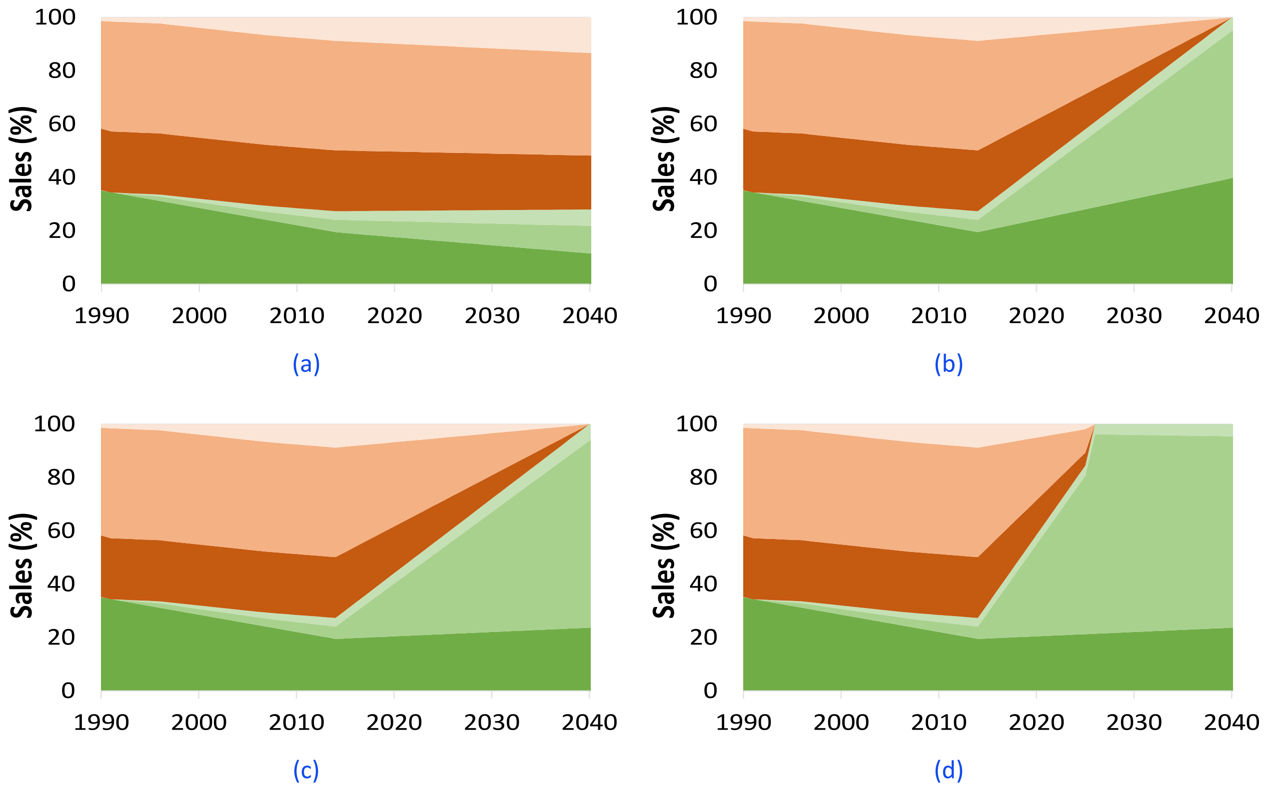


Figure 56. Projected DHW sales for Victoria. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Stock

