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THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Water-Energy-Carbon Research Group

A STRATEGY FOR A NET ZERO GHG EMISSIONS WATER CYCLE – FINAL REPORT

APRIL 2021

Phase 1: Drivers for energy reduction in the use of water in residential households – Opportunities

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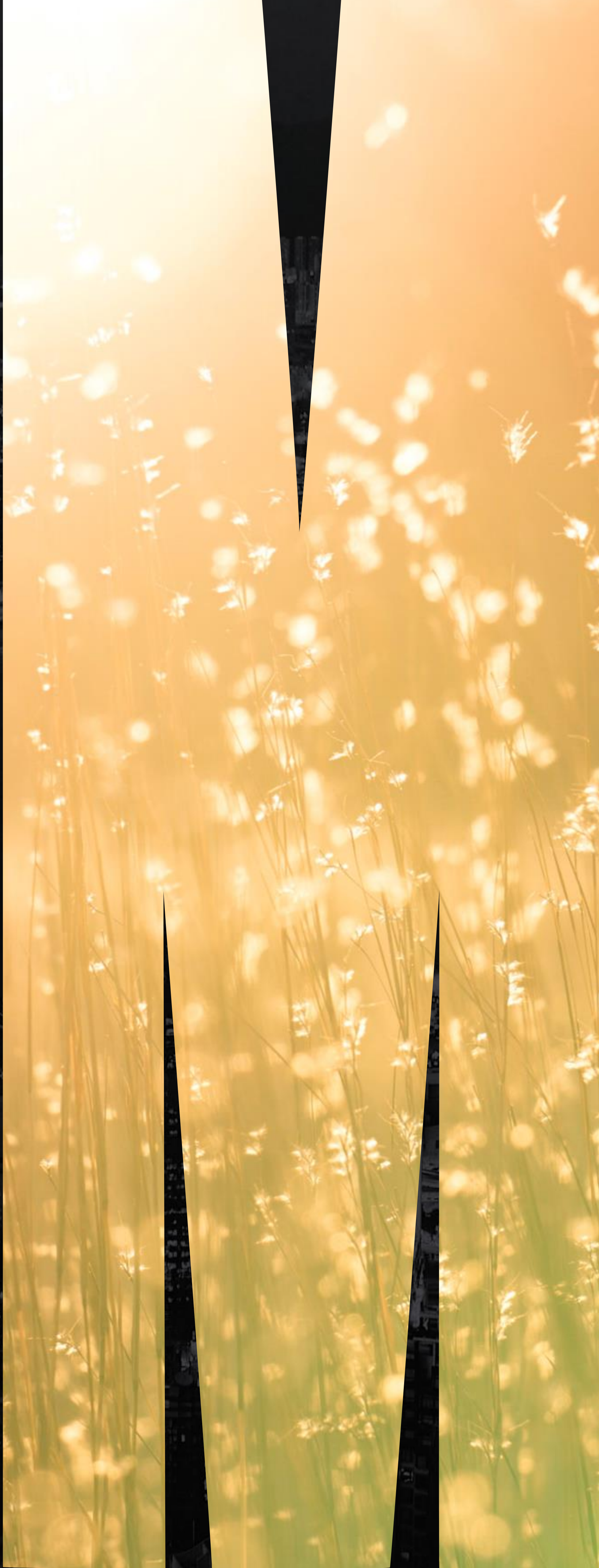

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Declarations of Conflict of Interest

The authors have no conflicts to declare.

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Executive Summary

Why is the Net Zero Water Cycle Program important?

The Victorian Government has committed to legislating a long-term target of net-zero greenhouse gas (GHG) emissions from Victoria by 2050. The State's water plan, Water for Victoria, recognises the obligation to achieve net-zero GHG emissions by 2050. The plan commits water corporations to (1) be leaders in both climate change mitigation and adaptation, (2) to demonstrate a pathway to net-zero emissions, and (3) to pledge an interim emission reduction target to be achieved by 2025, while being cognisant of vulnerable customers.

The aim of the Net Zero Water Cycle program is to help build on the innovation and leadership of the water sector in moving towards "net Zero GHG *organisations*". It seeks to grow the role of the water sector via multiple contributions towards Net Zero GHG emissions *cities*.

The Net Zero Water Cycle Program has three proposed Projects, this report focusses on Project 1, Residential Households. Project 1 has three distinct phases. **Phase 1** – *Opportunities Focus* is addressed in this report. **Phase 2** – *Options Focus* – (intended for delivery in 2021-2022) this report will establish the value proposition for this work to be undertaken. **Phase 3** – *Impact Focus* is intended as a series of large-scale interventions to reap the water, energy, GHG and other benefits identified in Phases 1 and 2.

Phase 1 aims to improve the understanding of the significant influence of residential water use on energy, and identify opportunities to reduce water-related energy and GHG emissions. It seeks to also identify key enabling policy and regulatory reforms to support utilities taking these proactive measures. It aims to understand the factors related to social disadvantage and contribute to a climate-ready economy and community.

What has been our approach?

The approach to Phase 1 has been to integrate across technical modelling analysis, behaviour change management and institutional reform methods. Specifically, this comprised the following steps: (i) establishing governance, (ii) applying criteria for site-selection for case study analysis, (iii) reviewing evidence and data and creating a mathematical model of water-related energy, related GHG emissions and costs in two case study areas (the suburbs of Reservoir and Frankston, each approximately 50,000 people). The method also included a (iv) review of behavioural literature and practice, and a (v) high level review of institutional arrangements and opportunities to support the proposed measures.

The analysis simulated various scenarios of shower technology and behaviour change such a shift to average 6.3 L/minute showers and all community members having shower duration of 4 minutes. These scenarios were intended to be illustrative only to communicate the quantum of opportunity if the change was able to be made. Further discussion with participating utilities is necessary to formulate realistic and implementable scenario options.

With all these steps complete it was possible to develop a catalogue of broad options to recommend for optimisation analysis in Phase 2.

What did we find?

A summary of water and water-related electricity and gas, and wastewater flows is presented in Table 2-1 for the two case study sites; in the suburbs of Reservoir and Frankston. Heating of water in households accounting for 55-65 GWh/energy across each case study site (approximately 3 KWh/person/day). This comprises approximately **18%** of total energy (electricity plus gas use) in the suburb of Reservoir, where measured data was available. Water-related GHG emissions was approximately 1.6 kgCO_2-e/person.day, **3.8%** of Victoria's total GHG emissions in 2018. In Reservoir, water-related electricity accounted for some 39% of the 57 GWh used in 2013. Water-related gas accounted for approximately 13% of total residential gas use in Reservoir used in 2013. We note the need for obtaining more recent data for suburb-scale residential electricity and gas use, as well as hot water system and appliance types, in order to fully validate the fraction of electricity and gas in the suburb, which is influenced by water.

Showers are the dominant water-related energy end use accounting for approximately half of the total. This is followed by **system losses**, **clothes washers** and **dishwashers** (27%, 9%, and 7% of water-related energy respectively). Clothes washers and dishwashers contribute a larger percentage of water-related GHG emissions because they draw disproportionately on coal-fired electrical energy.

To illustrate one example, we quantified the potential benefits from a shower intervention program in each case study. As an example, by shifting the residential population in the "Reservoir" case study to 6.3 L/min shower heads (Scenario 1) plus shifting behaviours to 4 minute showers (Scenario 2) this would save 0.4 GL water, 12 GWh energy and 4.3 ktCO_2-e/year. Specifically, this would involve influencing some 15,500 people (6,000 households) to reduce from the current average shower flow of 12 L/min, and some 22,000 people to reduce from a current average 10 minute shower duration (see Table ES-1). Ultimately, this means some sort of change for approximately 40% of the entire suburb of Reservoir. Very similar numbers were identified for the "Frankston" case study (with South East Water) while noting limited suburb specific data was available which was a key limiting factor. In both case studies, water utilities would also save additional energy from reduced water and wastewater treatment and pumping.

We note that these scenarios are intended to be illustrative of the potential opportunity for water efficiency to influence water-related energy and GHG emissions. In Phase 2 these initial scenarios need to be refined and developed with strong input from partners on key factors.

Assuming the Reservoir case study is representative, scaled up estimates of Scenario 2 to all of Melbourne and all of Victoria are shown in Table ES-2.

Table ES-1 Energy savings from potential shower interventions in Reservoir (Case Study 1).

Baseline for Reservoir (3073)						
Flow Rate (L/min)	Flow Duration (min)	% HH	No. of People	Water Use (ML/yr)	WRE Use (GWh/yr)	GHGs ($ktCO_2$-e/yr)
12	10	14	6,838	555	12.2	5.7
12	4	17	8,703	468	8.6	4.8
6.3	10	30	15,220	926	18.4	9.6
6.3	4	39	19,371	900	15.4	9.3
Totals		**100**	**50,132**	**2,849**	**54.6**	**29.5**
Scenario 1: Shower head Upgrade for Reservoir (3073)						
Flow Rate (L/min)	Flow Duration (min)	% HH	No. of People	Water Use (ML/yr)	WRE Use (GWh/yr)	GHGs ($ktCO_2$-e/yr)
6.3	10	44	22,058	1,357	22.4	14.1
6.3	4	56	28,074	1,311	27.1	13.5
Totals		**100**	**50,132**	**2,668**	**49.5**	**27.6**
Water, Energy, and GHG Savings from Scenario 1				**-181**	**-5.1**	**-1.8**
Scenario 2: Showerhead Upgrade + Behaviour Change Program for Reservoir (3073)						
Flow Rate (L/min)	Flow Duration (min)	% HH	No. of People	Water Use (ML/yr)	WRE Use (GWh/yr)	GHGs ($ktCO_2$-e/yr)
6.3	4	100	50,132	2,431	42.6	25.1
Totals		**100**	**50,132**	**2,431**	**42.6**	**25.1**
Water, Energy, and GHG Savings from Scenario 2				**-418**	**-12**	**-4.3**

Table ES-2 Predicted savings of water (and wastewater), energy and GHG emissions if Scenario 2 (a shower technology upgrade to 6.3 L/min and behaviour change program in Reservoir (to 4 minute showers)) could be scaled to all of Melbourne or Victoria.

	Melbourne (1.8 million households)	Victoria (2.4 million households)
Water (and wastewater)	61 (GL/yr)	80 (GL/yr)
Water-Related Energy	2,090 (GWh/yr)	2,763 (GWh/yr)
GHG Emissions	619 ($ktCO_2$-e/yr)	818 ($ktCO_2$-e/yr)

Achieving the savings identified in this modelled example depends on householders actually taking up the low-flow shower heads **and** changing their behaviour (all taking 4 minute showers) and committing to continue with these changes. In other words, it is necessary to “optimise” the specification of this low-flow shower head option by analysing the various technical **and** behavioural components of the option – and to identify the enabling factors that can best support its successful implementation. These matters will be explored in Phase 2 of this project.

Least cost analysis

Costs and benefits of water and energy cost savings to households of Scenario 1, a shower head exchange program, (see Table ES-1) were compared with existing GHG emissions reduction measures committed under the Pledge. Analysis was conducted (a) from "utility perspective" (considering only costs and benefits to water utilities), (b) from a "community perspective" (considering only costs and benefits to households), and (c) from a "combined perspective" (considering costs and benefits to water utilites and household, less water bill saving/revenue). In this analysis the shower head replacement program is the least-favoured option from a "utility perspective" and the most favoured (ie, the least cost) from the "community perspective" (see Figure ES-1).

Within Scenario 1, a detailed least cost analysis was performed on 20 household categories (ie, 4 household compositions and 5 hot water system types). It demonstrated how least cost analysis can be used to identify household categories for more cost-effective targeted implementation of management opportunities.

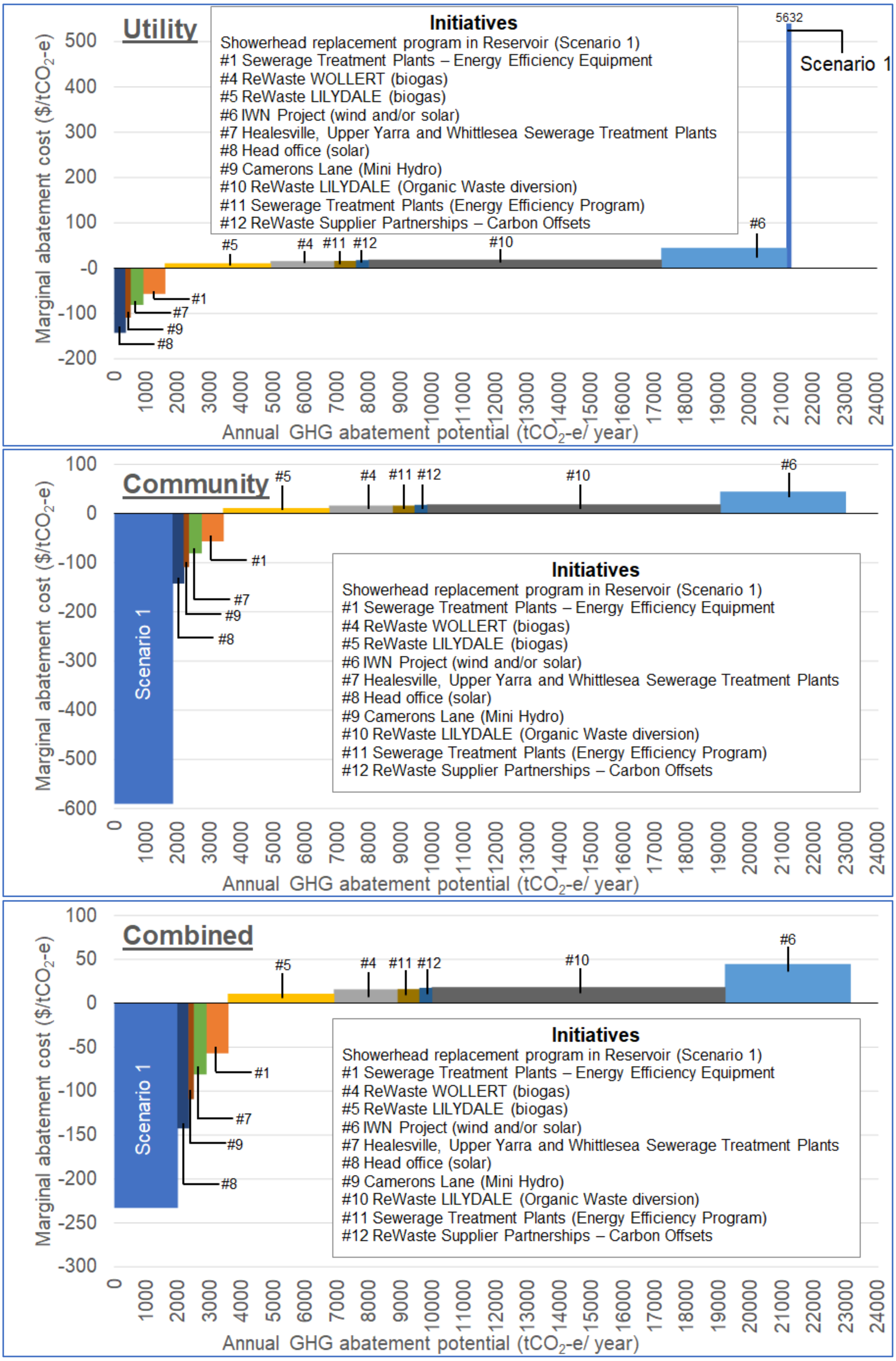

Figure ES-1 “Utility perspective”, “Community perspective”, and “combined perspective” marginal GHG abatement cost comparing current Yarra Valley Water energy/GHG initiatives (in the GHG Pledge) and Scenario 1 (a program of replacing shower heads for 15,500 people (~6,000 households) in the suburb of Reservoir (see Table ES-1).

Behavioural review

A second strand of Phase 1 was to review literature and conduct interviews with practitioners in water-related energy to identify:

- The behaviours that have been targeted and interventions that have been used to reduce households' water-related energy consumption.
- Interventions that have been used to successfully influence water-related energy behaviours.

We found that, although the concept of water-related energy is understood, there is very little literature or practice-based evidence. That said, several water-related energy behaviours have been targeted, primarily to reduce water consumption. Of these, showering was the most commonly cited behaviour, followed by washing clothes and dishwashing. The most common programs addressing household water-related energy use were: (i) installing efficient appliances, or encouraging shorter showers, and (ii) reducing the upfront cost of installing retrofits, particularly for vulnerable households. As indicated, most programs have generally focussed on water-saving messaging rather than an energy-saving message and emphasise collectivism and importance of individual actions in achieving collective outcomes.

In terms of interventions, innovative approaches and best-practice global management of water-related energy use include: use of digital metering to provide information and related incentives and allowing for gamification as well as innovative approaches to water pricing. The importance of working with communities to develop relevant programs, or bundling different approaches into a cohesive strategy was also seen as important.

At present, very few water efficiency programs engage different households differently depending on variables such as household size, language, religion and location. However, some segmentation of marketing messages based on water use and income has been undertaken. The Victorian Department of Environment Land and Water Planning (DELWP) and water authorities target low-income households to provide financial and practical assistance for water-efficient retrofitting. Practice review interviewees indicated that water authorities in Victoria are well positioned to support households to reduce water-related energy use. A key constraint to this initiative was a lack of reliable, long-term, funding for efficiency programs and to maintain the necessary skills and information.

Key enabling opportunities

A third strand to Phase 1 was to assess for structural barriers and enablers to assist with wider roll-out of water-related energy interventions. Key institutional opportunities identified included:

i. A reform agenda to the State Victorian Energy Efficiency Transfer (VEET) scheme to incentivise technical innovation roll-out for utilities.

ii. The development of a methodology to support the generation of emissions credits from household water-energy efficiency programs as part of the Federal Emissions Reductions Fund (ERF).

iii. The tailoring interventions and/or installations for particular vulnerable groups. A range of schemes (such as Solar Vic) are understood to be taking a similar approach.

Both the VEET and ERF schemes are potential future enablers to encourage water utilities to put more time and effort into WRE. It is worth noting that there appears to be no current major limitation (other than funding and financial/business signals) stopping utilities implementing a shower head replacement scheme or other similar interventions right now.

Underpinning these and other opportunities identified as part of this analysis is a series of governance related opportunities identified as 'catalysts' for transformative change.

A broad spectrum of opportunities exists to influence energy, GHG and costs

This review identified a broad range of opportunities including options such as (i) behavioural incentives, (ii) increased uptake of water efficient technologies, (iii) reduce losses through a range of technical and behavioural approaches, (iv) metering and related pricing signals, (v) changes to hot water system energy source (eg, solar or heat pump), (vi) manipulation of delivered cold-water supply temperature, (vii) institutional changes, and (viii) combinations of all options.

What major gaps were identified?

The study has identified gaps in the management of water-related energy and GHG emissions that need to be taken into account in the second phase of the project.

- There is a **paucity of comprehensive technical data and knowledge** of energy and carbon efficiency through the entire water cycle – particularly end use. Such knowledge is key for comparing across "utility-scale" and "household/community"-scale management options.
- **Current understanding of behaviour, and changes necessary for customers or customer segments to adopt new techniques or systems is low**. This is important if utilities plan to interface in ways which help achieve efficiencies while simultaneously improving affordability and wellbeing.
- **Governance and leadership to achieve combined efficiencies across water and the related energy impact that it has**. This is both in utilities and State Agencies. Water-related energy.
- **There is a wide range of confusing terms spanning** "carbon neutral", "net zero", and "100% renewable" energy and GHG emissions water and water cycle. Improved clarity of these concepts and more consistent use of terms would be helpful to ensure alignment of agency programs.

This project is taking steps to address these gaps. It offers a customer-focussed opportunity to achieve significant savings by in reducing consumption of both water and related energy.

What is the rational for going forward?

Economic, social and environmental reasons for progressing to Phases 2 and 3 are:

- It would strengthen customer-centric solutions and more customised end use management.
- The solutions are least cost from a community perspective.
- It would add value to the planned digital meter roll-out.
- The program would simultaneously contribute significantly towards State goals.
- It would bring forward integrated resources planning.
- It would help inform future water strategies.
- It would, if scaled up, cost-effectively offset Melbourne's next water augmentation and delay needs for energy upgrades.
- Create new areas of trans-disciplinary work across the water-energy sector and spanning institutional, social and physical science components.

- Find new optimal solutions and strengthen the rationale for investment pathways.
- It would create a strong research-industry government partnership.
- It would put information into the public domain and help drive innovation.

The key reasons for progressing the work to Phase 2 and 3 are:

- Financial/economic – as the approach represents least-cost GHG management from a community perspective while additionally delaying infrastructure investment needs.
- Social – strengthening customer-centric approaches and improving affordability for communities.
- Environmental – by contributing significantly to State goals and integrated resources planning.
- Driving innovation – by putting relevant information into the public domain and providing supporting enabling environments.

What do we recommend?