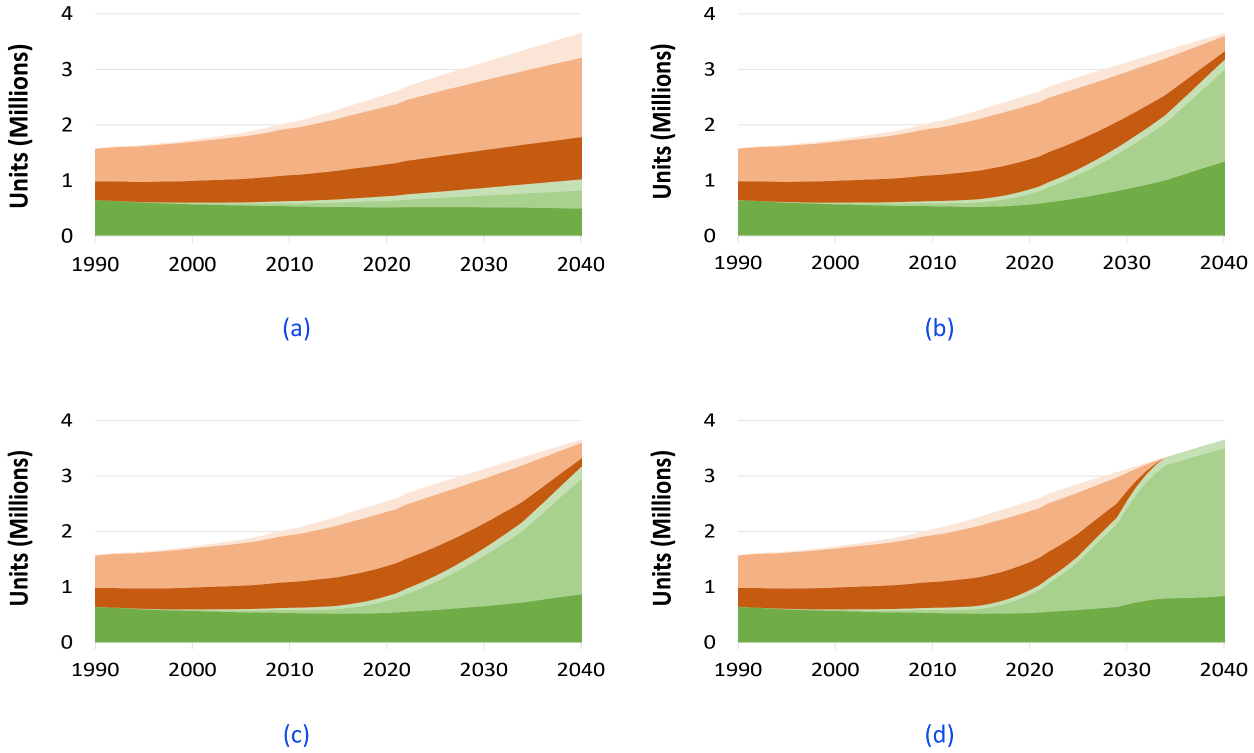
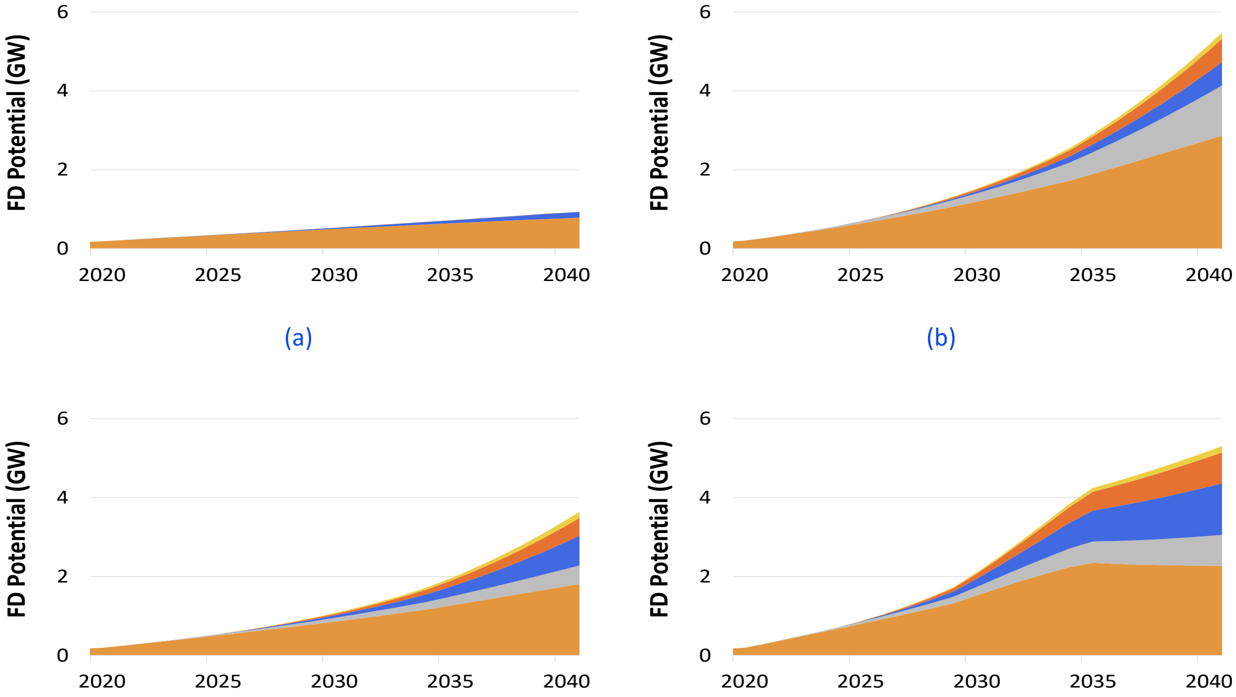