Primary recommendations include:

1 The project should progress to Phase 2 (optimisation of options).

Phase 1 has demonstrated a compelling case, showcasing opportunities to reduce water related energy in households, using robust scientific rigour. Specifically, during Phase 2 (and 3) the project should keep in mind system-wide impacts (eg, energy load shifting, water asset implications, and social and wellbeing implications, not just water and energy efficiency). This could include hot water as an energy storage option enabling more renewables into the energy supply side. Wherever possible the project outcomes should inform the Metropolitan Urban Water System Strategy currently being developed by the water utilities. Finally, a cornerstone of the project is the enabling of systematic and long-term behaviour change and the project can play a significant role in achieving circular economy outcomes.

2 Phase 2 optimisation of options should focus on Shower Systems, Clothes Washer Systems, Dishwasher Systems and related losses.

Phase 1 has identified these are the areas where GHG reduction, residential cost saving, energy efficiency saving, and water-based benefits are collectively greatest. For example, as demonstrated in case study 1 (Reservoir), shifting the entire population to 6.3 L/min shower heads and 4 minute shower duration has the potential to save 12 GWh/yr energy, 0.4 GL water (and wastewater) and reduce 4.3 ktCO_2-e (in the suburb). If applied across all of Melbourne, it would save an estimated 61 GL/yr in water savings and 619 ktCO_2–e.

The optimisation of options should integrate technical and behavioural opportunities to understand the singular and combined influence of each. The optimisation of options in Phase 2 should consider in detail the impacts and opportunities for vulnerable/disadvantaged groups to ensure the solutions improve overall wellbeing and affordability.

3 Phase 2 should undertake small scale pilots with the aim of implementing preferred interventions during Phase 3 at a suburb-scale.

Interventions in Phase 3 are intended at the scale of the entire suburb, initially in Reservoir and followed by Frankston. A third case study in Greater Western Water's jurisdiction could be considered but has not been scoped in this proposal. During Phase 2, small scale pilots (eg, a shower head exchange of ~100 to 500 households) is anticipated led by partnering utilities and with associated digital meter installation. This will enable and support a related monitoring program (led by the research partners) to capture key data (eg, with Amphiro unit installation) and quantify impacts on energy, GHG emissions.

4 Further analysis and, if appropriate, changes to the enabling environment should be pursued throughout Phases 2 and 3.

Appropriately supportive enabling environments are absolutely key to achieving sustained and state-wide benefits of this research. Preliminary reviews suggest there are opportunities for appropriate changes in these areas. For example, the project presents an opportunity to explore a shift towards a situation that would allow water utilities to claim wider community value of such initiatives (ie, wider than a utility-focus alone).

5 The opportunities of Water in a Net Zero GHG city should be progressively articulated and documented.

This recommendation recognises that this project creates opportunities for far greater changes than to the VEEC (Victorian energy efficiency certificates) program in the area of shower head efficiency. If all the opportunities present in residential water management which can save water, energy and GHG emissions are considered, there is a very large scope for change – however, changes to the enabling environment are necessary for this to occur. An even greater role of the water sector in net zero cities could be created if utilities are also given scope to influence water-related energy in the industrial and commercial sectors, and in landscape-level cooling. However, this opportunity, how it is defined, managed and regulated, needs far better description which will explored in Phase 2.

Supplementary Recommendations

Additional recommendations relating to work to be undertaken in Phase 2, related to the enabling environment, behavioural factors method, data and modelling to be progressed are presented below.

Enabling environment factors - areas of further exploration under Phase 2 should include:

- The ongoing review of VEEC/VEET regulatory measures and the piloting of a program to test new methodologies to support technical innovation upgrades in household appliance stock (to determine how people will use them, whether efficient household upgrades stay installed, and can we quantify the benefits).
- Advocacy and cross-sector collaboration to support the development of an Emissions Reduction Fund (ERF) (Federal) approved methodology for household appliance upgrades.
- Supporting intergovernmental practice and leadership culture to drive a customer–centric approach to water energy servicing.
- Scaling innovation to support whole of system or state-wide benefits and outcomes.
- A working group to support best practice Household Appliance Stock Regulation and Policy.
- Develop a stakeholder communications and engagement strategy.
- Supporting concession, low-income and rental households.

Behavioural focus areas to support Phase 2 outcomes should include:

- Developing a strategy that combines multiple approaches but evaluates the contributions of individual interventions.
- Selecting digital metering installations that allow water authorities to provide individualised feedback to households.
- Establishing positive social norms (good examples) around water-related energy use.

Improved data - Focus areas to support Phase 2 include:

- Demographic data such as the number of people per household to accompany household scale water or energy use data.
- Collection of data from a larger number of customers and wider representation of socio-economic groups.
- Sourcing suburb-scale verification data (water use, electricity use, natural gas use) broken down by different socio-demographic groups and also by end use (this is very important).
- Improving access to current and historical digital meter data collected by utilities.
- Accelerating data access, and creation of primary data (including use of metered data).

Modelling analysis and monitoring focus areas to support Phase 2 outcomes include:

- Improving the project's understanding of the impacts of potential interventions on different socio-economic groups.
- Designing a detailed monitoring program.
- Simulating a range of new technologies particularly heat pump systems.
- Clarifying the scale of analysis and agreement on who will use the data.
- Analysing additional household characteristics and intervention options using improved data.
- Modelling interventions that target a wider range of behavioural changes.

Tables and Figures

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Units, Measures, and Definitions

List of Abbreviations

ABS	Australian Bureau of Statistics
BOM	Bureau of Meteorology
DHHS	Department of Health and Human Services
Elec-S	Electric hot water system – Storage
ESC	Essential Services Commission
Gas-C	Gas hot water system – Continuous
Gas-S	Gas hot water system – Storage
GHG	Greenhouse Gas
GIS	Geographic Information System
H1	Household type 1 of 16 shower use and clothes washing variations
MAC curve	Marginal abatement cost curve
MMFA	Mathematical Material Flow Analysis
NCOS	National Carbon Offset Standard
P1	Parameter 1 of 145 input parameters for the ResWE model
ResWE	Residential Water and Energy model (created by UQ to model Residential Water-Related Energy).
S1	Scenario 1 (A showerhead replacement program). The first of 7 scenarios simulated.
SA1	Statistical Area level 1 (A geographic area defined by the ABS, approximately 500 hh).
SEIFA	Socio-Economic Indexes for Areas
Solar PV	Solar photovoltaic system
Sol-E	Solar hot water system – Electric boost
Sol-G	Solar hot water system – Gas boost
WRE	Water-Related Energy
WRE-GHG	Water-Related Energy – Greenhouse Gas
YVW	Yarra Valley Water

Units

%	Percent
°C	Degrees Celsius
CO_2-e	Carbon dioxide equivalent
kgCO_2-e/person.day	Kilograms of carbon dioxide equivalent per person per day
GL/yr	Gigalitres per year
GJ/yr	Gigajoules per year
GWh/yr	Gigawatt hours per year
ktCO_2-e/yr	Kilotonnes of carbon dioxide equivalent per year
kWh/day	Kilowatt hours per day
kWh/hh.day	Kilowatt hours per household per day
kWh/hh.yr	Kilowatt hours per household per year
kWh/ML	Kilowatt hours per megalitre
kWh/person.day	Kilowatt hours per person per day
L/day	Litres per day
L/min	Litres per minute
m^2	Metres squared
min/yr	Minutes per year
$W/m^{2}°K$	Watts per metre squared kelvin
wk^{-1}	Per week

Contributing Partners

Victoria State Government — Environment, Land, Water and Planning

The University of Queensland Australia

Monash University

Yarra Valley Water

City West Water

South East Water

BehaviourWorks Australia

Monash Sustainable Development Institute

Section 1 – Aims, Approach and Overview Results

1 Introduction

1.1 About this Study and the NZWC Program

The Victorian Government and other governments in Australia have committed to achieving net-zero GHG emissions by 2050. Prior to commencing this (Phase 1) work it was estimated that approximately 0.5-1% of Victoria's GHG emissions relate to water supply and sewerage treatment by the State's water utilities, while a further 7.5% are related to the use of water in residential, industrial and commercial premises (estimation based on Kenway et al 2011, and Kenway et al 2015).[1] **Phase 1 results of this project indicate water-related energy in residential households account for approximately 4% of Victoria's per capita GHG emissions, largely related to water heating using gas and coal-fired electricity.**

The Victorian Government's water strategy, *Water for Victoria*, requires water corporations to commit to a pathway to the 2050 net-zero emissions commitment and to pledge an interim emission reduction target to be achieved by 2025 (Figure 1-1). Many water utilities in Victoria are on a pathway to be Net Zero organisations when Scope 1 and 2 GHG emissions are accounted for (Figure 1-2). Typically, a water utility would consider Scope 1 and 2 emissions within their "zone of control", whereas Scope 3 emissions are typically considered more of indirectly, possibly within a "zone of influence". The view that Scope 1 and 2 emissions are more "controllable" by water utilities is also further reinforced by Federal Emissions management programs and protocols which require reporting on Scope 1 and 2 emissions but do not yet have methods for systematic tracking or reporting of Scope 3 emissions. As water utilities comprise some 24% of GHG emissions from Victorian Government (see *Climate change and the Victorian water sector*) there is a clear role for the water sector to take a lead role in Government strategies for GHG emissions management.

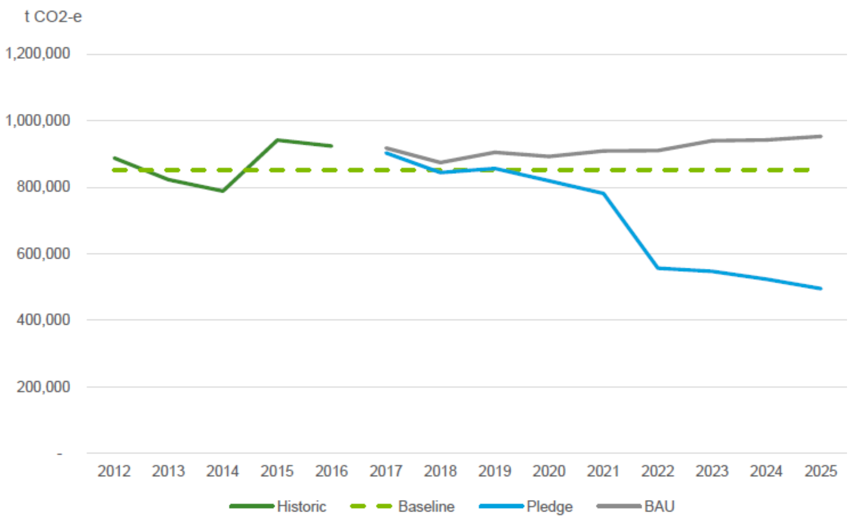

Figure 1-1: Victorian Water Industry forecast (Scope 1 and 2, direct + supplied energy) emissions profile (Deloitte Access Economics 2017).

1 Kenway et al, 2011 (Table 4), and Kenway 2015 for details for South East Queensland. See also Kenway et al 2019 for global perspective, Kenway 2008 for background, Binks et al 2015 and 2016 for household level analysis and Bors et al 2018 for the influence of cold water temperature and suburb-scale analysis.

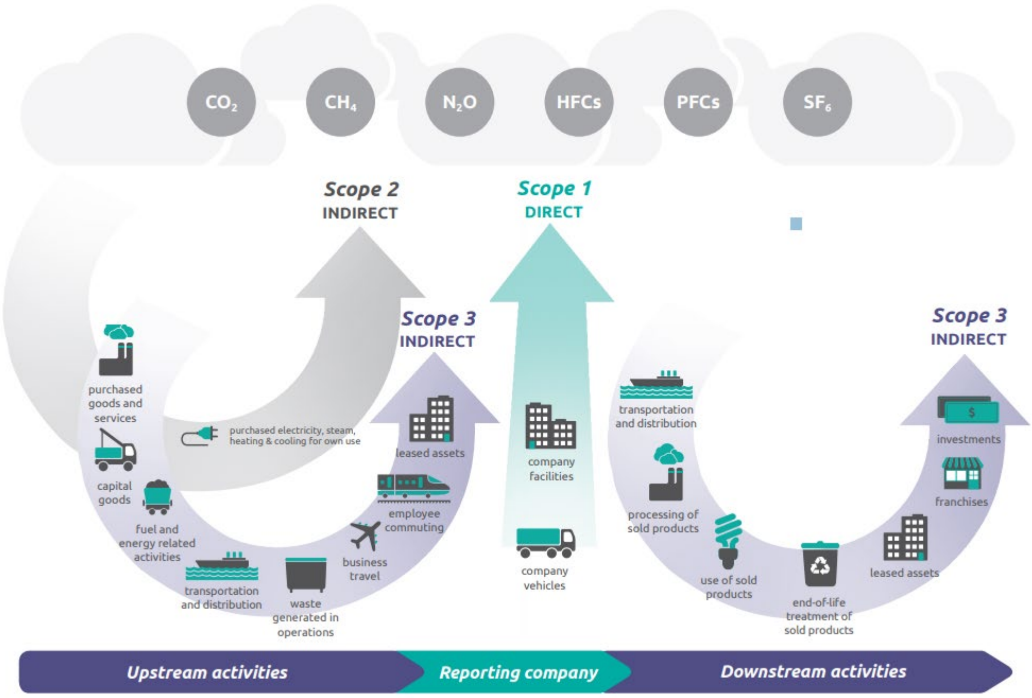

Figure 1-2: Depiction of Scope 1, 2 and 3 emissions. Source **(accessed 8 February 2020).**

However, as important as these Water Corporations savings are, the Net Zero Water Cycle Program being presented here aims to achieve an even greater potential savings opportunity (the prize), which is to significantly reduce – towards zero – the amount of GHGs emitted through *the entire water cycle*. It seeks to achieve this by developing innovative new methods to influence energy use and GHG emissions via the use of water in: (i) residential households (Project 1), (ii) industry and businesses (Project 2), and (iii) the cooling of urban areas, by the irrigation of green infrastructure in residential precincts (Project 3). This report focuses on Phase 1 of Project 1 – the drivers for the reduction of water-related energy GHGs in residential households (Figure 1-3).

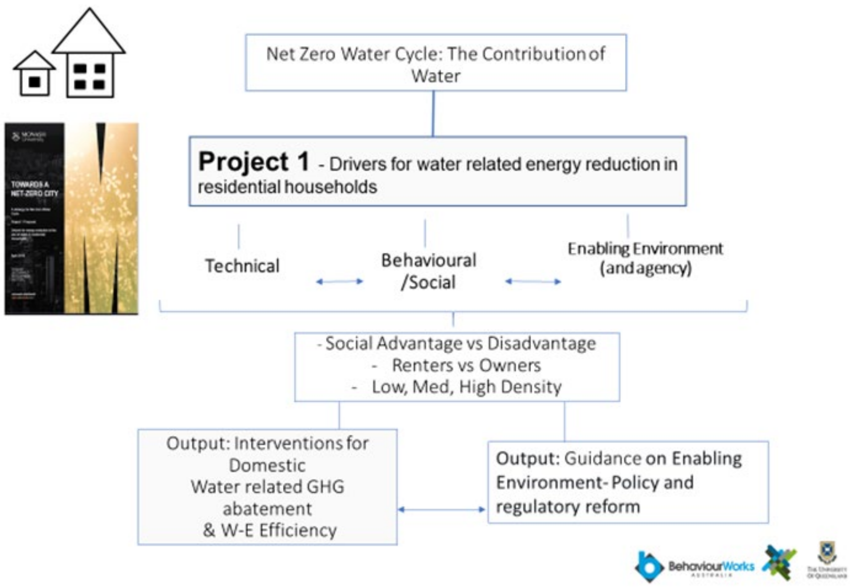

Figure 1-3: The three key elements of the project (technical analysis of water-energy-GHG links, behavioural/social analysis and the related enabling environment and agency).

Project 1 has three distinct phases:

Phase 1 – *Opportunities Focus* – (this report) aims to identify baseline water-energy-GHG flows and related costs guided by available data. It also seeks to review current literature and practice in the domain of water management for energy outcomes in the residential sector, and related broad institutional/enabling environment (and agency) opportunities and contextual drivers.

Phase 2 – *Options Focus* – (intended in 2021-2022) – this phase will develop options and assess potential benefits and source new information (data) to fill key gaps including strategic field work. It seeks to identify the drivers of selected target behaviours with a view to matching behaviour change tools to variables that influence behaviour. Finally, it is intended to design and help plan intervention trials anticipated to be run by partner utilities.

Phase 3 – *Impact Focus* – will implement interventions, monitor behavioural outcomes, and evaluate and report results.

The Victorian Department of Environment Land and Water Planning (DELWP) have funded Phase 1 of this project. At present Phases 2 and 3 are not yet committed. A funding proposal (prospectus) has been provided to DELWP and participating utilities to implement Phase 2 to follow on the completion of Phase 1. The prospectus also puts forward options for funding research elements (particularly during Phase 3) with support from an ARC Linkage Grant (ARC Linkage CRC-P (CRC-Project funding). The recommendations of this Phase 1 report together with the prospectus will shape subsequent analysis phases.

1.2 Research Aims – the Major Prize we are Aiming for

The overall aim of Project 1 is to identify the opportunity for technical, behavioural, and enabling environment (and agency or "motivation to act") factors that lead to sustainable reductions in water-related energy (electricity and gas) and GHGs from residential households. The program will provide clear and proven technical, behavioural and enabling environment interventions for water-related GHG abatement and water efficiency together with guidance and recommendations that relate to:

- Understand water-energy links in individual households.
- Opportunities to reduce water-related energy GHGs.
- Enabling environment policy and regulatory reforms.
- Factors related to social disadvantage of individuals and households.
- Contribution to climate-ready economy and community.

The core aim of Phase 1 is to investigate opportunities for the overall reduction in water, water-related energy demand, and associated GHGs in the residential sector. In the broader context, this research hypothesises that a concerted effort in applying interventions to reduce residential water-related energy (eg, upgrading shower technology and behaviour) will make a significant contribution to reducing GHGs and becoming a key climate-ready economy and community initiative. It also has potential for significant asset deferrals (eg, deferral of a new desalination and new powerplant build).

1.3 Approach Taken to the Study

The approach to Phase 1 has been to integrate across technical modelling analysis, behaviour change management and institutional reform methods. Specifically, this comprised the following steps:

1. Establish project governance.
2. Develop and apply criteria for site-selection for case study analysis.
3. Review evidence and data and conduct research to create an overview mathematical model of water-related energy, related GHG emissions and costs in the case study areas.
4. Review of behavioural literature and practice.
5. Review of institutional arrangements and opportunities to support the proposed measures.
6. Develop a catalogue of options to consider in Phase 2.

1.2.1 Project Governance

This project is a collaboration spanning DELWP, Monash University (MSDI and Behaviour Works), The University of Queensland (Advanced Water Management Centre), Victorian Water retail utilities and others. A project governance structure and related terms of reference was established including:

- A Program Leadership Group (PLG) to provide high-level direction and guidance.
- A Stakeholder Working Group (SWG) to represent participants and shape the research.
- A Program Management Group (PMG) to coordinate between DELWP and the universities.

Case study groups also met regularly to provide information and data across the diverse groups within water utilities (eg, spanning water use data, energy management, vulnerable communities, digital metering, and communication).

1.2.2 Criteria for Case Study Selection

Criteria were developed consultatively to shape selection of areas for analysis (in Phase 1) and potential longer-term monitoring and intervention (in Phases 2 and 3). Key criteria included (see also Case Study reports):

- Opportunity for the application of new pathways for innovative water-energy saving opportunities which have been difficult to develop in the past.
- Availability of detailed data to model and verify results across water use, electricity use, gas use, and understanding of water-related energy GHGs.
- Benefits to residents in the area and across Melbourne. Builds the capacity to engage with vulnerable communities.
- Ability to scale solutions at later stages, ie, applicability of the results to greater Melbourne.
- Area subject to development pressure.
- Utility willingness to provide in-kind technical support/data ideally over the planned duration of the Project (~3 years).

After considering these criteria Phase 1 has used two case study area **Reservoir** and **Frankston**. Summary statistics are presented in Chapter 2.1.

1.2.3 Review Data and Create an Overview Mathematical Model to Quantify Technical Opportunities

The Phase 1 technical analysis involved:

- Reviewing literature on modelling household energy demand, particularly the water-related fraction.

- Developing an overall conceptual model to guide analysis including energy used by water utilities to provide water and wastewater services, together with energy used by households when water is used (see also Kenway et al 2019).
- Reviewing and compiling data relevant to water use, energy use, household stock and behaviours within the identified case study sites (in accordance with a data management plan). Data draws on previous modelling analysis updated to current timeframes including household characteristics (eg, population, demographics), hot water systems (energy sources, plumbing arrangements), showering (frequency, rate, duration, temperature), bathing, clothes washing, tap water use, toilet use, outdoor water use, air-conditioning and other energy uses, etc (a full list of parameters used in the models built can be seen in Kenway et al (2013)).
- Assembling data and information in accordance with the overarching conceptual model.
- Undertaking scenario (options) analysis for targeted potential interventions focussed primarily on shower and clothes-washer systems.
- Using the overview models developed (of the suburbs Reservoir and Frankston) to quantify existing water use, and related energy use, GHG emissions and costs. It provided a foundational understanding for the order of magnitude influence of potential intervention measures. The analysis created a baseline performance. It also helped identify data gaps.
- Reviewing (at high level) selected major existing water efficiency implemented by DELWP and utilities in order to approximate the savings of water, energy, GHG and related costs in a least cost analysis. As very few existing water efficiency programs of scale were identified we additionally briefly reviewed existing major energy and GHG efficiency measures.