Figure 57. Projected DHW stock for Victoria. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Flexible demand potential

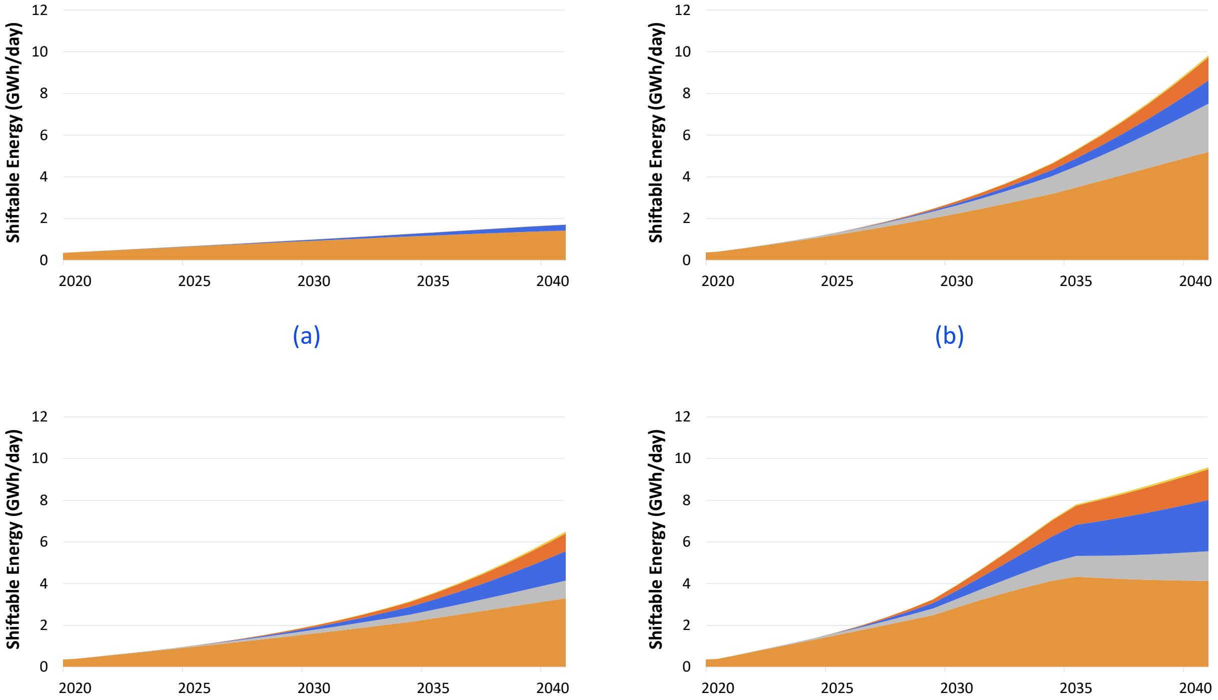


(a) (b)

(c) (d)

Figure 58. Projected flexible demand potential from DHW for Victoria. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Flexible demand depth