1.2.4 Review of Behavioural Literature and Practice

A literature and practice review was undertaken to identify behaviours and interventions (or programs) that have been targeted to reduce water-related energy and water-related GHG emissions. The literature and practice review focussed on the behaviours that increase or decrease water-related energy use. This includes daily behaviours, such as showering or washing clothes, and one-off behaviours, such as installing low-flow shower heads.

1.2.5 Review of Enabling Environment and Opportunities

In close collaboration with DEWLP (and utilities), this review involved three interlocking components:

(i) Systems analysis – a review of relevant legislative, policy, regulatory, programmatic and institutional arrangements that define current practice, and thus shape opportunities for Victorian households.

(ii) Stakeholder analysis – discussions with key stakeholders across the public sector, water and energy utilities, regulatory bodies (eg, Essential Services Commission (ESC)) and community support organisations.

(iii) Opportunities analysis to identify key points of leverage for system optimisation in supporting future water-related energy efficiency outcome in households.

1.2.6 Develop a Catalogue of Options to Consider in Phase 2

Drawing on opportunities identified from the three reviews above, a preliminary listing of options developed has been for further in-depth examination and intervention (in Phases 2 and 3).

2 Overview Opportunity for Energy, Water and GHG Savings

2.1. Physical/Technical Opportunities

A summary of water and water-related electricity and gas, and wastewater flows is presented in Table 2-1 for the two case study sites; in the suburbs of Reservoir and Frankston. Water-related energy accounted for approximately 18% of total energy (electricity plus gas use) in the suburb of Reservoir, where measured data was available. Water-related GHG emissions was approximately 1.6 kgCO_2-e/person.day, 3.8% of Victoria's total GHG emissions in 2018. In Reservoir, water-related electricity accounted for some 39% of the 57 GWh used in 2013. Water-related gas accounted for approximately 13% of total residential gas use in Reservoir used in 2013. We note the need for obtaining more recent data for suburb-scale residential electricity and gas use, as well as hot water system and appliance types, in order to fully validate the fraction of electricity and gas in the suburb, which is influenced by water. Differences between Reservoir (case study 1) and Frankston are relatively small (partly due to lack of suburb specific data), however can be explained by differences in household distribution of family with children households (24% Reservoir compared with 39% Frankston, Tables 5-3 to Table 5-4), and the percentage of households with solar hot water systems (26% Reservoir compared with 13% Frankston, Table 5-5), hot water system and appliance stocks, and water use patterns.

A more detailed breakdown of water-related energy for Reservoir (suburb) was estimated drawing on previous modelling (Bors 2019) (Table 2-2). This demonstrated that showers are the dominant water-related energy end use accounting for approximately half of the total. This is followed by an estimate of losses (27%) for clothes washers and dishwashers.

2.2 Behavioural Opportunities

A rapid literature review was undertaken to identify, evaluate and synthesise published literature addressing the following question: *What are the behaviours that have been targeted and interventions that have been used to reduce households' water-related energy consumption?*

The aim for this review was to identify behaviours that are targeted to reduce water-related energy consumption and interventions that aim to increase the uptake of the target behaviour. In addition, we included factors (behavioural drivers) commonly reported to influence these target behaviours as they provide important information for intervention design.

Search terms were identified in collaboration with the project management and stakeholder working group and the key search terms combined 'energy', 'water', 'intervention' and 'households'. The database search produced 2,618 citations. Following screening, no systematic reviews were identified and five narrative reviews with a focus on water and/or energy conservation intervention were eligible for inclusion. It was necessary to supplement the reviews with more specific studies. In addition to the included reviews a further 10 primary studies and two industry reports were identified.

The majority of the papers included in this review did not target a specific behaviour, rather they focused on decreasing water and/or energy consumption in general. In general, these behaviours were those that were classed as discretionary, such as showering, clothes washing, dishwashing, using taps, bathing and adopting efficiency technology.

Table 2-1: Summary of case study sites quantifying existing water, energy, and GHG flows (c 2016).

			Case Study Site*	
		Units	Reservoir	Frankston
People	Postcode area analysed	-	3073	3199
	Number of households (~2016)	-	20,845	24,438
	Number of people (~2016)	-	50,132	54,298
Regional water and energy use (residential sector)[a]				
Water	Water use (modelled – 2020)	GL/yr	2.8	3.1
	Water use (measured – residential 2013)[b]	GL/yr	3.0	3.5
Energy	Total energy use (electricity + gas)	GWh/yr	303.4	NA
	Water-related energy use (electricity + gas)	GWh/yr	54.6	64.2
	Water-related energy use (electricity + gas as a percentage)	%	~18	NA
Electricity	Total electricity use (measured - residential 2013)[c]	GWh/yr	56.8	NA
	Water-related electricity use (modelled – 2020)	GWh/yr	21.9	21.7
	Water-related electricity use (as a percentage)	%	~39	NA
Gas	Total gas use (measured - residential 2013)[d]	GWh/yr	246.6	NA
	Water-related gas use (modelled – 2020)	GWh/yr	32.7	42.5
	Water-related gas use (as a percentage)	%	~13	NA
GHG	Water-related energy GHG emissions	$ktCO_2$-e/yr	29.5	31.4
Resource use per capita (residential sector)[a]				
	Water use	L/person.day	156	155
	Water-related electricity use	kWh/person.day	1.20	1.10
	Water-related gas use	kWh/person.day	1.79	2.14
	Water-related energy (electricity + gas)	kWh/person.day	2.99	3.24
	Water-related GHG emissions[e]	$kgCO_2$-e/person.day	1.61	1.58
	Victorian GHG emissions	Gg CO_2-e	102,119	

[a] Modelled results pending verifcation through measured data in Phase 2; [b] (YVW 2014; SEW 2021a); [c](Jemena 2014); noting approximately 95% coverage of smart electricity meeters may slightly underestimate the total. [d] (APA Group 2015), [e]This equates to ~3.75% of Victoria's GHG emissions (102,119 Gg in 2018) drawing on Federal Government Reporting of Victorian GHG emissions Link using United Nations Framework Convention on Climate Change *For case study modelled results refer to the overview model analysis in this report.

Table 2-2: Quantum of water-related energy in Reservoir by end use.

Component	Electricity + Gas (GWh/yr)*	%	kWh/hh.day
Shower	28.9	45	4.0
Bath	2.5	4	0.3
Clothes washer	6.0	9	0.8
Taps	2.8	4	0.4
Dishwasher	4.3	7	0.6
Kettle	2.0	3	0.3
Air conditioning (water-related)	0.7	1	0.1
Losses estimate (pipe, storage, efficiency)	17.5	27	2.4
Total	**64.6**	**100**	**8.8**
*Analysis for the approximate year 2013 with 47,637 people included.			

Results showed that contextual factors such as house type and technology installed often act as barriers and enablers of water-related energy, that socio-demographic factors such as the number and age of residents can influence water-related energy and psychosocial factors such as habits and norms also influence water-related energy consumption. In terms of effective interventions, while there were many interventions associated with change, the evidence suggested normative appeals, community-based initiatives and prompts as more effective intervention approaches. Importantly, many of the authors suggested that interventions should be combined to include multiple strategies and target multiple behaviours. A general format was suggested wherein an intervention should start with providing general information and then making that information useful through tailoring it.

Practice review

A practice review consists of structured one-on-one interviews with a small number of people who are actively involved in running programs to change water-related energy behaviour. We were particularly interested to find out what works for whom and what are the barriers to implementation? Practice reviews can reveal invaluable information on how best-practice recommendations from research have played out in the real world and what barriers to implementation have been faced.

An interview guide focused broadly on:

- **Existing programs/initiatives** that aim to reduce household water-related energy consumption.
- **Innovative approaches** to support households to reduce water-related energy consumption.
- Specific **challenges** and **strategies** for engaging target household types (eg, single parent, low-income, apartment, rental).
- **Logistical and political challenges** for water authorities engaging households on water-related energy consumption.

Interviewees were sourced through a list of contacts provided by the project management and stakeholder working group. We also asked interviewees for recommendations of further contacts. The research team was introduced in most cases by members of the project management group or stakeholder working group.

In total, we completed **28** individual or small group interviews. Interviewees included:

- 12 policymakers (Victorian state government, Israeli government)
- 6 national and international academics
- 8 national and international water industry representatives
- 2 Australian energy company representatives.

We asked interviewees to identify programs targeting household water-related energy use in Victoria. While Australian interviewees observe that activities to encourage water saving have reduced significantly since the end of the Millennium Drought, international experts continue to name Victoria, or Australia more generally, as a leader in water saving programs. Most of the programs that address household water-related energy use are based on economic or information-based approaches to reducing hot water consumption. Key findings from the practice review were:

- Activities to reduce household water-related energy used most commonly involve reducing hot water use by installing efficient appliances, or encouraging shorter showers.

- Economic incentive programs focus on reducing the upfront cost of installing retrofits, particularly for vulnerable households. In contrast, communications and education campaigns have a whole of population focus and are generally mass media campaigns that deliver a range of water-saving tips.
- Water-related energy reduction is generally delivered as a water-saving message rather than an energy-saving message. Collectivism is emphasised to highlight the importance of individual actions.

We asked interviewees to identify innovative approaches and best-practice water-related energy use programs, anywhere in the world. Interviewees noted the difficulty in measuring the reach and effectiveness of behavioural programs, and that there are few rigorous evaluations available to draw on. Data-driven electricity reduction programs were highlighted because water authorities may be able to take a similar approach once digital metering becomes widespread, making granular water data available. Key findings from the practice review were:

- Digital metering as a standalone tool is likely to produce small changes in water-related energy behaviour. However, the data generated by digital meters allows for gamification of water use, gamification was previously only possible for electricity use. Competition pairs gamification and social norms by tracking household or community data and comparing it with other households or communities.
- While digital metering and the potential to use digital meter data to create data-driven behavioural approaches such as gamification were the most commonly cited innovation, other interviewees highlighted innovative approaches to water pricing, the importance of working with communities to develop relevant programs, or bundling different approaches into a cohesive strategy.

We asked interviewees to identify programs that target specific populations, as well as challenges and effective strategies for engaging those populations. Many interviewees highlighted the importance of engaging different households differently depending on variables such as household size, language, religion and location. However, this segmentation approach is relatively new for water-conservation programs in Australia and few interviewees were able to provide examples of targeted programs. Key findings from the practice review were:

- Segmentation of advertising campaigns has been used to target messages to populations with the highest average discretionary water consumption, particularly under-35s. Vulnerable households, such as those with low-incomes, English as a second language, or single parent households, do not have high average discretionary water consumption and are not targeted by mass media campaigns.
- DELWP and water authorities target low-income households to provide financial and practical assistance for water-efficient retrofitting. Trust is important for many vulnerable households. Water authorities can build trust by using face to face engagement when possible.

We asked interviewees to reflect on the positioning of water authorities to support households in water-related energy use. Where needed, interviewees were prompted to think about regulatory and policy context, water and energy targets, connections to community, and community attitudes and behaviours. Key findings from the practice review were:

- Water authorities in Victoria are well positioned to support households to reduce water-related energy use. Water authorities are well trusted by householders and Victorian households, particularly those who remember the Millennium Drought, having a high level of water literacy.
- The most frequently identified constraint on water authorities' (and other organisations) ability to support households to reduce water-related energy use is the lack of ongoing funding dedicated to water conservation. Reliable, long-term, funding is required to establish data about effective strategies for changing household behaviour and to create a workforce of specialised practitioners to deliver household programs.

2.3 Enabling – Institutional Opportunities

The enabling institutional component of the research sought to understand the critical levers of influence for optimising water-energy efficiency outcomes for Victorian households. We outline key findings that have emerged identifying opportunities for systems optimisation and the necessary governance processes required to catalyse change. We note that focussed institutional review is anticipated as important in Phase 2 to address details of proposed intervention options.

Opportunities include:

i. A reform agenda to the State Victorian Energy Efficiency Transfer scheme to incentivise technical innovation roll-out for utilities.

ii. The development of a methodology to support the generation of emissions credits from household water-energy efficiency programs as part of the Federal Emissions Reductions Fund.

iii. Optimising rental, concession holder and social housing efficiency upgraded through segmented customer servicing outcomes for rental properties and concession holders.

Underpinning these are other opportunities identified as 'catalysts' for transformative change. These include:

iv. Net Zero Water Cycle Governance and leadership – including leadership culture.
v. Institutional processes, tools and culture for scaling innovation.
vi. Forecasting and adaptive governance to respond to horizon opportunities.

These findings present important implications for state government and water utility practitioners and policy makers, in considering how water-efficiency pilot programs can be optimised for implementation at broader whole of systems scales, and in ways that enhance service provision for government, utilities and service provision outcomes for communities. Both opportunities and recommendations stemming from this initial investigation will form the basis of further research in Phases 2 and 3. There is likely a need to better understand barriers to utilities shifting towards the wider role of managing water-related energy articulated here, ie "Why aren't water utilities doing anything in this space (including general water efficiency measures)? And also, why isn't the market having a stronger effect, particularly if the methods identified are genuinely least cost?

2.4 A Broad Spectrum of Opportunities Exist

Combining the results of the physical technical/modelling with insights associated with the review of behavioural has enabled us to develop an initial range of opportunities and options (potential interventions) which are summarised in Table 2-3.

Table 2-3: Potential opportunities for reducing water, wastewater, water-related electricity, water-related gas, and associated GHGs in households.[2]

Opportunities		Potential for Direct Saving in Households				
		Water Use	Wastewater Production	Water-Related		
				Electricity use	Gas use	GHG emissions
1	***Behavioural incentives/scenarios***					
1.1	- Installation of flow and energy feedback on showers	Mod-High	Mod-High	Mod-High	Mod-High	High
1.2	- Encouraging showering within specific times (rather than throughout the day).	Moderate	Moderate	Moderate	Moderate	Moderate
2	***Increased uptake of water efficient technologies (eg, promote/incentivise) in combination with behaviour change***					
2.1	Shower head replacement program[1]	High	High	High	High	High
2.2	Shower head replacement plus reduced shower duration	Very High	Very High	Very High	Very High	Very High
2.3	Clothes washers (eg, shifting the proportion of appliances or wash cycle temperatures)*	Moderate	Moderate	Moderate	Moderate	Moderate
2.4	Dishwashers	Moderate	Moderate	Low	Low	Low
2.5	Evaporative air conditioners	Nil (water use may increase)	Low	Low	Low	Low
3	***Reduction in losses insulation and delivered water temperature***					
3.1	Hot and cold-water intake from hot water systems to clothes washers	Low	Low	Moderate	Moderate	Moderate
3.2	Selection of specific clothes wash cycles (cold/eco-efficient)	Low	Low	Moderate	Moderate	Moderate
3.3	Insulation of hot water systems and pipes	Low	Low	Moderate	Moderate	Moderate
4	***New technologies with low penetration***					
4.1	Recirculating showers (rapid treatment reusing water and embedded energy)	High	High	High	High	High
4.2	Recirculating showers (stored water reusing water only)	High	High	Low-Mod	Low-Mod	Low-Mod
4.3	Recirculating showers (heat coil reusing energy only)	Low	Low	High	High	High
5	***Metering and related pricing signals***					
5.1	Metering and changes to pricing of water, electricity and gas tariffs	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain
5.2	Water metering for efficiency	Mod-High	Mod-High	Low-Med	Low-Med	Low-Med
6	***Changes to hot water system energy source***					
6.1	Solar hot water heaters	Low	Low	High	High	High
6.2	Heat pump hot water systems	Low	Low	High	High	High

[2] Indicative potential for savings of water, energy and gas has been quantified for Options 2.1 (shower head replacement), Option 2.2 (shower head replacement and behaviour change, Scenario 2) as well as clothes-washer scenarios (Option 2.3) in Sections 3 and 4 of this report – the case studies. The ranking of "High", "Medium" and "Low" potential savings of other options is illustrative and relative to the shower head replacement options. Quantification and detailed ranking of sub-options is proposed in Phase 2 of this study.

Opportunities		Potential for Direct Saving in Households				
				Water-Related		
		Water Use	Wastewater Production	Electricity use	Gas use	GHG emissions
6.3	Devices for off-peak electricity supply	Low	Low	Low	Low	Low
7	***Manipulation of delivered cold-water supply temperature***	Low	Low	Moderate	Moderate	Moderate
8	***Combinations of technologies and behaviour (eg, altered appliance plumbing configurations, new heat source, efficient shower, and new use)***	High	High	High	High	High

**We note many more behavioural and institutional options could be added above.*

The opportunities identified above have focussed on household scale water efficiency measures. In addition, a range of opportunities can be considered at household scale to enable local supply of water (eg, greywater recycling, rainwater tank usage, etc). Some of these measures have potential to reduce household energy use and some (eg, through use of additional pumping) may increase household energy use. Some devices which enable water heating with off-peak electricity have low savings of resources (eg, water or energy), however, they can reduce household costs.

The opportunities summarised above comprise mainly physical options. Within each of these options there remains multiple sub-options such as targeting specific demographics, areas, or scales. Similarly, options exist to target specific levels of performance (eg, replacing shower heads with 5 L/minute flows or 6 L/minute flows). Consequently, a very wide range of potential options exists. Finding "optimal" solutions within this is a focus of the proposed "Phase 2" of the Net Zero Residential Project.

In addition to the household opportunities identified above there is also a range of larger-scale opportunities suitable at say precinct, local government, or utility level. Examples include renewable energy programs, sewer heat recovery and energy generation from wastewater. However, these are generally already well considered by utilities (Deloitte Access Economics 2017). Similarly, new forms of urban design (eg, new buildings stocks of higher density or new design) can also enable greater levels of water and related energy efficiency.

Based on the Phase 1 analysis (which is summarised in Table 2-3 above) the following options are recommended for detailed optimisation in Phase 2:

2.4.1 Potential for Unintended Outcomes

Each of the options summarised above has some influence on water, wastewater, electricity, gas, GHG emissions. They also have potential impacts on financial flows and related social elements such as wellbeing. Understanding these options and their full influence in these dimensions is important to avoid potential unintended outcomes (eg, increases in electrical energy demand due to shifting from top loading clothes washers receiving hot water from gas or solar systems, to front-loading clothes washers with internal electric powered heating).

2.4.2 Segmenting within Social Disadvantage of Individuals and Households

In Phase 1 of the project, it has not been possible to segment the quantity of water-related energy (and related GHG emissions and costs) into different groups such as concession holders, renters, households with low-incomes or those experiencing forms of social disadvantage. Primarily this is due to limitations with current data and confidentiality issues, however, findings from the institutional analysis (see Chapter 7) also point to institutional processes between stakeholders which add further complexity to the availability of information and delivery of on-ground outcomes. The research team and partners have flagged the need for a more segmented focus to water-energy servicing arrangements to ensure that any implementation of technical and behavioural efficiency outcomes can be supportive of the lived experiences, needs and capacities of different communities and individuals.

Installing, or supporting the installation of water-efficient devices in households experiencing social disadvantage was typically identified as more difficult in previous water conservation programs. From our preliminary analysis it is clear that a number of drivers can influence this. Sometimes this is because communications can be more complex often involving landlords, property owners, community support agencies as well as tenants. While in other instances, the sorts of programs designed are not supportive of the living arrangements of these customer segments, or are implemented over a short time-frame limiting opportunities for more effective and ongoing forms of community engagement, participation and development. Institutional and legislative arrangements bring added complexity, at times limiting the availability of information between stakeholders and opportunities for integrated servicing arrangements.

Phase 2 and 3 of this research, as a priority, needs to build on preliminary findings established from Phase 1 to develop pathways for more context sensitive customer servicing outcomes. Technical modelling will seek to establish a richer picture of segmented community groups and sub-groups, while focus group discussions will draw on behavioural insights and an understanding of the relationship of localised experiences, needs and capacities to water and energy behaviours and practices. As the Phase 1 institutional analysis highlights, substantive opportunities exist for water and energy utilities, community support providers and relevant state government agencies to better coordinate processes for rental, concession and vulnerable community water and energy efficiency servicing. Ongoing analysis into the institutional, policy and regulatory drivers for supporting these outcomes will be undertaken together with relevant stakeholders and agencies.

2.5 One Obvious Opportunity: Shower Head Replacement and Behaviour Program

From the analysis presented above it is clear that a very wide range of potential options exists. Finding “optimal” (least cost or maximised benefit) solutions within this is a focus of the proposed “Phase 2” of the Net Zero Residential Project.