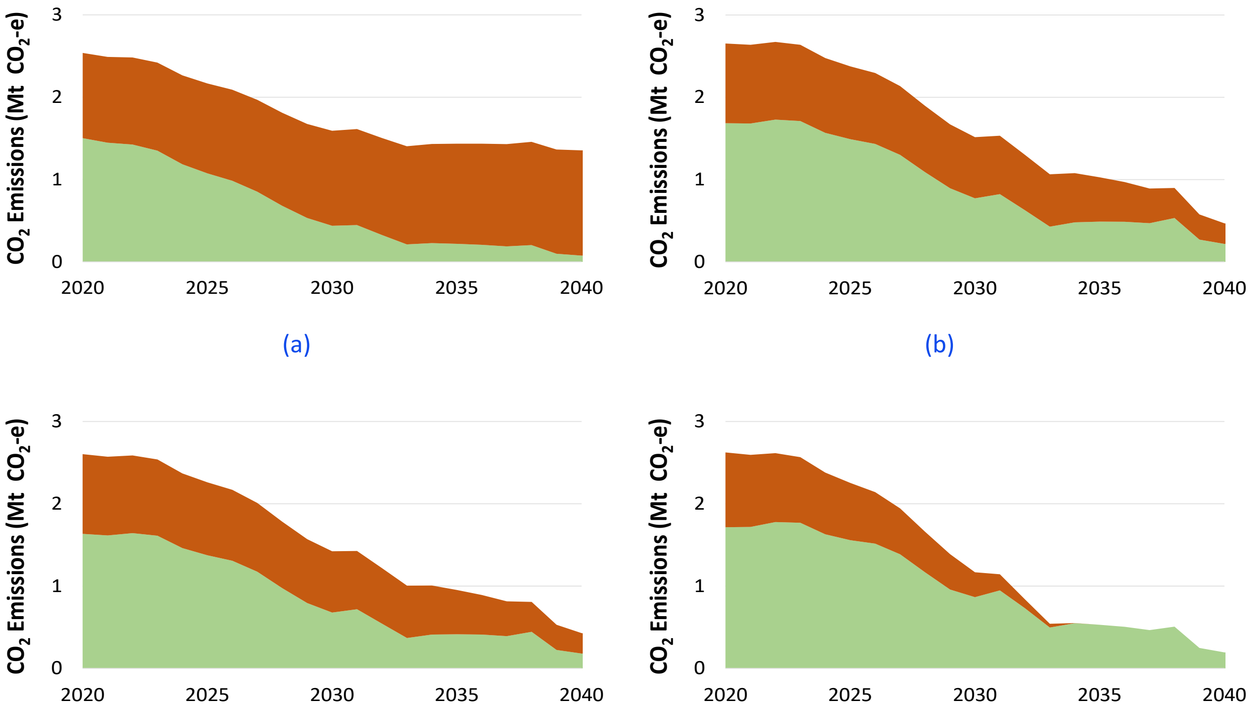


(a) (b)

(c) (d)

Figure 59. Projected flexible demand depth from DHW for Victoria. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Greenhouse gas emissions



(a)

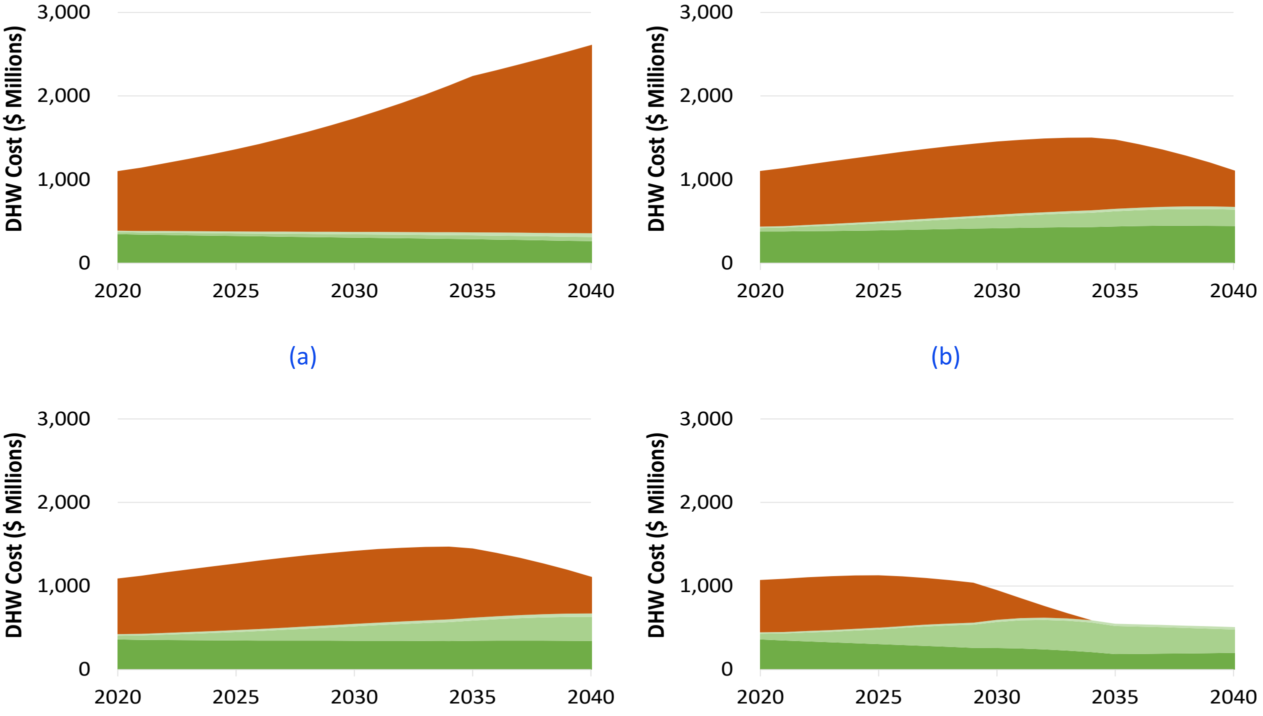
(b)