Whilst Phase 2 will explore these options in more detail, it is already apparent from this Phase 1 analyses that significant reductions could be obtained through water efficiency measures focussed on shower management (Table 2-4 and Table 2-5).

Scenario 1 (refer Section 3.3.4 for details) simulates replacing shower heads for showering of Reservoir (Case Study 1) to reduce average flow rate from an average of 12 L/min to an average of 6.3 L/min (noting some suitable new shower heads now can deliver showers at 5 L/min). This would reduce water-related energy by 5.1 GWh/yr. Scenario 2 simulates additionally reducing average shower duration from 10 minutes to 4 minutes. Assuming all households in Reservoir were installed with ~6 L/min shower heads and all occupants adopted a maximum 4-minute shower routine, this would reduce water-related energy by 12 GWh/yr from the baseline. These scenarios would represent a substantial and sustained water-efficiency program.

Scenarios 1 and 2 intervention measures were scaled from household to city scale in Melbourne (Table 2-6 and Table 2-7). Table 2-6 outlines the capacity for simultaneously reducing water, water-related energy, and GHG emissions with a shower technology upgrade. Table 2-7 demonstrates the upper most potential impacts of demand management with a shower technology upgrade and a behaviour change program where showering time is reduced from 10 minutes down to 4 minutes. Both scenarios highlight the key opportunities for simultaneous water, water-related energy, and GHG emissions reduction through demand management.

Table 2-4: Estimated energy savings from potential shower interventions in Reservoir (Case Study 1).

Baseline for Reservoir (3073)						
Flow Rate (L/min)	Flow Duration (min)	% HH	No. of People	Water Use (ML/yr)	WRE Use (GWh/yr)	GHGs (ktCO2-e/yr)
12	10	14	6,838	555	12.2	5.7
12	4	17	8,703	468	8.6	4.8
6.3	10	30	15,220	926	18.4	9.6
6.3	4	39	19,371	900	15.4	9.3
Totals		**100**	**50,132**	**2,849**	**54.6**	**29.5**
Scenario 1: Shower head Upgrade for Reservoir (3073)						
Flow Rate (L/min)	Flow Duration (min)	% HH	No. of People	Water Use (ML/yr)	WRE Use (GWh/yr)	GHGs (ktCO2-e/yr)
6.3	10	44	22,058	1357	22.4	14.1
6.3	4	56	28,074	1311	27.1	13.5
Totals		**100**	**50,132**	**2,668**	**49.5**	**27.6**
Water, Energy, and GHG Savings from Scenario 1				**-181**	**-5.1**	**-1.8**
Scenario 2: Shower head Upgrade + Behaviour Change Program for Reservoir (3073)						
Flow Rate (L/min)	Flow Duration (min)	% HH	No. of People	Water Use (ML/yr)	WRE Use (GWh/yr)	GHGs (ktCO2-e/yr)
6.3	4	100	50,132	2,431	42.6	25.1
Totals		**100**	**50,132**	**2,431**	**42.6**	**25.1**
Water, Energy, and GHG Savings from Scenario 2				**-418**	**-12**	**-4.3**

Table 2-5: Estimated energy savings from potential shower intervention measures in Frankston precinct (Case Study 2).

Baseline for Frankston (3099)						
Flow Rate (L/min)	**Flow Duration (min)**	**% HH**	**No. of People**	**Water Use (ML/yr)**	**WRE Use (GWh/yr)**	**GHGs ($ktCO_2$-e/yr)**
12	10	25	13,357	993	23.2	10.3
12	4	16	8,905	444	8.6	4.5
6.9	10	35	19,221	1,080	22.6	11.1
6.9	4	24	12,814	555	9.9	5.6
Totals		**100**	**54,298**	**3,072**	**64.2**	**31.4**
Scenario 1: Shower head Upgrade for Frankston (3099)						
Flow Rate (L/min)	**Flow Duration (min)**	**% HH**	**No. of People**	**Water Use (ML/yr)**	**WRE Use (GWh/yr)**	**GHGs ($ktCO_2$-e/yr)**
6.9	10	60	32,579	1,855	17.0	19
6.9	4	40	21,719	947	39.0	9.5
Totals		**100**	**54,298**	**2,802**	**56.0**	**28.5**
Water, Energy, and GHG Savings from Scenario 1				**-270**	**-8.2**	**-2.9**
Scenario 2: Shower head Upgrade + Behaviour Change Program for Frankston (3099)						
Flow Rate (L/min)	**Flow Duration (min)**	**% HH**	**No. of People**	**Water Use (ML/yr)**	**WRE Use (GWh/yr)**	**GHGs ($ktCO_2$-e/yr)**
6.9	4	100	54,298	2,451	45.0	24.6
Totals		**100**	**54,298**	**2,451**	**45.0**	**24.6**
Water, Energy, and GHG Savings from Scenario 2				**-621**	**-19.2**	**-6.8**

Table 2-6: Estimated demand management outcomes for the shower technology upgrade, Scenario 1.[a]

	Household[b]	**Melbourne[c]**
Water	-29 (kL/hh.yr)	31 (GL/yr)
Water-Related Energy	-991 (kWh/hh.yr)	1,070 (GWh/yr)
GHG Emissions	-293 ($kgCO_2$-e/hh.yr)	316 ($ktCO_2$-e/yr)

[a] Scenario 1: Shower head technology upgrade from 12 L/min to 6.3 L/min (Redhead et al. 2013; Roberts 2012).

[b] ResWE model results, weighted average across all household types (Bors 2019).

[c] Based on replacing all ~12 L/min shower heads with ~ 6 L/minute shower heads in 1,080,000 households in Melbourne (ie, replacing 60% of the estimated 1.8 million households) in Melbourne (Ghobadi et al. 2013).

Table 2-7: Estimated demand management outcomes for the shower technology upgrade and behaviour change, Scenario 2.[a]

	Household[b]	Melbourne[c]
Water	-42 (kL/hh.yr)	-61 (GL/yr)
Water-Related Energy	-1,451 (kWh/hh.yr)	-2,090 (GWh/yr)
GHG Emissions	-430 (kgCO_2-e/hh.yr)	-619 (ktCO_2-e/yr)

[a] Scenario 2: Shower head technology upgrade from 12 L/min to 6.3 L/min (Redhead et al. 2013; Roberts 2012; Ghobadi et al. 2013), and behaviour change by reducing shower duration from 10 min (summer) and 12 min (winter) (Redhead et al. 2013) to 4 min (all year round).

[b] ResWE model results, weighted average across all household types (Bors 2019).

[c] Estimated 1.8 million households, 60% with the capacity for a shower upgrade (Ghobadi et al. 2013), and 50% with the capacity to reduce their shower duration (ABS 2013b).

It is possible that a concerted effort in applying shower related demand management interventions to reduce residential water-related energy has the potential for significant asset deferrals (Table 2-8 compared with Melbourne case in Table 2-6 and Table 2-7).

Table 2-8: Statistics to help compare the quantum of savings.[a]

Potential Asset Deferrals	#	Units
Annual Water Supply from Catchments to Melbourne in 2050 (medium scenario)	500	(GL/yr)
Somerton Gas Plant	1,402	(GWh/yr)
Eildon Hydro	1,050	(GWh/yr)
Melbourne Waters' Hydro Electricity	55	(GWh/yr)
YVW GHG Emissions Baseline	34	(ktCO_2-e/$_{2016\text{-}17}$)
Victorian Water Sector Annual GHG Emissions Baseline	868	(ktCO_2-e/yr)

[a] Potential asset deferral table sourced from personal communications (Pamminger 2020).

Considering demand management interventions would take time to fully implement yet asset deferrals could be achieved over substantial periods. More importantly, advancements in implementing measures to reduce residential water-related energy would make a significant contribution to reducing GHGs and becoming a climate-ready economy and community.

2.5.1 Comparing with Existing Energy Initiatives

Least cost analyses of existing initiatives and Scenario 1 from the Reservoir Case Study were compared. The energy and CO_2-e savings per $ investment of the current initiatives of the Net Zero Pledge indicates some important points emerging from the study. To illustrate the cost-effectiveness potential of the Net Zero Program, we have included Scenario 1 into the cost curve; that is: installing a low flow (~6 L/min) shower head in approximately 50% of households (which do not currently have low flow shower heads) in the suburb of Reservoir. Key points are:

- When costs and benefits of water and energy cost savings to households are included into the analysis, Scenario 1 (shower head replacement) is the least-favoured option from a utility perspective (Figure 2-1), and the most favoured from a customer perspective (Figure 2-2).
- Scenario 1 has additional impacts including (a) reduced water demand, and (b) reduction of wastewater flows when compared with all other options which are energy-focussed initiatives only. Put alternatively, the other projects appear to have no impacts on water demand or wastewater flows, in contrast to the benefits evident in Scenario 1. It is possible some of the initiatives (#2-12) in the Pledge could lead to increased water demand (eg, for cleaning of new infrastructure such as solar panels).

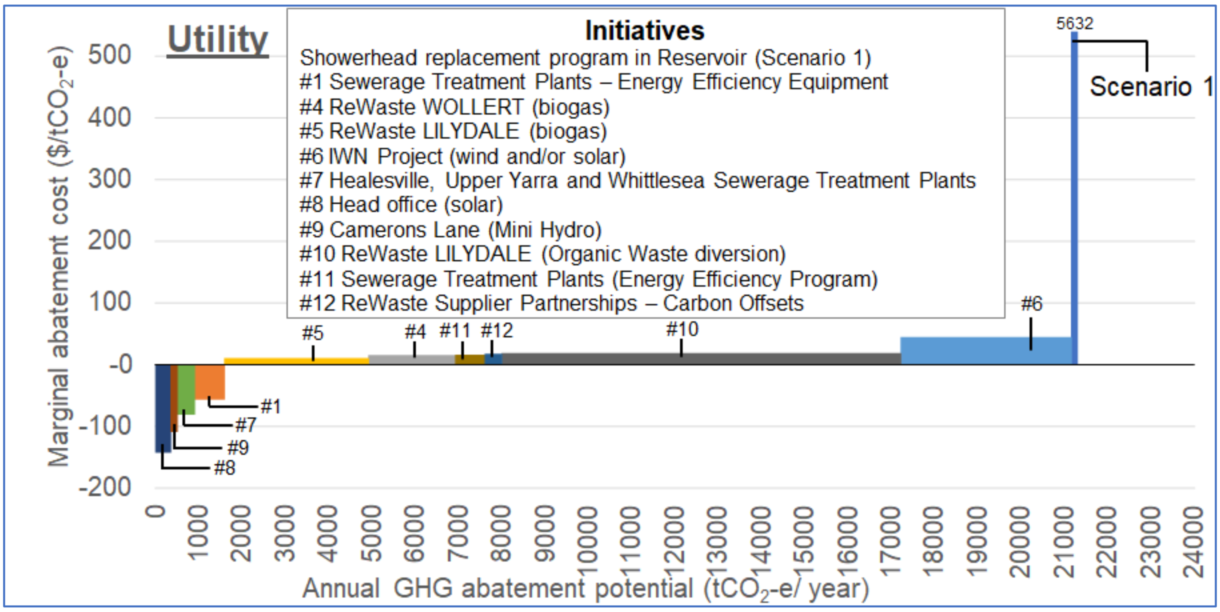

Figure 2-1: "Utility perspective" marginal abatement cost comparing all Yarra Valley Water energy/GHG initiatives (in the GHG Pledge) and Scenario 1 (a program of replacing ~50% shower heads in the suburb of Reservoir).[3]

[3] The graph is "Utility perspective" because it focusses on costs and benefits at water utility.

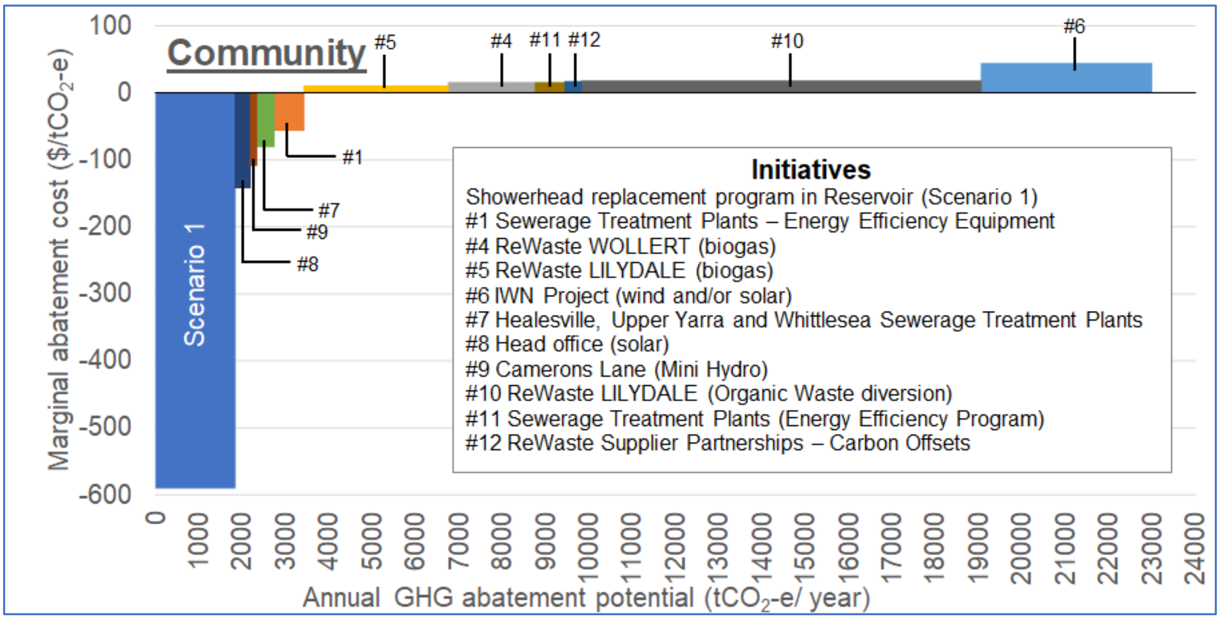

Figure 2-2: **"Community perspective" marginal abatement cost comparing all Yarra Valley Water energy/GHG initiatives (in the GHG Pledge) and Scenario 1 (a program of replacing ~50% shower heads in the suburb of Reservoir).**[4]

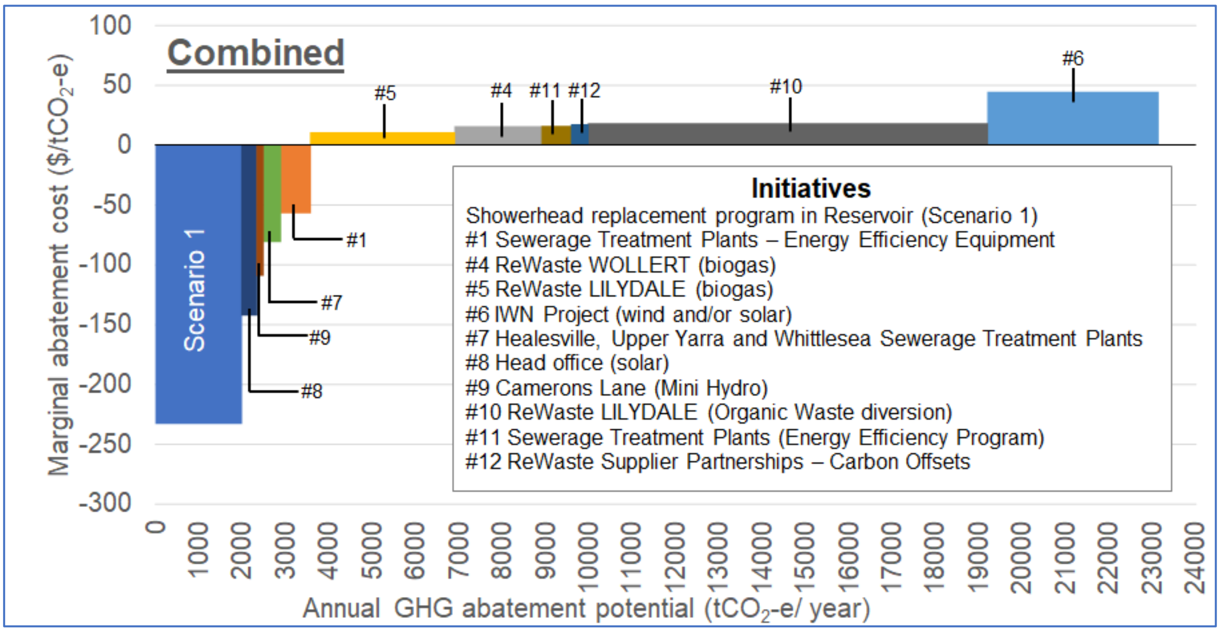

Figure 2-3: **"Combined perspective" marginal abatement cost comparing all Yarra Valley Water energy/GHG initiatives (in the GHG Pledge) and Scenario 1 (a program of replacing ~50% shower heads in the suburb of Reservoir).**[5]

Note that in all least-cost analysis long-term behaviour change costs and strategies have not been included. We have only analysed Scenario 1 (a shower head exchange program) to illustrate the anticipated use of least cost analysis which is planned more substantially in Phase 2 of this project.

[4] The curve is "Community perspective" because it focusses on household (rather than water utility) costs and benefits.
[5] The curve is "Combined perspective" because it focusses on costs and benefits at both household and water utility.

2.5.2 Behaviour Change Components of a New Shower Head Program

The effectiveness of implementing a shower head replacement program (eg, Scenario 1) is very compelling. Even more compelling is a program of shower head replacement augmented by behaviour modification – provided user behaviour is modified to accept the new conditions imposed by the scenario and the new technology performs as anticipated in conjunction with that behaviour. As a component of optimisation in Phase 2 behaviour change considerations must be included.

2.6 Existing Energy Measures Retail Utilities

Across Melbourne and Victoria, there is a range of programs being implemented by utilities and state agencies such as DEWLP to reduce GHG emissions (Deloitte Access Economics 2017). While it is beyond the aim of this project to review all of these, it is worth flagging that no programs are specifically focussed on household water-related energy. Almost all initiatives fall within the following major categories:

- Efficiency projects – (eg, operational efficiencies) typically capital investments.
- In-front of the meter renewable energy – typically renewable installations including the Intelligent Water Networks (IWN) platform. This is part of the Zero Emissions Water (https://zew.org.au/), a multi-water utility project to install larger-scale renewable energy options.
- Behind-the-meter renewable energy – typically small-scale solar PV and batteries.
- Self-generated offsets – including forestry.
- Purchase of GreenPower or other offsets – noting these purchases are allowed under the DELWP guiding principles, but offset purchases are not.

Example measures to meet GHG Pledge Commitments include (Deloitte Access Economics 2017):

- Yarra Valley Water has pledged to reduce its emissions by 64% (20,340 tCO_2-e) relative to its baseline by 2024-25, and has committed to the accelerated target of net-zero by 2030. Collectively this aims to reduce some 19,000 tCO_2-e/yr by 2025 with the largest contributors being Lilydale organic waste diversion, Lilydale and Wollert Biogas, and wind/solar projects comprising the majority (9,200, 5,300, and 4,000 tCO_2-e/yr respectively). Across Melbourne Yarra Valley Water coordinated an awareness program called “Hey Melbourne!”.
- South East Water has pledged to reduce its GHG emissions by 18,356 tCO_2-e in 2024-25. This corresponds to a 45% reduction in emissions relative to the baseline (average emissions from 2011-12 to 2015-16). Large scale renewable energy projects comprise the majority of these savings including solar (eg, with Zero Emissions Water initiative), cogeneration and new battery infrastructure. The Aquarevo development (currently ~100 households) has a goal of reducing demand on drinking water supplies for uses that do not require it by 70%.
- City West Water has pledged to reduce GHG emissions by 9,930 tCO_2-e in 2024-25. This corresponds to an 80% reduction in emissions relative to the baseline. Large scale renewable energy projects comprise the majority of these savings.

There appears to be relatively little water efficiency programs planned by water utilities. Water security investments made in the period 2005-2010 appears to have resulted in the water industry to have no incentive to pursue ongoing efficiency programs. Specific measures noted during this project include:

- A shower head replacement program at Yarra Valley Water in 2020. This involved a free replacement program where households could swap existing shower heads for new high efficiency (>5 L/min) shower heads. Approximately 1000 shower heads were replaced.
- Research into several methods (Apps and Amphiro shower energy meter devices) intended to reduce water (and related energy) at South East Water.
- Both City West Water and Yarra Valley Water are trialling ‘water saving’ initiatives as part of the Digital Metering rollout. This includes improved leak notifications, neighbourhood comparisons and app development (to provide customers on digital metering trial with better information).
- Melbourne wide, the metropolitan water retailers have been in a communications campaign “Make Every Drop Count” (https://www.makeeverydropcount.com.au/ since 2019.

Several challenges were experienced in the effort to compile information on water management programs intended to support energy efficiency outcomes. These included:

- Water efficiency and energy or GHG management within water utilities are typically managed out of different sections of the organisation. Typically, this is also separate to customer hardship, digital metering, marketing, and education. Not surprisingly it is a relatively complex task to compile information across these dimensions. Effectively this creates a knowledge or information gap or blind spot for the utilities as well. This is because the interactions of these areas are not easy to ascertain given the fragmented information. A similar pattern is common in state agencies due to the separation of different functions within government.
- Many water utilities did track energy and carbon savings within household related to water (eg, through shower head replacement programs). However, this practice ceased about 10 years ago. Around 2010 state-based accounting methods stopped giving water utilities carbon credits for household water efficiency when many state-based schemes were incorporated into Australian Government measures. Consequently, activity as well as tracking of household water-related energy savings also stopped.

2.6.1 State-Wide Significance of the Shower Head Program Example

Scenarios 1 and 2 intervention measured scaled from household to state-wide rollout in Victoria (Table 2-9). Table 2-9 outlines the estimated state-wide capacity for simultaneously reducing water, water-related energy, and associated GHGs through: (i) a shower technology upgrade (Scenario 1), and (ii) a shower technology upgrade and behaviour change program. Note the magnitude of the predicted shift in water, water-related energy, and GHGs from a technology upgrade alone (Scenario 1) without the requirement of a cultural shift in showering behaviour. It is important to note that preliminary results represent an upper limit of potential savings. These results are estimated from scaling up a weighted household average (ie, from suburban households) and further research would be required to determine metropolitan vs regional household capacity for a shower head upgrade and behaviour change program.

Table 2-9: Estimated Victorian-scale outcomes for the shower technology upgrade (Scenario 1), and the shower technology upgrade with a behaviour change program (Scenario 2)

	Shower Technology Upgrade (Scenario 1)[a, c]	Shower Technology Upgrade & Behaviour Change Program (Scenario 2)[b, c]
Water	41 (GL/yr)	80 (GL/yr)
Water-Related Energy	1,415 (GWh/yr)	2,763 (GWh/yr)
GHG Emissions	418 (ktCO_2-e/yr)	818 (ktCO_2-e/yr)

[a] Scenario 1: Shower head technology upgrade from 12 L/min to 6.3 L/min (Redhead et al. 2013).
[b] Estimated 2.38 million households (DEWLP 2019), 60% with the capacity for a shower upgrade (Ghobadi et al. 2013). State-wide results are directly scaled from a weighted average across all household types (Bors 2019).
[c] Scenario 2: Shower head technology upgrade from 12 L/min to 6.3 L/min (Redhead et al. 2013; Ghobadi et al. 2013), and behaviour change by reducing shower duration from 10 min (summer) and 12 min (winter) (Redhead et al. 2013) to 4 min (all year round).
[d] Estimated 2.38 million households (DEWLP 2019), 60% with the capacity for a shower upgrade (Ghobadi et al. 2013), and 50% with the capacity to reduce their shower duration (ABS 2013b). State-wide results are directly scaled from a weighted average across all household types (Bors 2019).

Section 2 – Technical Modelling, Data Review, and Least Cost Analysis

3 Reservoir: Residential Water Use, Related Energy and GHG Emissions (Case Study 1)

Regional water use, water-related energy use and associated emissions were modelled through scaling up a household model to regional scale using census data and local water authority information to characterise end use variability between individual households. The model was used to evaluate and compare changes in regional water and energy demand through technological and behaviour change scenarios.

3.1 Reservoir Site: Background Information

The site selected for Case Study 1 was the suburb of "Reservoir" in the Yarra Valley Water utility region, Melbourne, Australia (postal boundary 3073, Figure 3-1).

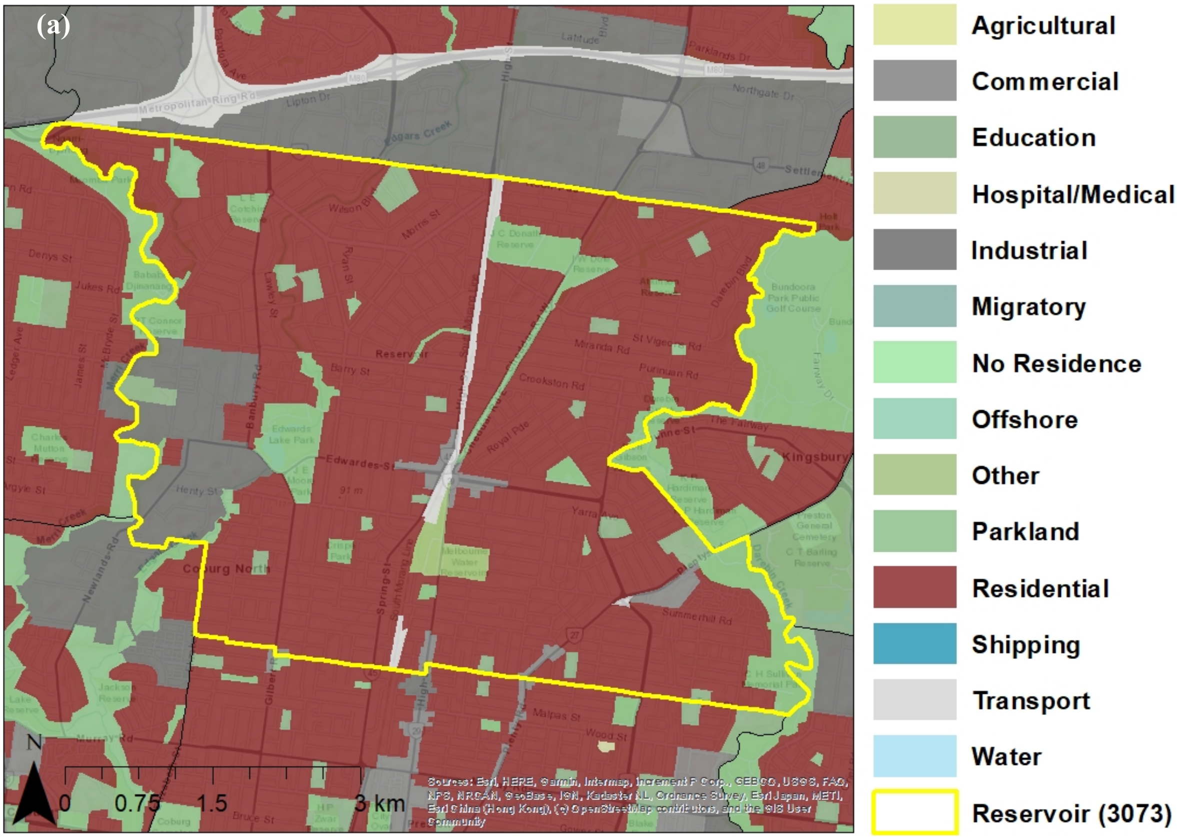

Figure 3-1: Reservoir's postal boundary (3073) land use classifications, Melbourne, Australia (ABS 2013c, 2011b).

The case study boundary for Reservoir was determined to include 50,132 people (49% Male, 51% Female), and 21,845 households, through the most recent census data in addition to local water authority data (ABS 2019; YVW 2014). The climate region is classified as a mild temperate climate zone with four distinct seasons where summer and winter can exceed human comfort, autumn and spring are ideal (ABS 2013a) and a median annual rainfall over 800 mm (BOM 2005).

An important goal in this study, is to identify resource efficiency solutions across a broad spectrum of socio-economic groups, inclusive of vulnerable communities. Overall, Reservoir (postcode boundary 3073) registers at the mid to lower end of the Socio-Economic Indexes for Areas (SEIFA) at the suburb scale, and registers as socio-economically diverse at a higher data resolution scale (Figure 3-3, and Table 3-1). Reservoir is classified as the 3rd decile – Index of Relative Socio-Economic Disadvantage, 4th decile – Index of Relative Socio-Economic Advantage and Disadvantage, 2nd decile – Index of Economic Resources, and 6th decile – Index of Employment and Occupation (ABS 2018).

Within these Indexes is a representation of the first eight deciles at Statistical Area Level 1 (SA1) data resolution where Reservoir is split into smaller areas (111 SA1 data level areas), each with an individual SEIFA score (ABS 2018).

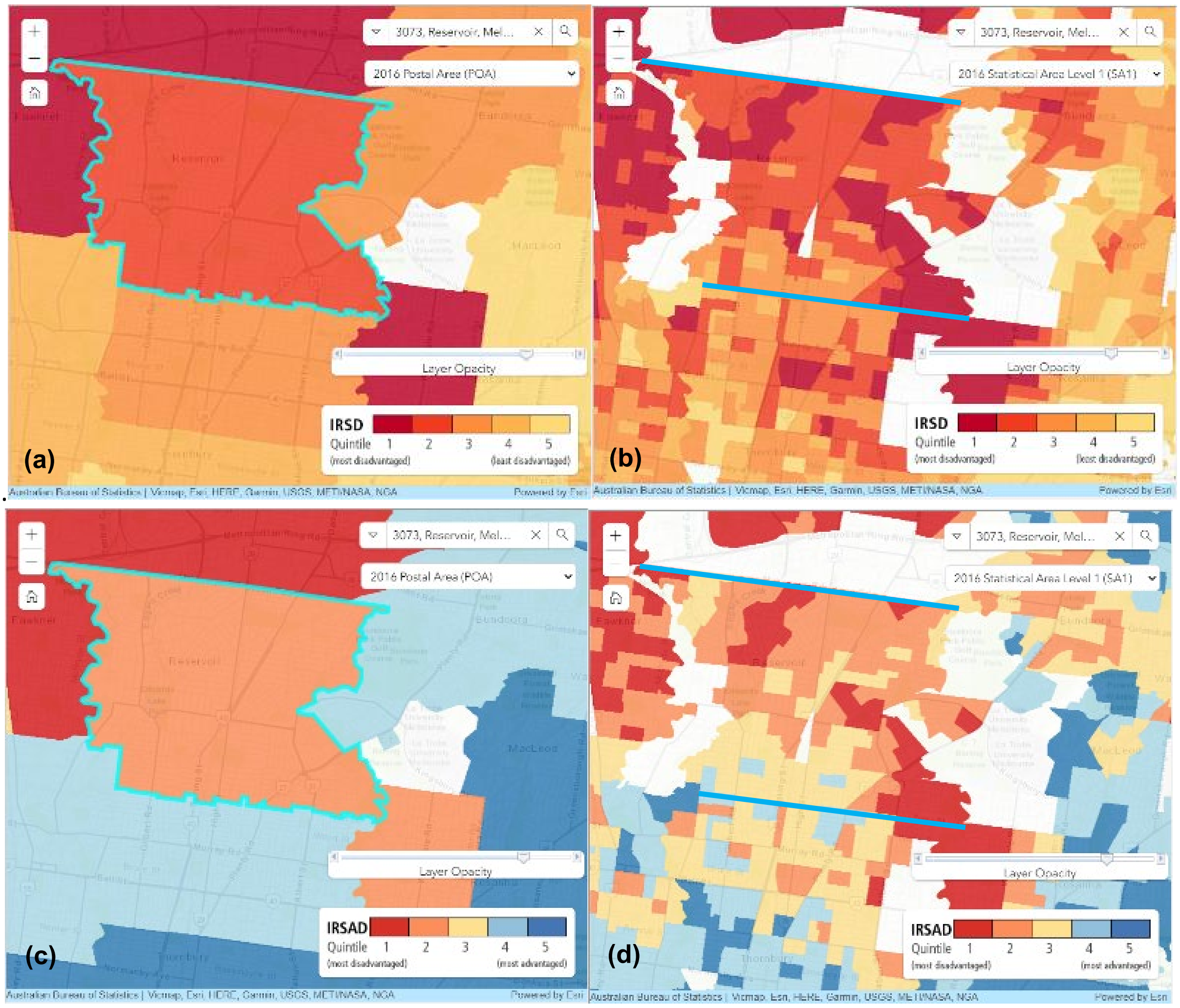

Figure 3-2: SEIFA indicators for Reservoir (3073): (a) postcode level SEIFA indicator from the Index of Relative Socio-Economic Disadvantage (IRSD); (b) SA1 level SEIFA indicator distribution from the Index of Relative Socio-Economic Disadvantage (IRSD); (c) postcode level SEIFA indicator from the Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD); and (d) SA1 level SEIFA indicator distribution from the Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD) (ABS 2018). Note in in sub-figures b and d only the northern and southern site boundary is shown.

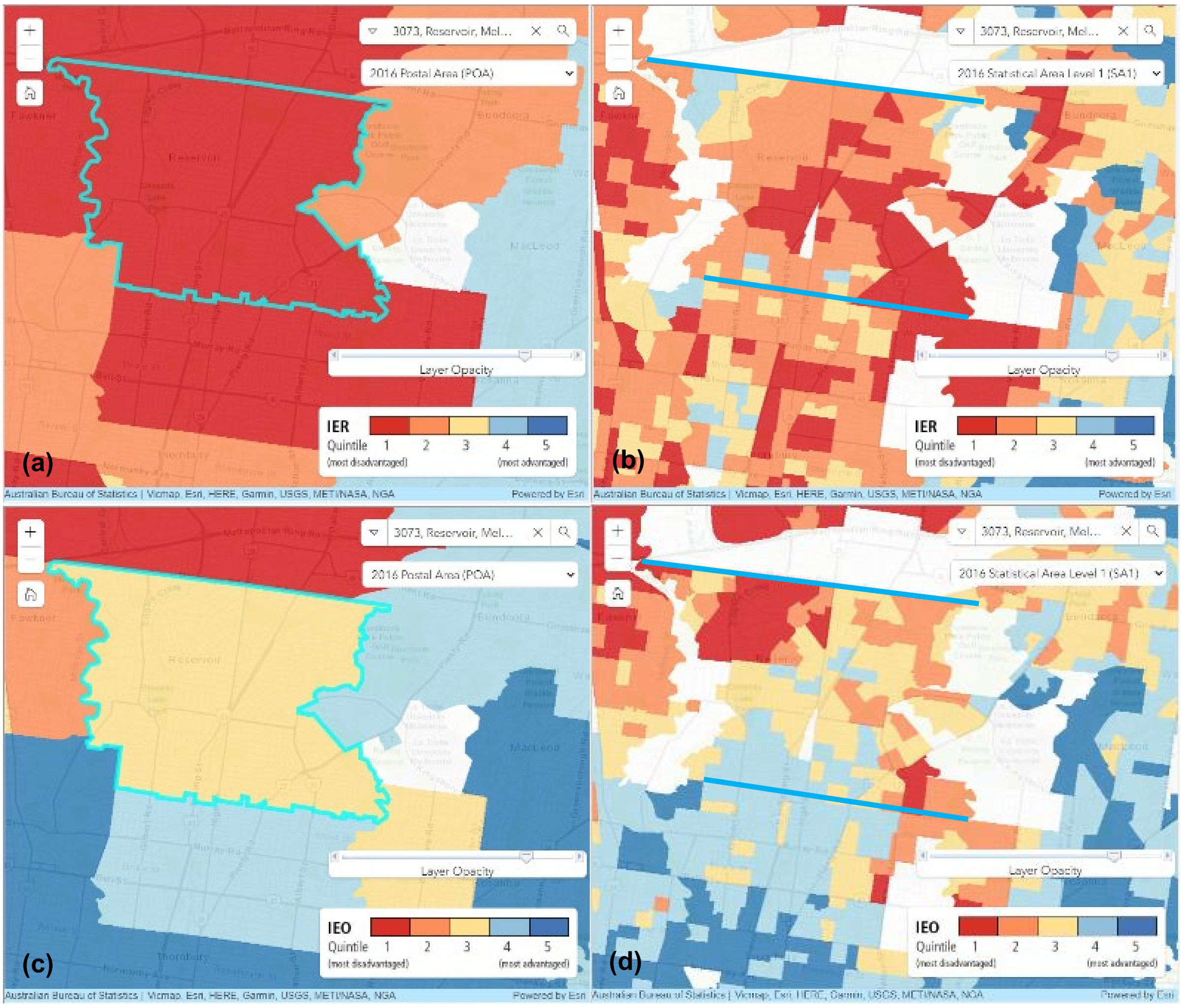

Figure 3-3: SEIFA indicators for Reservoir (3073): (a) postcode level SEIFA indicator from the Index of Economic Resources (IER); (b) SA1 level SEIFA indicator distribution from the Index of Economic Resources (IER); (c) postcode level SEIFA indicator from the Index of Employment and Occupation (IEO); and (d) SA1 level SEIFA indicator distribution from the Index of Employment and Occupation (IEO) (ABS 2018). Note in in sub-figures b and d only the northern and southern site boundary is shown.

Table 3-1: SEIFA SA1 level distribution indicators for socio-economic diversity in Reservoir.

Index	Decile Distribution of the Statistical Area Level 1s (SA1s) for Reservoir (Postcode 3073)										
	Decile 1	Decile 2	Decile 3	Decile 4	Decile 5	Decile 6	Decile 7	Decile 8	Decile 9	Decile 10	Total SA1s
IRSD	11	19	32	25	11	10	2	1	0	0	111
IRSAD	5	16	25	25	20	17	2	1	0	0	111
IER	15	21	31	27	7	4	6	1	0	0	112
IEO	4	13	13	13	17	27	17	7	0	0	111

IRSD – Index of Relative Socio-Economic Disadvantage; IRSAD – Index of Relative Socio-Economic Advantage and Disadvantage; IER – Index of Economic Resources; IEO – Index of Employment and Occupation

3.2 Reservoir Site: What Makes Reservoir a Good Site for this Study?

Considerations for Case Study 1 site selection included:

- A high proportion of residential land use thereby ensuring residential water and energy use could be assessed. The Australian Bureau of Statistics (ABS) land use digital layer identifies a high proportion of mesh blocks labelled as residential use in this area (ie, >80% (ABS 2012a)).
- Nested ABS digital boundaries to incorporate census data and other ABS datasets. This simplifies data scaling for multi-scale analysis and ensures long term viability of the study site. Reservoir's postcode boundary neatly divides into two SA2 areas (Reservoir-West and Reservoir-East), 116 SA1 areas, and 636 mesh block areas (ABS 2012c).
- Socio-economic diversity ensuring representation of vulnerable customers. There is clear representation of the first eight deciles of each of the Socio-Economic Indexes for Areas (SEIFA) datasets at SA1 level of data resolution (Table 3-1) (ABS 2018).

Site selection criteria identified by the stakeholders (universities, DELWP, and utilities), and analysis of the target site against the primary (Table 3-2) and secondary (Table 3-3) criteria.

Table 3-2: Primary criteria for Case Study 1 site selection.

Criteria	Reservoir (postcode 3073)
1.1. Opportunity for the application of new pathways for historic options which have been hard in the past.	Reservoir Suburb (East and West) represent populations of quintiles 1-4 (of 5) in all categories other than the least disadvantaged, Figure 3-2 and Figure 3-3 (ABS 2018). It also is mid-range affordability within the Yarra Valley Water supply district.
1.2. Benefits to residents in the area and across Melbourne. Builds the capacity to engage with vulnerable communities.	
2. Ability to scale solutions at later stages ie, applicability of the results to all of Melbourne.	Representative for all other than higher socio-economic category (see 1.1 and 1.2 above).
3. Area subject to development pressure.	Reservoir is currently going through development and so changes are anticipated.
4. Availability of detailed data to model and verify results across water use, electricity use, gas use, and understanding of water-related energy GHGs.	High availability of compiled data and strongly nested ABS and related data. See Table 5-1 for model input data and Table 5-2 for model verification data.
5. Utility willingness to provide in-kind technical support/data for Phase 1 of this project but ideally over the planned duration of Project 1 (~3 years).	Partners (eg, Yarra Valley Water, South East Water, Jemena, and APA Gas) have confirmed, and/or shared data, etc.

Table 3-3: Secondary criteria for Case Study 1 site selection.

Criteria	Reservoir (postcode 3073)
6. Areas constrained with current assets such that the program could support asset deferral.	Need to confirm (see Section 2.5).
7. Existing measures in the area such as Climate Change Adaptation Action plans. Moreover, enabling environments that support the contextually appropriate uptake for diverse sub-sections of the community.	DELWP have indicated ~50 records for the Residential Scorecard program within Reservoir. This program is relevant and being implemented nationally.
8. High levels of consumption.	Consumption levels vary significantly from house to house, and location to location, but Reservoir appears typical.
9. Areas where stakeholders are seeking to understand and effect change across water, energy, and GHGs.	Northern Alliance for Greenhouse Action articulated (~2017) goals relevant to Reservoir.

3.3 Methodology for Modelling Water, and Water-Related Energy Use

ResWE, a mathematical material flow analysis (MMFA) model has been developed for quantifying Residential Water-related Energy (ResWE). Ten major end use subsystems were simulated in detail to capture water and energy use in: (i) showers, (ii) baths, (iii) clothes washing, (iv) indoor taps, (v) dishwashing, (vi) outdoor use, (vii) toilet, (viii) kettle, (ix) air-conditioning, and (x) other energy use, as outlined in Kenway et al. (2013). The current study focused on the regional scale application of the ResWE model developed in Bors (2019) (see Appendix A for a summary of model development).