(c)

(d)

Figure 60. Projected greenhouse gas emissions from DHW for Victoria. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Operating costs



(a)

(b)

(c)

(d)

Figure 61. Projected total retail operating costs of DHW for Victoria. (a) Business as Usual. (b) Highly Flexible. (c) Highly Efficient. (d) Rapid Electrification.

Appendix C—System transformation

This section presents the detailed inputs and outputs from a sense-making workshop held with ARENA and ISF. The workshop was used to discuss the main findings from this research and to map out solution pathways and next steps.

System transformation model

As part of the workshop exercise, we used the system transformation model illustrated in **Figure 62**. In this model, the current system is represented by a set of **system drivers**, which are forces outside the system we cannot control, **business-as-usual** elements, which are mostly things we want to change, and **innovations**, which are things we can keep or build on as part of the system transformation. To transition to the **transformed system** will require a number of **actors** and **levers**, acting in concert.

System drivers

The **system drivers** are large-scale forces largely outside of the control of the system we are seeking to transform, namely DHW. The main system drivers identified are:

- **Climate change**—which underpins the urgent need to decarbonise the energy system.
- **Transition of the electricity system** (decarbonisation, decentralisation, digitalisation)—driven by the above, combined with low and falling renewable energy prices.

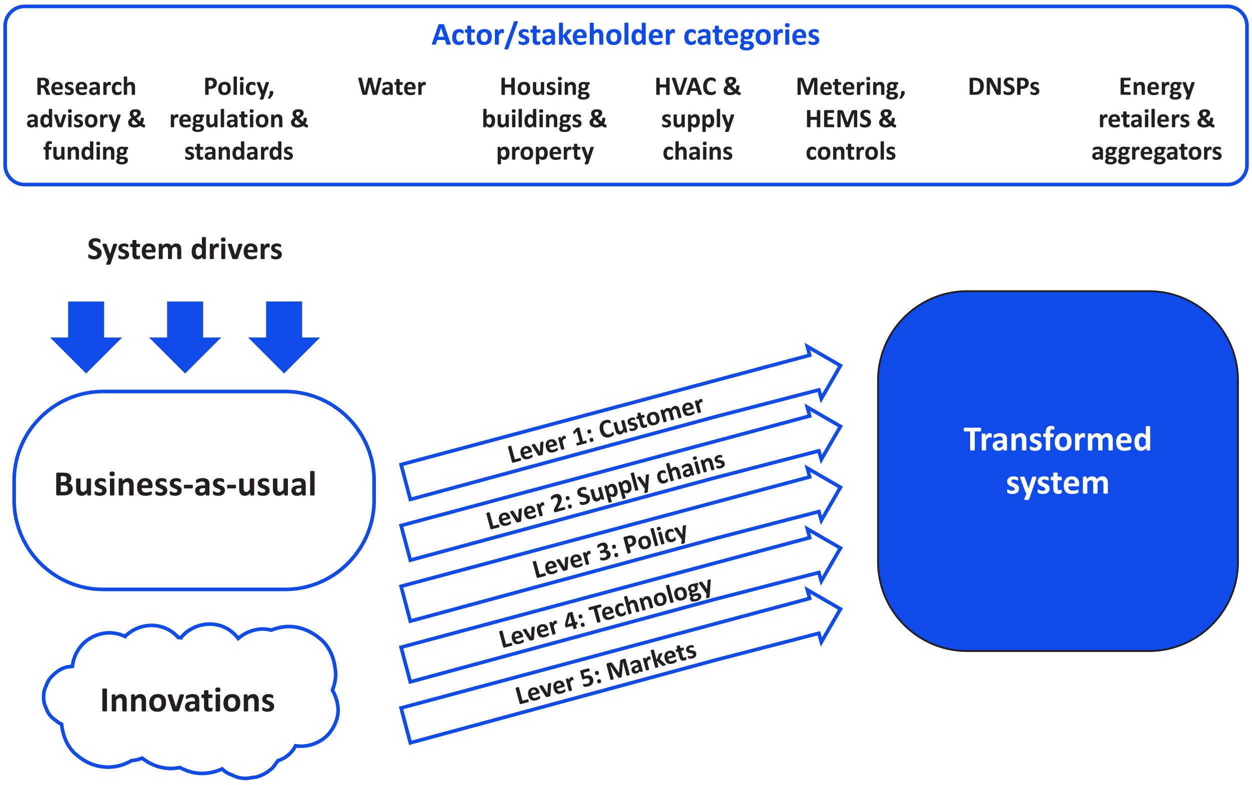


Figure 62. The system transformation model used for this project.

- **Current high electricity and gas prices**—particularly related to global events).
- **Technology advancements**—including improvements in heat pump and FD-enabling technologies.
- **Increasing population density**—which constrains the application of some technologies, including heat pumps.

Business-as-usual

The **business-as-usual** elements describe the main aspects of the current system we want to change. The main business-as-usual elements identified are as follows:

Customers