Opportunities for reducing residential water-related energy use were identified through modelling the most significant factors influencing both water and water-related energy use. Previous studies have found the significant factors to be: (i) household composition (Kenway et al. 2013; Cominola et al. 2018), (ii) hot water system type (Agudelo-Vera et al. 2014; Vieira, Beal, and Stewart 2014), (iii) shower use (Makki et al. 2013; Kenway et al. 2016), (iv) clothes washing use (Stamminger 2011; Beal, Bertone, and Stewart 2012), and (v) seasonal factors (Bors et al. 2017; Escriva-Bou, Lund, and Pulido-Velazquez 2015). Variations in the significant factors were used to characterise 320 household types. This process captured end use variability across Reservoir.

3.3.1 Defining Household Types

A total of 320 household types were used to capture household end use variability. This was done through: (i) 4 household compositions, (ii) 5 hot water system types, (iii) 2 shower head efficiencies, (iv) 2 shower durations, (v) 2 clothes washing machine types, and (vi) 2 washing cycle temperatures (ie, 4x5x2x2x2x2=320 household types, Figure 3-4). The model required 145 input parameters for each of the 320 household types to calculate household water use, water-related energy use and associated GHG emissions (see Appendix C, Table C-1 for sources of data).

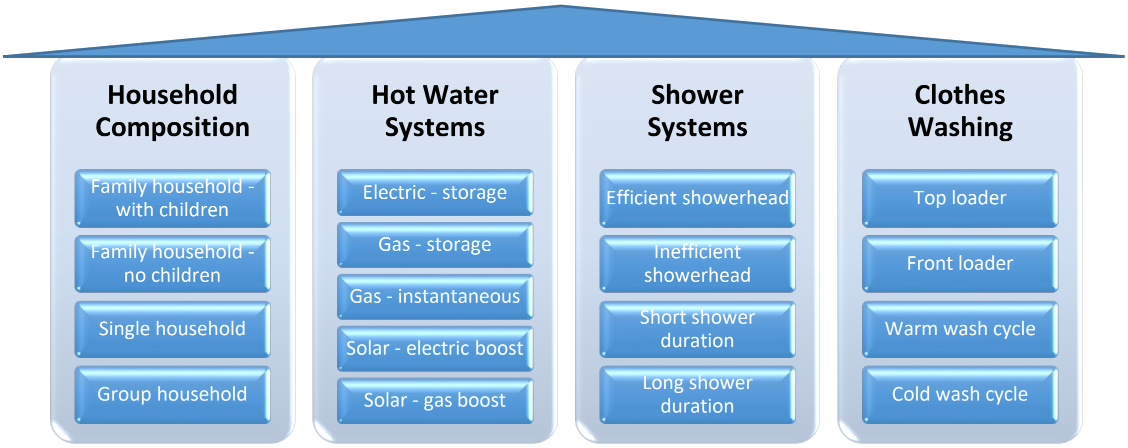

Figure 3-4: Significant factors characterising water-related energy use variability.

Variability in seasonal factors was accounted for by running the model on a monthly time-step. An important assumption was that factors driving water-related energy use were considered independent of each other. This simplification was applied in the absence of any information about the interactions between demographic groups, technology, and behaviour.

3.3.2 Regional Water-Related Energy Model

Total water use was calculated for Reservoir by aggregating ResWE model predictions for each combination of household composition, hot water system type, shower use and clothes washer use parametrisations creating the 320 household types. The number of households of each of the 320 household types was simply the product of the total number of households in Reservoir, and the proportion of households with the specific characteristics. The same method was used to evaluate Reservoir's water-related electricity use and water-related gas use from ResWE model predictions for each of the 320 household types. Water-related GHG emissions were evaluated by using emission factors to convert Reservoir's water-related electricity and water-related gas use. A summary of the ResWE model development is presented in Appendix A, summary of data inputs in Appendix C.

Model results were calibrated primarily against measured water use and gas use inputs due to the availability of more robust water and gas use datasets for verification. The mean absolute percentage error was used to quantify uncertainty. Errors in predictions in decreasing order of model fit were gas use (4%), water use (7%), and electricity use (8%).

3.3.3 Overview Model for Characterising Impacts of Potential Interventions

The University of Queensland's existing ResWE model has been used to generate the water use, and water-related energy use inputs to create the Overview Model. Data and information have been compiled for the key factors of influence (eg, household composition, hot water system type, shower systems and clothes washers), and used to update the Overview Model for this case study.

Key model functions include: (a) quantifying the residential baseline of water use, related energy use, GHGs, and costs; and (b) scenario testing of various interventions to ascertain the reduction potential of water use, water-related energy use, and GHG emissions. This is important for guiding later phases of research and help quantify the order of magnitude influence for potential asset deferrals. A summary of the Overview Model development is presented in Appendix B, and a summary of the Overview Model data inputs is presented in Chapter 4.

3.3.4 Scenarios for Estimating the Potential Reduction of Residential Water Use, Water-Related Energy Use, and GHGs

An important prelude to the scenario testing was the establishment of a baseline of resource use for different household types. Different household types for Reservoir were modelled through different combinations of household compositions (Table 3-4), hot water system types (see Chapter 5, Table 5-5), shower systems and clothes washing use (Table 3-5).

This captured the variability in household types across a region and provided an estimation of the base case for water use, water-related energy use, and GHGs. See Section 5.1 for detailed information on characterising variability between household types.

Table 3-4: Household composition for quantifying resource use in Reservoir.

Household Composition	Family with Children	Family no Children	Single	Group
Number of Adults	2.11	2.49	0.98	2.59
Number of Children	1.78	-	-	-

Table 3-5: Shower and clothes washing combinations for quantifying resource use in Reservoir.

Household #	Shower head Efficiency	Shower Duration	Clothes Washer	Wash Cycle
HH1	Efficient (6.3 L/min)	Short (4 min)	Top Loader	Warm (40°C)
HH2	Efficient (6.3 L/min)	Short (4 min)	Top Loader	Cold (tap temp.)
HH3	Efficient (6.3 L/min)	Long (10 min)	Top Loader	Warm (40°C)
HH4	Efficient (6.3 L/min)	Long (10 min)	Top Loader	Cold (tap temp.)
HH5	Inefficient (12 L/min)	Short (4 min)	Top Loader	Warm (40°C)
HH6	Inefficient (12 L/min)	Short (4 min)	Top Loader	Cold (tap temp.)
HH7	Inefficient (12 L/min)	Long (10 min)	Top Loader	Warm (40°C)
HH8	Inefficient (12 L/min)	Long (10 min)	Top Loader	Cold (tap temp.)
HH9	Efficient (6.3 L/min)	Short (4 min)	Front Loader	Warm (40°C)
HH10	Efficient (6.3 L/min)	Short (4 min)	Front Loader	Cold (30°C)
HH11	Efficient (6.3 L/min)	Long (10 min)	Front Loader	Warm (40°C)
HH12	Efficient (6.3 L/min)	Long (10 min)	Front Loader	Cold (30°C)
HH13	Inefficient (12 L/min)	Short (4 min)	Front Loader	Warm (40°C)
HH14	Inefficient (12 L/min)	Short (4 min)	Front Loader	Cold (30°C)
HH15	Inefficient (12 L/min)	Long (10 min)	Front Loader	Warm (40°C)
HH16	Inefficient (12 L/min)	Long (10 min)	Front Loader	Cold (30°C)

[a] Efficient vs inefficient shower head flowrate (weighted average of efficient flowrate vs weighted average of inefficient flowrate), calculated from a distribution of typical shower head flowrates for YVW in Table 13 (Ghobadi et al. 2013). Assumption: shower head flowrates less than 9 L/min were considered efficient however, Table 13 in Ghobadi et al. (2013) grouped shower head flowrates in the following categories: >0 to ≤4, >4 to ≤8, >8 to ≤12, >12 to ≤16, >16 to ≤20, >20 to ≤24. Therefore shower head flowrates were calculated from distributions ≤8 L/min.
[b] Short vs long shower duration (weighted average of short shower duration vs weighted average of long shower duration), calculated from a frequency distribution of shower durations for YVW in Figure 12 (Roberts 2017). A key assumption is that a 4-minute shower is an achievable goal previously set during the Millennium Drought. Therefore shower durations less than 5 min (weighted average = 4 min) were categorised as short and shower durations above 5 min (ie, 6-15 min, weighted average = 10 min) were categorised as long.

Scenarios were then developed for testing the impact of potential interventions on residential water use, water-related energy use, and associated GHGs (Table 3-6).

The water utility actions evaluated for this case study were: (i) the potential to reduce residential water use through increased penetration of water efficient shower heads and water efficient clothes washers, and (ii) the potential to reduce water-related energy GHGs in the urban water system (eg, either through the implementation of water conservation measures such as increased penetration of water efficient shower heads or the use of clothes washers that are less reliant on the grid).

Table 3-6: Scenarios for testing simultaneous changes in water use, water-related energy use, associated GHGs, and household costs for Reservoir.

Technology Change Scenarios		Technology Change & Behaviour Change Scenarios	
S1	100% of households use a 6.3 L/min shower head.	**S2**	**S1** and every household member takes a maximum 4 min shower.
S3	100% of households use a front loader clothes washer.	**S4**	**S3** and every household uses a cold wash cycle.
S5	100% of households use a top loader clothes washer.	**S6**	**S5** and every household uses a cold wash cycle.
Assumptions			
S1	Reducing the shower head capacity from 12 L/min to 6.3 L/min.[a]	**S2**	**S1** and shower duration is reduced from 10 min down to 4 min (all year round).[b]
S3	All clothes washers are a front loader with a single plumbing connection.	**S4**	**S3** and changing the wash cycle temperature from a warm wash of 40°C to a cold wash of 30°C.
S5	All clothes washers are a top loader with dual plumbing connection.	**S6**	**S5** and changing the wash cycle temperature from 40°C to a cold wash cycle (ie, water temperature).

[a] Flow rates for efficient vs inefficient shower heads were derived from a distribution of typical flow rates of shower heads in YVW utility region households, Table 13, (Ghobadi et al. 2013).

[b] Shower times for short vs long shower durations were derived from the most recent ASUPS reporting frequency distribution of shower duration for YVW customers, Figure 12, (Roberts 2017).

Changes in shower head efficiency and clothes washing technology were evaluated through scenarios S1, S3, and S5 whilst the associated behaviour change in addition to the technology interventions were evaluated through scenarios S2, S4, and S6 (Table 3-6). Scenario S5 was proposed to test its potential effect on reducing water-related energy GHGs in the urban water system.

3.4 Household Water-Related Energy Results and Preliminary Cost Savings

3.4.1 Factors Affecting Household Consumption

Variability between individual households across the study site was captured through modelling the upper and lower bounds of the most significantly influential water-related energy use factors using localised data. For example, shower duration was modelled as either a short shower (4 minutes) or a long shower (10 minutes). Each household composition was modelled with 16 shower use and clothes washing use combinations. The water-related energy use quantified for each of the 16 types (described in Table 3-5), was divided into four quartiles and categorised as: low, moderate, high, or very-high water-related energy use households (Table 3-7).

Table 3-7: Water-related energy use characterisation (average kWh/person.day) of the 16 shower use and clothes washing use combinations for different household compositions.

Categories of Water-Related Energy Use		Shower Systems		Clothes Washing		Household Composition			
		Shower head Efficiency	Shower Duration	Clothes Washer	Wash Cycle	Group	Family with children	Family no children	Single
						Average kWh/person.day			
Low	H2	Efficient	Short	Top	Cold	1.1 ±0.3	1.5 ±0.4	1.5 ±0.5	2.3 ±0.9
	H10	Efficient	Short	Front	Cold	1.3 ±0.3	1.7 ±0.4	1.7 ±0.5	2.6 ±0.9
	H6	Inefficient	Short	Top	Cold	1.6 ±0.5	1.9 ±0.6	2.0 ±0.6	2.8 ±1.1
	H9	Efficient	Short	Front	Warm	1.6 ±0.2	2.0 ±0.4	2.1 ±0.4	3.2 ±0.8
Moderate	H14	Inefficient	Short	Front	Cold	1.8 ±0.5	2.1 ±0.6	2.2 ±0.6	3.1 ±1.1
	H4	Efficient	Long	Top	Cold	2.2 ±0.7	2.2 ±0.7	2.6 ±0.8	3.4 ±1.2
	H1	Efficient	Short	Top	Warm	1.8 ±0.5	2.3 ±0.7	2.4 ±0.7	3.5 ±1.2
	H13	Inefficient	Short	Front	Warm	2.1 ±0.5	2.4 ±0.6	2.6 ±0.6	3.6 ±1.0
High	H12	Efficient	Long	Front	Cold	2.4 ±0.7	2.4 ±0.7	2.8 ±0.8	3.7 ±1.2
	H5	Inefficient	Short	Top	Warm	2.3 ±0.7	2.6 ±0.8	2.9 ±1.0	4.0 ±1.4
	H11	Efficient	Long	Front	Cold	2.7 ±0.6	2.8 ±0.6	3.2 ±0.8	4.3 ±1.1
	HH3	Efficient	Long	Top	Warm	2.9 ±0.9	3.0 ±0.9	3.5 ±1.1	4.6 ±1.5
Very High	H8	Inefficient	Long	Top	Cold	3.8 ±1.3	3.3 ±1.1	4.2 ±1.4	5.0 ±1.7
	H16	Inefficient	Long	Front	Cold	3.9 ±1.3	3.4 ±1.1	4.4 ±1.4	5.3 ±1.7
	H15	Inefficient	Long	Front	Warm	4.2 ±1.3	3.8 ±1.0	4.7 ±1.4	5.8 ±1.7
	H7	Inefficient	Long	Top	Warm	4.7 ±1.5	4.0 ±1.3	5.1 ±1.7	6.1 ±2.1

ResWE model results demonstrate that shower systems (ie, shower head efficiency and shower duration) have the greatest impact on water-related energy use across all household types.

The lowest water-related energy use was modelled in households with a short shower duration, most of which had efficient shower heads. These households consumed on average 1.1-3.2 kWh/person.day. Moderate households consumed on average 25-40% (0.5-0.7 kWh/person.day) more water-related energy than low energy households. This group was modelled with a mix of short showers, efficient and inefficient shower heads. Households in the high category consumed on average 53-83% (0.9-1.4 kWh/person.day) more water-related energy than low energy households. These households were mostly modelled with efficient shower heads and long showers. Households in the very high category consumed on average 103-189% (1.8-2.8 kWh/person.day) more water-related energy than low energy households and were modelled with inefficient shower heads and long showers.

Greater variability of water-related energy use was observed in households with higher adult occupancy rates whilst single person dwellings consumed the most water-related energy per capita.

Households with a top loader clothes washer and using a warm wash cycle consumed at least 50% more energy than the lowest energy households. Front loader clothes washers used less water but more energy than top loaders on a cold wash cycle. However, the largest water and energy usage of all was for top loaders on a warm wash cycle.

3.4.2 Preliminary Household Cost Savings

Preliminary household cost savings for shower-related interventions were evaluated for combined water, water-related electricity, and water-related gas costs (Table 3-8 and Table 3-9).

Table 3-8: Average annual cost savings for water use and water-related energy use by upgrading shower heads to a more efficient model.[a, b]

Hot Water System Type	Average Annual Changes in Household Costs for Water, Electricity, and Gas in Reservoir (Δ $/household) – Scenario 1							
	Group		Family with Children		Family no Children		Single	
	Short Shower	Long Shower	Short Shower	Long Shower	Short Shower	Long Shower	Short Shower	Long Shower
Sol-E	-$124	-$397	-$137	-$406	-$137	-$402	-$45	-$148
Sol-G	-$98	-$287	-$103	-$290	-$99	-$280	-$37	-$108
Sto-E	-$203	-$586	-$208	-$583	-$201	-$570	-$76	-$221
Sto-G	-$126	-$353	-$128	-$352	-$121	-$340	-$48	-$134
Ins-G	-$135	-$379	-$136	-$377	-$130	-$365	-$51	-$143

[a] Short Shower: households that have the capacity for a shower head upgrade and take short showers. Long Shower: households that have the capacity for a shower head upgrade and take long showers.
[b] Sol-E = Solar-Electric Boost; Sol-G = Solar-Gas Boost; Sto-E = Electric Hot Water System with Storage; Sto-G = Gas Hot Water System with Storage; Ins-G = Instantaneous Gas Hot Water System.

The most significant shower-related cost savings could be accomplished in households that had the scope for reducing their showering time in addition to a shower head efficiency upgrade (see Tech Δ and Behav Δ, Table 3-9). The next significant cost savings were achieved in long shower taking households that could upgrade their shower heads, without the need for changing shower behaviour (see Long Shower, Table 3-8). Households that already use an efficient shower head but had the capacity to reduce their showering time achieved the next level of potential savings (see Behav Δ, Table 3-9). Whilst households that already take short showers but do not have the most efficient shower head model achieved the lowest amount of potential cost savings for shower related interventions (see Short Shower, Table 3-8).

Table 3-9: Average annual cost savings for water use and water-related energy use by upgrading shower head efficiency and reducing showering time.[a, b]

Hot Water	Average Annual Changes in Household Costs for Water, Electricity, and Gas in Reservoir (Δ $/household) – Scenario 2

System Type	Group		Family with Children		Family no Children		Single	
	Behav Δ	Tech Δ & Behav Δ	Behav Δ	Tech Δ & Behav Δ	Behav Δ	Tech Δ & Behav Δ	Behav Δ	Tech Δ & Behav Δ
Sol-E	-$259	-$656	-$253	-$659	-$247	-$649	-$98	-$247
Sol-G	-$176	-$463	-$175	-$465	-$169	-$449	-$67	-$175
Sto-E	-$357	-$943	-$349	-$932	-$343	-$913	-$135	-$357
Sto-G	-$211	-$564	-$208	-$560	-$203	-$543	-$80	-$214
Ins-G	-$227	-$605	-$223	-$600	-$218	-$583	-$86	-$229

[a] Behav Δ: households that already have an efficient shower head but have the capacity to reduce their shower duration (10 min to 4 min). Tech Δ and Behav Δ: households that have the capacity for a shower head upgrade (12 L/min to 6.3 L/min) and the capacity to reduce shower duration (10 min to 4 min).
[b] Sol-E = Solar-Electric Boost; Sol-G = Solar-Gas Boost; Sto-E = Electric Hot Water System with Storage; Sto-G = Gas Hot Water System with Storage; Ins-G = Instantaneous Gas Hot Water System.

Combined water, and water-related energy savings were also evaluated for clothes washers and wash cycles (Table 3-10, Table 3-11). Households that preferred to wash in cold water, achieved annual savings regardless of the clothes washer type (see Behav Δ, Table 3-10, Table 3-11).

Households that switched from a front loader to a top loader but still washed in warm water, increased their annual household costs most likely due to the increase in energy costs for an increase in the amount of water that needs to be heated (see Tech Δ, Table 3-11). However, the same households were able to achieve a greater reduction in household costs if they switched from a warm wash cycle to a cold wash cycle, ie, top loaders use the water supply temperature for a cold wash cycle resulting in the smallest energy costs per wash cycle (see Behav Δ, Table 3-11).

In this case study, front loader clothes washers were economical across a wider variety of household types. The exception was front loader households that had gas boosted solar hot water systems and chose a warm wash cycle (see Tech Δ, Table 3-10). These households could achieve annual savings by switching to a cold wash cycle thus reducing their energy costs.

Table 3-10: **Average annual changes in household costs for water use and water-related energy use by switching to a water efficient washing machine and a cold-water wash cycle.[a, b]**

Hot Water System Type	Average Annual Changes in Household Costs for Water, Electricity, and Gas in Reservoir (Δ $/household) – Scenarios 3 and 4							
	Group		Family with Children		Family no Children		Single	
	Tech Δ	Behav Δ	Tech Δ	Behav Δ	Tech Δ	Behav Δ	Tech Δ	Behav Δ
Sol-E	-$1	-$90	-$25	-$133	-$20	-$95	-$4	-$57
Sol-G	+$12	-$71	+$16	-$118	+$12	-$89	+$8	-$48
Sto-E	-$48	-$73	-$95	-$123	-$70	-$89	-$34	-$49
Sto-G	-$5	-$65	-$9	-$119	-$6	-$87	-$3	-$46
Ins-G	-$10	-$66	-$18	-$119	-$13	-$87	-$6	-$46

[a] Tech Δ: change in technology from top loader to a front loader. Behav Δ: change in behaviour ie, when a front loader household switches from a warm wash cycle to a cold wash cycle.

[b] Sol-E = Solar-Electric Boost; Sol-G = Solar-Gas Boost; Sto-E = Electric Hot Water System with Storage; Sto-G = Gas Hot Water System with Storage; Ins-G = Instantaneous Gas Hot Water System.

Table 3-11: **Average annual changes in household costs for water use and water-related energy use by switching to a top loader washing machine and a cold-water wash cycle.[a, b]**

Hot Water System Type	Average Annual Changes in Household Costs for Water, Electricity, and Gas in Reservoir (Δ $/household) – Scenarios 5 and 6							
	Group		Family with Children		Family no Children		Single	
	Tech Δ	Behav Δ	Tech Δ	Behav Δ	Tech Δ	Behav Δ	Tech Δ	Behav Δ
Sol-E	+$1	-$101	+$25	-$170	+$20	-$124	+$4	-$68
Sol-G	-$12	-$38	-$16	-$68	-$12	-$49	-$8	-$26
Sto-E	+$48	-$162	+$95	-$291	+$70	-$213	+$34	-$113
Sto-G	+$5	-$61	+$9	-$110	+$6	-$81	+$3	-$42
Ins-G	+$10	-$71	+$18	-$129	+$13	-$95	+$6	-$50

[a] Tech Δ: change in technology from front loader to top loader. Behav Δ: change in behaviour ie, when a top loader household changes from a warm wash cycle to a cold wash cycle.

[b] Sol-E = Solar-Electric Boost; Sol-G = Solar-Gas Boost; Sto-E = Electric Hot Water System with Storage; Sto-G = Gas Hot Water System with Storage; Ins-G = Instantaneous Gas Hot Water System.

The average costs applied to these evaluations were sourced from water, electricity, and gas distributors for Reservoir. Water delivery and sewage disposal costs were priced at 0.38 ¢/L (0-440 L/day), 0.42 ¢/L (441-880 L/day), and 0.58 ¢/L (881+ L/day), from Yarra Valley Water, (ESC 2018). Electricity costs were priced at 26.99 ¢/kWh, based on an average of Jemena (local electricity distributor for postcode 3073) market offers in January 2020 (average $/kWh, basis of 1,200 kWh/yr, single rate) (SVDP 2020a). Gas costs were priced at 8.02 ¢/kWh, based on an average of AGN Central 2 (gas coverage for postcode 3073) market offers in January 2020 (average $/kWh, basis of 17,500 kWh/yr) (SVDP 2020b).

We recognise that we have modelled household costs using an average value of available market offers for Reservoir (January 2020). However, water and energy tariffs could impact a wide range of household costs, but that level of modelling is beyond the scope of the current project.

3.5 Baseline of Regional Water, Energy, and GHGs for Reservoir

Baseline conditions for Reservoir's (postcode 3073) water, energy and GHG suburb totals were based on the 2016 population of 50,132 residents living across 20,845 households. Suburb totals were estimated to be: 2.8 GL/yr water use, 21.9 GWh/yr water-related electricity use, 32.7 GWh/yr water-related gas use, and 29.5 ktCO_2-e/yr of water-related energy GHG emissions (see Figure 3-5 for a baseline comparison with scenario savings).

3.6 Scenario Results and Potential Savings (the prize)

3.5.1 Impact of Scenarios on Regional Consumption

Across the six technology and behaviour change scenarios, the regional model predicted that increasing efficient shower head penetration and reducing shower duration (S2) would cause the greatest reductions in water, water-related energy and GHGs across the study site. This provided an estimated annual water use reduction of -15% (-0.4 GL/yr), water-related electricity use reduction of -10% (2.2 GWh/yr), water-related gas use reduction of -30% (-9.8 GWh/yr), and associated GHG emissions reduction of -15% (-4.3 ktCO_2-e/yr) (Figure 3-5 (a-d), Table 3-12).

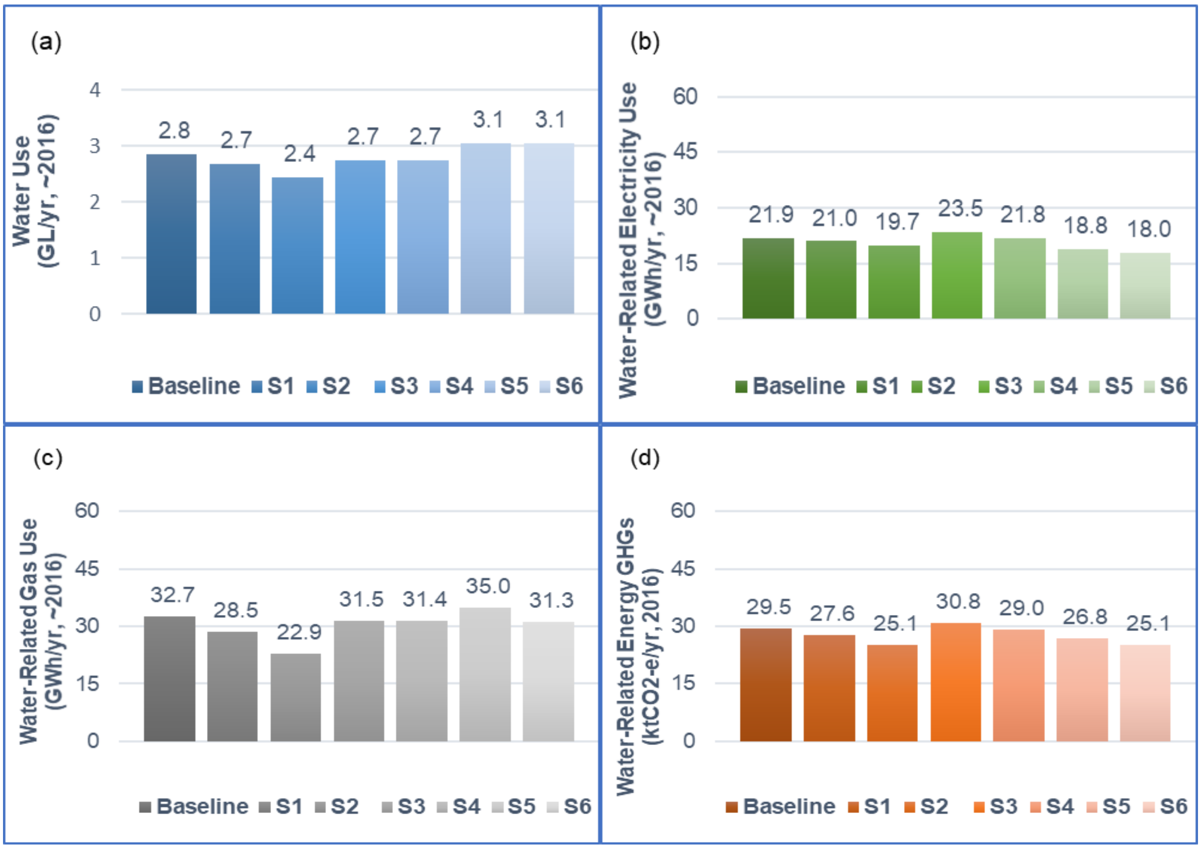

Figure 3-5: Reservoir baseline model and scenario (S1-S6) results in annual changes for: (a) water use, (b) water-related electricity use, (c) water-related gas use, and (d) GHG emissions.[6]

6 Scenarios: S1 – every household has an efficient shower head (6.3 L/min or less); S2 – every household has an efficient shower head (6.3 L/min or less), and every shower event is a maximum of 4 min; S3 – every household uses a front loader; S4 – every household uses a front loader and washes in cold water; S5 – every household uses a top loader; and S6 every household uses a top loader and washes in cold water.

Excluding behaviour change, the next largest potential reduction in water, water-related gas and GHGs came from installing efficient shower heads (S1) in households that have not yet upgraded. This was not the case for water-related electricity use. The second largest reduction in regional water-related electricity use resulted from swapping out front loader washing machines with top loader washing machines.

An increase in the use of front loaders compared with an increase in the use of top loaders had a mixed impact on annual water use, water-related energy use and associated GHGs.

Replacing top loaders with front loaders reduced Reservoir's annual water use by -4% (-0.1 GL/yr) and had a mixed impact on both water-related energy use from -2.5% to +0.7% (-1.4 to +0.4 GWh/yr), and GHG emissions from -1% to +5% (-0.4 to +1.4 ktCO_2-e/yr) due to the increased reliance on the electricity grid and the wash cycle temperature selection.

Replacing front loaders with top loaders increased Reservoir's annual water use by +7% (+0.2 GL/yr) but reduced both water-related energy use by -0.4 to -8% (-0.2 to -5.2 GWh/yr) and associated GHGs by -7 to -12% (-2.4 to -4.2 ktCO_2-e/yr).

Consequently, an increase in the penetration of front loaders reduced regional water use at the unexpected cost of increasing regional GHGs unless there is an increase in households choosing a cold wash cycle, which would be unlikely with current hygiene practices for COVID-19. Conversely, an increase in the penetration of top loaders increased regional water use but reduced regional water-related energy GHGs due to a reduction in the reliance on the electricity grid as most households used gas hot water systems in this study site. These results present a clothes washing paradox.

Table 3-12: Reservoir's scenario impacts on regional water use, water-related electricity use, water-related gas use, and associated GHGs.

	Impact of Scenarios on Regional Resources in Reservoir (3073)			
	Water (GL/Yr)	Electricity (GWh/Yr)	Gas (GWh/Yr)	GHGs (ktCO_2-e/Yr)
Scenario 1 (S1)	-0.2	-0.9	-4.2	-1.8
Scenario 2 (S2)	-0.4	-2.2	-9.8	-4.3
Scenario 3 (S3)	-0.1	+1.6	-1.2	+1.4
Scenario 4 (S4)	-0.1	-0.1	-1.3	-0.4
Scenario 5 (S5)	+0.2	-3.1	+2.3	-2.6
Scenario 6 (S6)	+0.2	-3.9	-1.4	-4.3

Economies of scale meant that household size affected water and energy use per capita. Smaller occupancy households (ie, singles and families without children) were the largest consumers per capita where a combined 55% of Reservoir's population lived in 70% of households and consumed 60% of resources (Figure 3-6). Conversely, larger occupancy households (ie, groups and families with children) were the lowest consumers per capita where 45% of the population lived in 30% of the household stock and consumed 40% of resources.

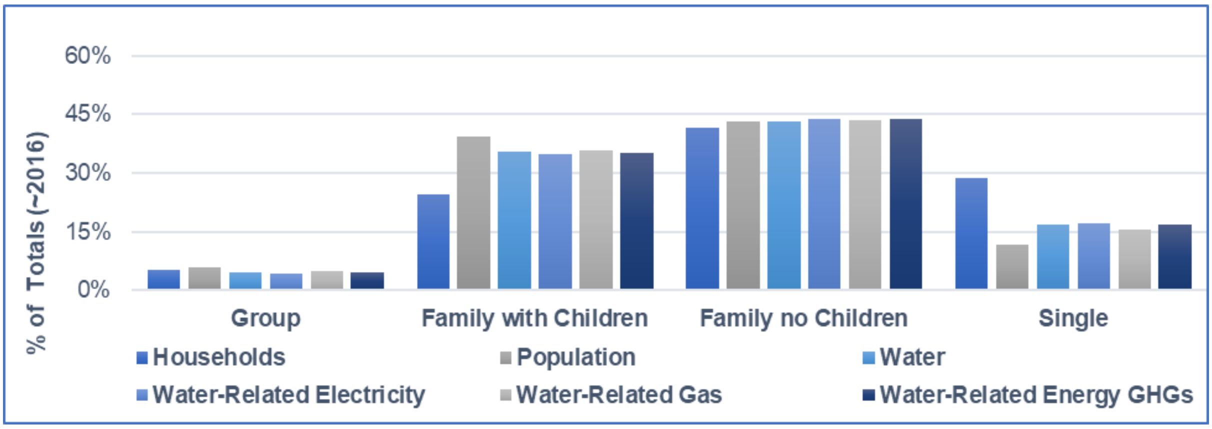

Figure 3-6: Household composition impact on regional water use, water-related energy use, and associated GHGs for Reservoir.

4 Frankston: Residential Water Use, Related Energy and GHG Emissions (Case Study 2)

Regional water use, water-related energy use and associated GHG emissions were modelled through the Overview Model developed in Appendix B using census data and local water authority information to characterise the distribution of different household types. The model was used to evaluate and compare changes in regional water and energy demand through technological and behaviour change scenarios.

4.1 Frankston Site: Background Information

The site selected for Case Study 2 was the suburb of "Frankston" in the South East Water (SEW) utility region, Melbourne, Australia (postal boundary 3199, Figure 4-1).

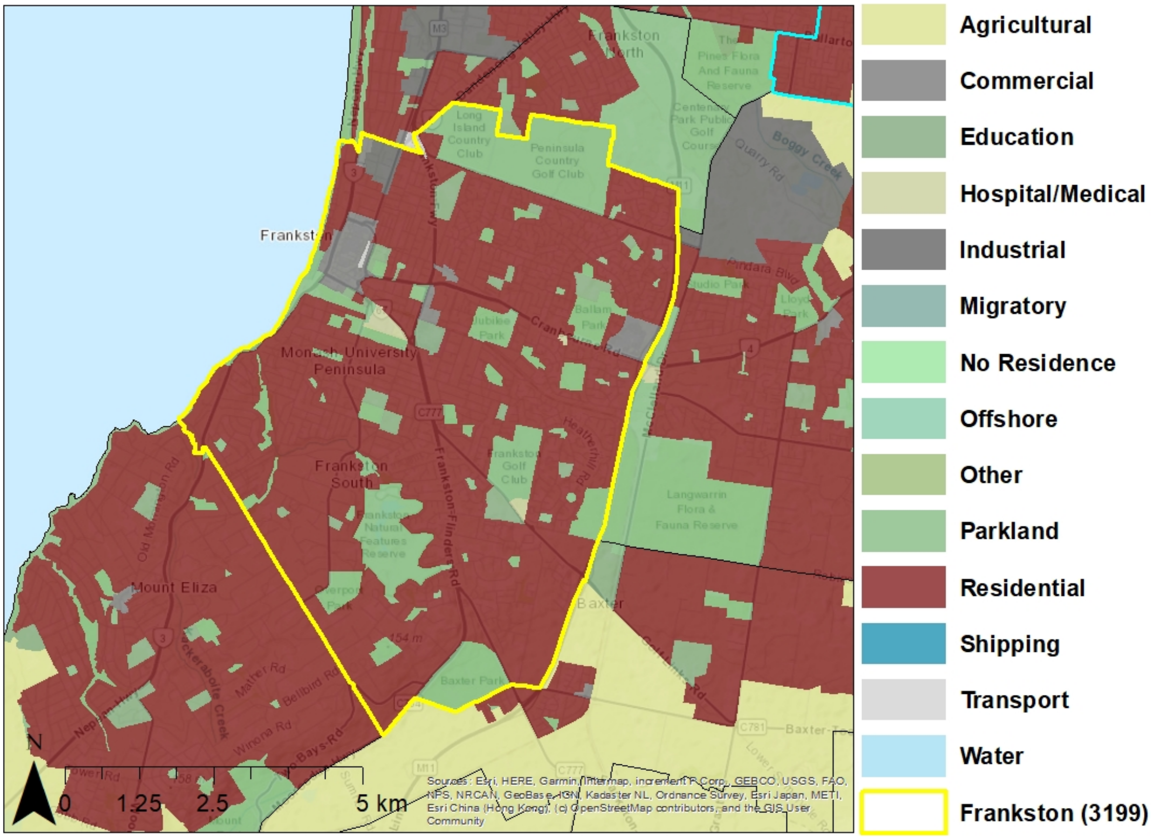

Figure 4-1: Frankston' postal boundary (3199) land use classifications, Melbourne, Australia (ABS 2013c, 2011b).

The most recent census data shows that Frankston's postcode boundary (3199) includes 54,298 people (48.2% Male, 51.8% Female), and 24,438 households (ABS 2017, 2020b). The climate region is classified as a mild temperate climate zone with a low diurnal temperature range, with four distinct seasons (ABS 2013a), and a median annual rainfall between 500-800 mm (BOM 2005).

Socio-economic diversity, inclusive of vulnerable communities is important for identifying a broad spectrum of resource efficiency solutions across the customer base. The Socio-Economic Indexes for Areas (SEIFA) Indexes, illustrate socio-economic diversity within Frankston precinct (postcode boundary 3199) at the Statistical Area Level 1 (SA1) data resolution scale (Figure 4-2, Figure 4-3, and

Table 4-1). Frankston is classified as the 5th decile – Index of Relative Socio-economic Disadvantage, 6th decile – Index of Relative Socio-economic Advantage and Disadvantage, 4th decile – Index of Economic Resources, and 6th decile – Index of Employment and Occupation (ABS 2018). Within these Indexes there is socio-economic representation across all deciles at SA1 level data resolution except for the Index of Employment and Occupation where there is only representation across the middle 8 deciles (ABS 2018). At least 133 SA1 level areas within the Frankston precinct have a SEIFA score in all four Indexes (ABS 2018).

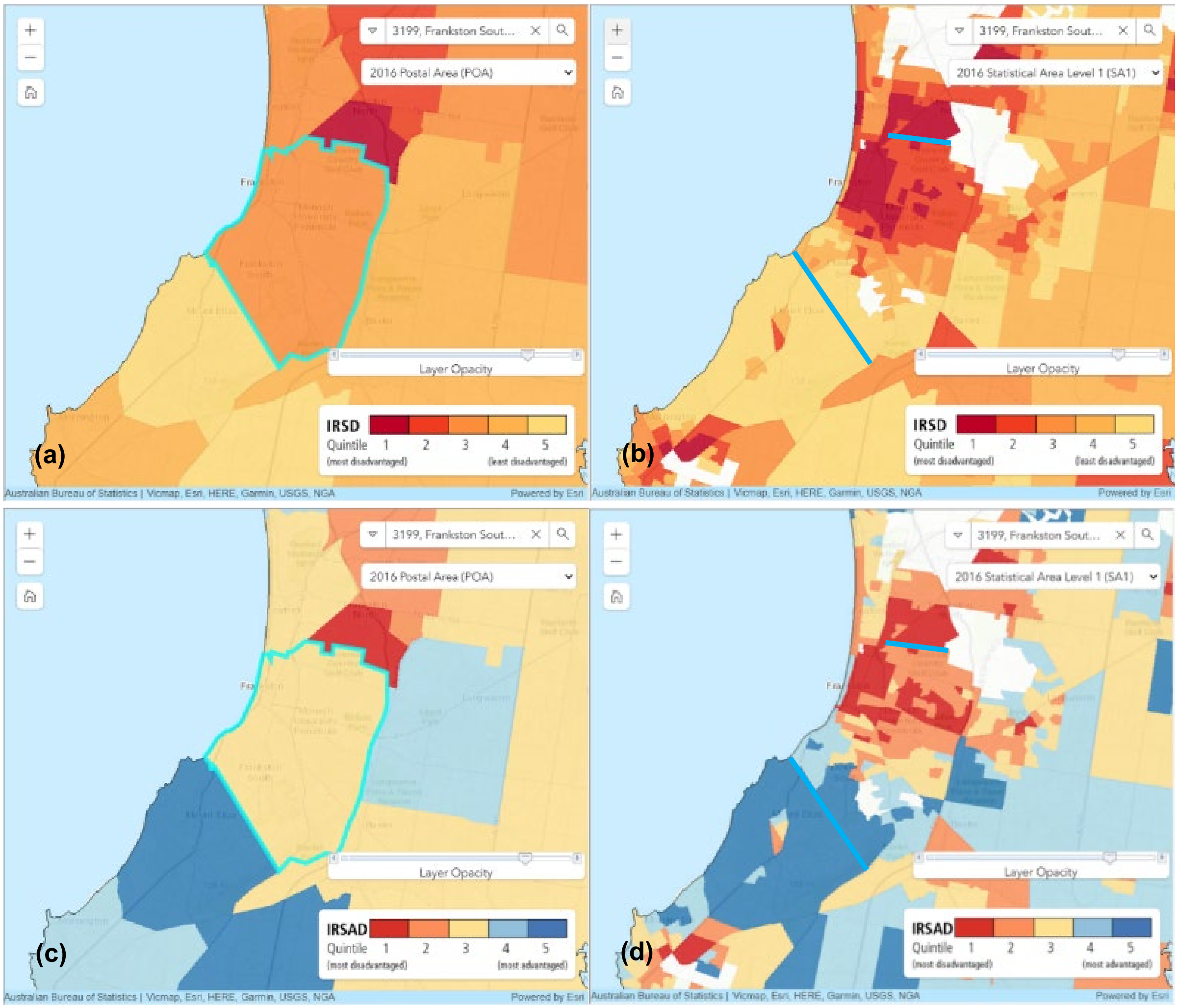

Figure 4-2: SEIFA indicators for Frankston precinct (3199): (a) postcode level SEIFA indicator from the Index of Relative Socio-Economic Disadvantage (IRSD); (b) SA1 level SEIFA indicator distribution from the Index of Relative Socio-Economic Disadvantage (IRSD); (c) postcode level SEIFA indicator from the Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD); and (d) SA1 level SEIFA indicator distribution from the Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD) (ABS 2018). Note in in sub-figures b and d only the northern and southern site boundary is shown.