- complacent about energy efficiency and flexible demand.
- confused and lacking trust
- driven by short-term costs and 'easy-fix' options

Supply chains

- concentrated manufacturing base
- fragmented solution delivery, lacking innovation, variable quality
- existing stock of resistance DHW units, with like-for-like replacements
- global supply chain issues
- labour issues and skilled labour
- strong influence of installers

Policy

- lack of gas transition policies
- no MEPS for heat pumps,
- suitability of current quality standards
- no STCs by 2031
- different state policies
- NCC favourable to gas and a barrier for FD
- restrictive energy market rules (BTM vs IFTM)
- different starting points and rules for each state
- slow smart meter rollout

Technology

- cheap instantaneous gas increasingly dominant
- lack of data, and lack of consistent and uniform data collection

Market

- weak incentives
- disconnect between customers and network benefits
- gentailer conflicts of interest
- ineffective DR incentive scheme
- weak DNSP incentives
- split incentives (e.g. landlords versus renters)

Innovations

The **innovation** elements are the parts of the current system that we can keep or build on as part of the system transformation. The main innovation elements identified are:

Customers

- growing awareness – 'electrify everything'
- existing familiarity with off-peak DHW

Supply chains

- some local manufacturing
- innovative installers
- start-ups and new industry entrants, including smart meter providers

Policy

- STCs, white label schemes, energy efficiency programs
- state policies (e.g. ACT)
- NCC updates, NatHERs updates
- AS 4755
- state-based response and potential for different solutions in each state in terms of demand flexibility versus efficiency

Technology

- more efficient heat pumps
- integrated and retrofit DREDs

- HEMS, solar diverters
- battery integration

Market

- ongoing DHW FD trials
- aggregator/VPP business models
- solar-soak tariffs
- green loans
- retailers ‘dabbling’ with DHW FD
- business model innovation
- DR incentive scheme ineffective
- value of FD (different for retailers and DNSPs)

UTS Institute for Sustainable Futures

ARENA

Australian Government
Australian Renewable Energy Agency