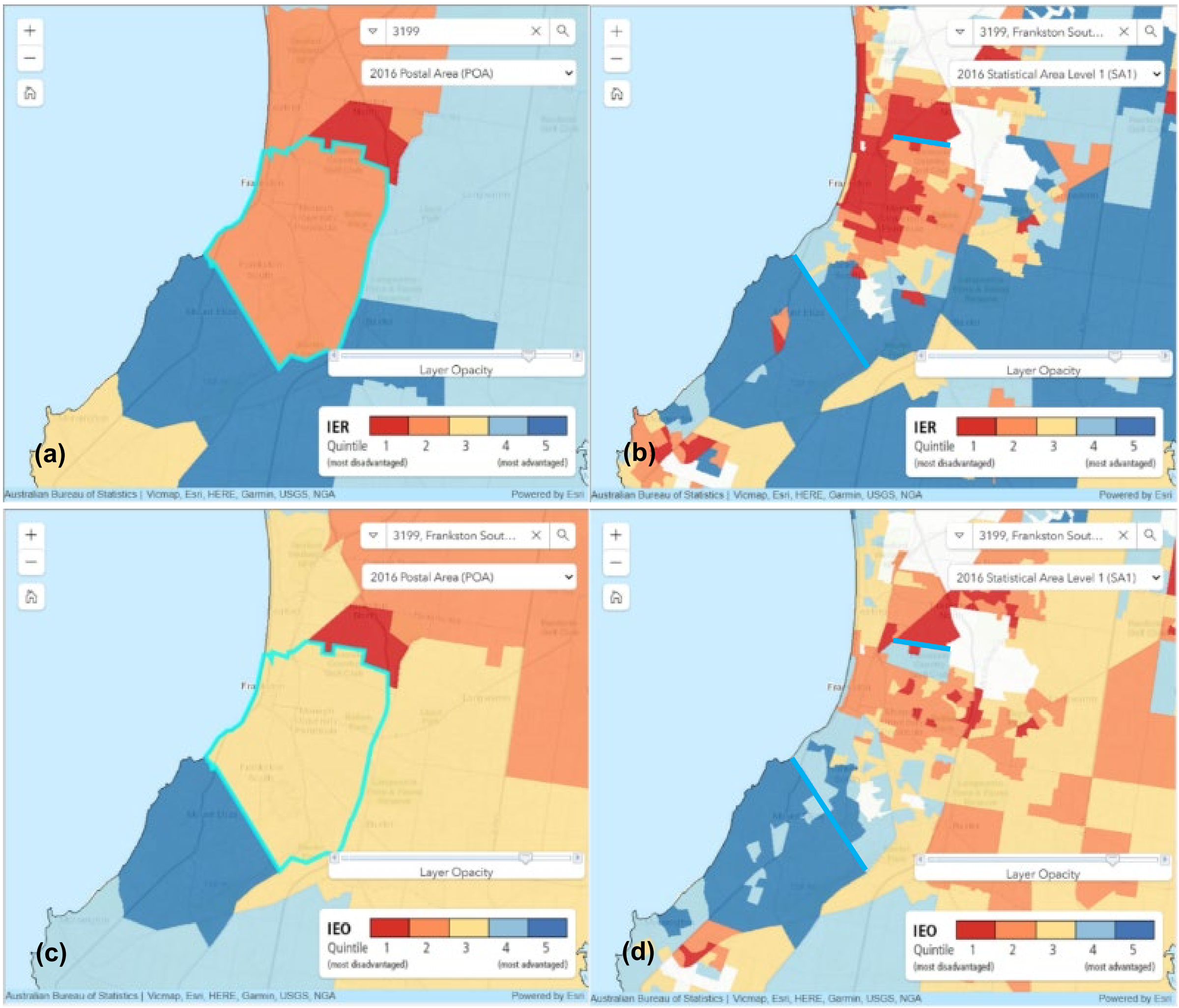

Figure 4-3: SEIFA indicators for Frankston precinct (3199): (a) postcode level SEIFA indicator from the Index of Economic Resources (IER); (b) SA1 level SEIFA indicator distribution from the Index of Economic Resources (IER); (c) postcode level SEIFA indicator from the Index of Employment and Occupation (IEO); and (d) SA1 level SEIFA indicator distribution from the Index of Employment and Occupation (IEO) (ABS 2018). Note in in sub-figures b and d only the northern and southern site boundary is shown.

Table 4-1: SEIFA SA1 level distribution indicators for socio-economic diversity in Frankston.

Index	Decile Distribution of the Statistical Area Level 1s (SA1s) for Frankston Precinct (Postcode 3199)										
	Decile 1	Decile 2	Decile 3	Decile 4	Decile 5	Decile 6	Decile 7	Decile 8	Decile 9	Decile 10	Total SA1s
IRSD	7	17	23	21	10	10	13	10	10	12	133
IRSAD	7	19	26	18	16	7	14	12	10	4	133
IER	16	16	17	20	14	11	11	11	4	14	134
IEO	0	5	21	26	14	21	16	23	7	0	133
IRSD – Index of Relative Socio-Economic Disadvantage; IRSAD – Index of Relative Socio-Economic Advantage and Disadvantage; IER – Index of Economic Resources; IEO – Index of Employment and Occupation											

4.2 Frankston Site: What makes Frankston Precinct a Good Site for this Study?

Several areas within the SEW distribution area were considered for case study analysis (Frankston, Baxter, and Aquarevo). Table 4-2 presents the primary criteria summary for the selected Case Study site of the Frankston precinct (postcode boundary 3199).

Table 4-2: Primary criteria for Case Study 2 site selection.

Criteria	Frankston precinct (postcode 3199)
1.1. Opportunity for the application of new pathways for historic options which have been hard in the past.	The Frankston demographic is the most hardship area of the areas suggested. However, the postcode boundary of 3199 also represent populations of quintiles 1-5 (of 5) in all categories (ABS 2018).
1.2. Benefits to residents in the area and across Melbourne. Builds the capacity to engage with vulnerable communities.	
2. Ability to scale solutions at later stages, ie, applicability of the results to all of Melbourne.	The advantage of this case study is that it presents a new opportunity to utilise higher resolution digital meter data in diverse socio-demographic groups. This creates the potential to provide relevant information to the wider roll-out of digital water meters across Melbourne which is anticipated in the next 3-5 years.
3. Area subject to development pressure.	Uncertain, need to confirm.
4. Availability of detailed data to model and verify results across water use, electricity use, gas use, and understanding of water-related energy GHGs.	Frankston East, some 800 digital meters have been installed for most of 2020. There was also an App trial of ~100 households in a nearby area which was targeted to hardship community. Frankston has been studied for leak detection, etc, which may have relevant data. Noted that the 100 households at Aquarevo have perhaps the most highly detailed water-energy datasets in Australia. While this is not in the demographic sought (ie, it does not contain significant hardship communities) it may provide an area to test different aspects of the modelling analysis and solutions/options implementation.
5. Utility willingness to provide in-kind technical support/data for Phase 1 of this project but ideally over the planned duration of Project 1 (~3 years).	SEW is willing to provide data for the area. A data agreement between SEW and UQ has been confirmed.

4.3 Methodology for Characterising Impacts of Potential Interventions

4.3.1 Model for Characterising Impacts of Potential Interventions

An Overview Model has been created to estimate the water use, water-related energy use, associated GHG emission, and costs for the Frankston precinct. Local water authority data and census data have been used to characterise changes in household technology and behaviour that influence water-related energy use (eg, household composition, hot water system type, shower systems and clothes washers).

Key Overview Model functions include: (a) quantify the residential baseline of water use, related energy use, associated GHGs, and costs; and (b) scenario testing of various interventions to quantify the potential change in residential water use, water-related energy use, associated GHGs, and costs. This is important for guiding later phases of research and to help quantify the order of magnitude influence for potential asset deferrals. A summary of the Overview Model development is presented in Appendix B, and a summary of data inputs used in the Overview Model is presented in Chapter 4.

4.3.2 Scenarios for Estimating the Potential Reduction of Residential Water Use, Water-Related Energy Use, and GHGs

A base case of resource use was established by quantifying water use, water-related energy use, and GHGs for different household types. Variability within household types was captured through household composition (Table 4-3), hot water system types (see Chapter 5, Table 5-5), shower systems, and clothes washing (Table 4-4).

Table 4-3: Household composition for quantifying resource use in Frankston precinct.

Household Composition	Family with Children	Family no Children	Single	Group
Number of Adults	1.84	2.27	0.94	3.01
Number of Children	1.76	-	-	-

Table 4-4: Shower and clothes washing combinations for quantifying resource use in Frankston precinct.

Household #	Shower head Efficiency	Shower Duration	Clothes Washer	Wash Cycle
HH1	Efficient (6.9 L/min)	Short (4 min)	Top Loader	Warm (40°C)
HH2	Efficient (6.9 L/min)	Short (4 min)	Top Loader	Cold (tap temp.)
HH3	Efficient (6.9 L/min)	Long (10 min)	Top Loader	Warm (40°C)
HH4	Efficient (6.9 L/min)	Long (10 min)	Top Loader	Cold (tap temp.)
HH5	Inefficient (12 L/min)	Short (4 min)	Top Loader	Warm (40°C)
HH6	Inefficient (12 L/min)	Short (4 min)	Top Loader	Cold (tap temp.)
HH7	Inefficient (12 L/min)	Long (10 min)	Top Loader	Warm (40°C)
HH8	Inefficient (12 L/min)	Long (10 min)	Top Loader	Cold (tap temp.)

Household #	Shower head Efficiency	Shower Duration	Clothes Washer	Wash Cycle
HH9	Efficient (6.9 L/min)	Short (4 min)	Front Loader	Warm (40°C)
HH10	Efficient (6.9 L/min)	Short (4 min)	Front Loader	Cold (30°C)
HH11	Efficient (6.9 L/min)	Long (10 min)	Front Loader	Warm (40°C)
HH12	Efficient (6.9 L/min)	Long (10 min)	Front Loader	Cold (30°C)
HH13	Inefficient (12 L/min)	Short (4 min)	Front Loader	Warm (40°C)
HH14	Inefficient (12 L/min)	Short (4 min)	Front Loader	Cold (30°C)
HH15	Inefficient (12 L/min)	Long (10 min)	Front Loader	Warm (40°C)
HH16	Inefficient (12 L/min)	Long (10 min)	Front Loader	Cold (30°C)

[a] Efficient vs inefficient shower head flowrate (weighted average of efficient flowrate vs weighted average of inefficient flowrate), calculated from a distribution of typical shower head flowrates for SEW in Table 13 (Ghobadi et al. 2013). Assumption: shower head flowrates less than 9 L/min were considered efficient however, Table 13 in Ghobadi et al. (2013) grouped shower head flowrates in the following categories: >0 to ≤4, >4 to ≤8, >8 to ≤12, >12 to ≤16, >16 to ≤20, >20 to ≤24. Therefore shower head flowrates were calculated from distributions ≤8 L/min.

[b] Short vs long shower duration (weighted average of short shower duration vs weighted average of long shower duration), calculated from a frequency distribution of shower durations from a SEW dataset (SEW 2021b). A key assumption is that a 4-minute shower is an achievable goal previously set during the Millennium Drought. Therefore shower durations less than 6 min (weighted average = 4 min) were categorised as short and shower durations above 6 min (ie, 6 min to 55 min, weighted average = 10 min) were categorised as long.

This captured the variability in household types across a region and provided an estimation of the base case for water use, water-related energy use, and GHGs. See Section 5.1 for detailed information on characterising variability between household types.

Scenarios were developed for testing the impact of potential interventions on residential water use, water-related energy use, associated GHGs, and household costs (Table 4-5).

The water utility actions evaluated for this study were: (i) the potential to reduce residential water use through increased penetration of water efficient shower heads and water efficient clothes washers, and (ii) the potential to reduce water-related energy GHGs in the urban water system (eg, either through the implementation of water conservation measures such as increased penetration of water efficient shower heads or the use of clothes washers that are less reliant on the grid).

Changes in shower head efficiency and clothes washing technology were evaluated through scenarios S1, S3, and S5 whilst the associated behaviour change in addition to the technology interventions were evaluated through scenarios S2, S4, and S6 (Table 4-5). Scenario S5 (ie, installation of a top loader clothes washer) was proposed to test its effects on the potential for reducing water-related energy GHGs in the urban water system.

Table 4-5: Scenarios for testing simultaneous changes in water use, water-related energy use, associated GHGs, and household costs for Frankston precinct (postcode boundary 3199).

Technology Change Scenarios		Technology Change & Behaviour Change Scenarios	
S1	100% of households use a 6.9 L/min shower head.	**S2**	**S1** and every household member takes a maximum 4 min shower.
S3	100% of households use a front loader clothes washer.	**S4**	**S3** and every household uses a cold wash cycle.
S5	100% of households use a top loader clothes washer.	**S6**	**S5** and every household uses a cold wash cycle.
Assumptions			
S1	Reducing the shower head capacity from 12 L/min to 6.9 L/min.[a]	**S2**	**S1** and shower duration is reduced from 10 min down to 4 min (all year round).[b]
S3	All clothes washers are a front loader with a single plumbing connection.	**S4**	**S3** and changing the wash cycle temperature from a warm wash of 40°C to a cold wash of 30°C.
S5	All clothes washers are a top loader with dual plumbing connection.	**S6**	**S5** and changing the wash cycle temperature from 40°C to a cold wash cycle (ie, water temperature).

[a] Flow rates for efficient vs inefficient shower heads were derived from a distribution of typical flow rates of shower heads in SEW utility region households, Table 13, (Ghobadi et al. 2013).

[b] Shower times for short vs long shower durations were derived from a distribution of customer perception of their shower usage after their participation in the mySEW Trial, Figure 5.4, (Byrne and Martin 2017) and a SEW shower use dataset (SEW 2021b).

4.4 Preliminary Cost Savings for Frankston Households

4.4.1 Factors Affecting Household Consumption

Factors affecting household consumption can be found in Chapter 3, Table 3-7.

4.4.2 Preliminary Household Cost Savings

Preliminary household cost savings for upgrading shower heads with a more efficient model were evaluated for combined water, water-related electricity, and water-related gas costs in Table 4-6. Table 4-7 demonstrates the combined cost savings households upgrading their shower head and reducing their showering time.

The most significant cost savings could be accomplished in households that had the scope for reducing their showering time in addition to a shower head efficiency upgrade (see Tech Δ and Behav Δ, Table 4-7). The next significant cost savings were achieved in long shower taking households that could upgrade their shower heads, without the need for changing shower behaviour (see Long Shower, Table 4-6). Households that already use an efficient shower head but had the capacity to reduce their showering time achieved the next level of cost savings (see Behav Δ, Table 4-7). Whilst households that take short showers but do not have the most efficient shower head model achieved the lowest amount of potential cost savings for shower related interventions (see Short Shower, Table 4-6).

Table 4-6: Average annual cost savings for water use and water-related energy use by upgrading shower heads to a more efficient model.[a, b]

Hot Water System Type	Average Annual Changes in Household Costs for Water, Electricity and Gas in Frankston Precinct (Δ $/household) – Scenario 1							
	Group		Family with Children		Family no Children		Single	
	Short Shower	Long Shower	Short Shower	Long Shower	Short Shower	Long Shower	Short Shower	Long Shower
Sol-E	-$128	-$411	-$113	-$335	-$111	-$326	-$38	-$125
Sol-G	-$99	-$288	-$82	-$232	-$78	-$221	-$30	-$89
Sto-E	-$213	-$614	-$174	-$487	-$165	-$468	-$66	-$190
Sto-G	-$127	-$358	-$103	-$284	-$96	-$269	-$40	-$111
Ins-G	-$136	-$384	-$110	-$304	-$103	-$290	-$42	-$119

[a] Short Shower: households that have the capacity for a shower head upgrade but take short showers. Long Shower: households that have the capacity for a shower head upgrade and take long showers (8 min).

[b] Sol-E = Solar-Electric Boost; Sol-G = Solar-Gas Boost; Sto-E = Electric Hot Water System with Storage; Sto-G = Gas Hot Water System with Storage; Ins-G = Instantaneous Gas Hot Water System.

Table 4-7: Average annual cost savings for water use and water-related energy use by upgrading shower head efficiency and reducing showering time.[a, b]

Hot Water System Type	Average Annual Changes in Household Costs for Water, Electricity, and Gas in Frankston Precinct (Δ $/household) – Scenario 2							
	Group		Family with Children		Family no Children		Single	
	Behav Δ	Tech Δ & Behav Δ	Behav Δ	Tech Δ & Behav Δ	Behav Δ	Tech Δ & Behav Δ	Behav Δ	Tech Δ & Behav Δ
Sol-E	-$301	-$711	-$233	-$568	-$224	-$550	-$94	-$219
Sol-G	-$198	-$486	-$156	-$389	-$149	-$369	-$62	-$151
Sto-E	-$419	-$1,033	-$325	-$812	-$314	-$782	-$130	-$320
Sto-G	-$239	-$597	-$187	-$471	-$180	-$449	-$74	-$185
Ins-G	-$257	-$641	-$201	-$505	-$193	-$483	-$80	-$199

[a] Behav Δ: households that already have an efficient shower head but have the capacity to reduce their shower duration (8 min to 4 min). Tech Δ and Behav Δ: households that have the capacity for a shower head upgrade (12 L/min to 6.9 L/min) and the capacity to reduce shower duration (8 min to 4 min).

[b] Sol-E = Solar-Electric Boost; Sol-G = Solar-Gas Boost; Sto-E = Electric Hot Water System with Storage; Sto-G = Gas Hot Water System with Storage; Ins-G = Instantaneous Gas Hot Water System.

Considering the pandemic and the increased advocacy for using warm wash cycles (Iredale 2020), it is important to take a closer look at clothes washing scenarios. The average annual changes in household costs were also evaluated for clothes washers and wash cycles (Table 4-8, Table 4-9, detailed clothes washing inputs presented in Table 5-8).

Cold wash households achieved annual savings regardless of the clothes washer type (see Behav Δ, Table 4-8, Table 4-9). Most households that switched from a front loader to a top loader but washed in warm water, increased their annual household costs most likely due to the energy costs associated with the increased use of warm water (ie, top loaders use more water than front loaders thus need more energy to heat up the water, see Tech Δ, Table 4-9).

More importantly, front loader clothes washers were economical across a wider variety of household types and were typically more economical than top loaders for a warm wash cycle. The key exception was warm wash front loader households that had gas boosted solar hot water systems (see Tech Δ, Table 4-8). The increased costs in these households were most likely due to the increased use of electricity that would not be used otherwise.

Table 4-8: Average annual changes in household costs for water use and water-related energy use by switching to a water efficient washing machine and a cold-water wash cycle.[a, b]

Hot Water System Type	Average Annual Changes in Household Costs for Water, Electricity, and Gas in Frankston Precinct (Δ $/household) – Scenarios 3 and 4							
	Group		Family with Children		Family no Children		Single	
	Tech Δ	Behav Δ	Tech Δ	Behav Δ	Tech Δ	Behav Δ	Tech Δ	Behav Δ
Sol-E	+$3	-$109	-$17	-$128	-$14	-$89	-$2	-$56
Sol-G	+$19	-$85	+$23	-$114	+$17	-$84	+$11	-$47
Sto-E	-$53	-$88	-$84	-$118	-$61	-$85	-$31	-$49
Sto-G	$0	-$79	$0	-$114	$0	-$82	+$1	-$45
Ins-G	-$6	-$79	-$8	-$114	-$6	-$82	-$3	-$45

[a] Tech Δ: change in technology from top loader to a front loader. Behav Δ: change in behaviour, ie, when a front loader household switches from a warm wash cycle to a cold wash cycle.

[b] Sol-E = Solar-Electric Boost; Sol-G = Solar-Gas Boost; Sto-E = Electric Hot Water System with Storage; Sto-G = Gas Hot Water System with Storage; Ins-G = Instantaneous Gas Hot Water System.

Table 4-9: Average annual changes in household costs for water use and water-related energy use by switching to a top loader clothes washer and a cold-water wash cycle.[a, b]

Hot Water System Type	Average Annual Changes in Household Costs for Water, Electricity, and Gas in Frankston Precinct (Δ $/household) – Scenarios 5 and 6							
	Group		Family with Children		Family no Children		Single	
	Tech Δ	Behav Δ	Tech Δ	Behav Δ	Tech Δ	Behav Δ	Tech Δ	Behav Δ
Sol-E	-$3	-$122	+$17	-$163	+$14	-$117	+$2	-$67
Sol-G	-$19	-$45	-$23	-$63	-$17	-$44	-$11	-$25
Sto-E	+$53	-$196	+$84	-$280	+$61	-$202	+$31	-$111
Sto-G	$0	-$71	$0	-$102	$0	-$74	-$1	-$40
Ins-G	+$6	-$83	+$8	-$120	+$6	-$87	+$3	-$47

[a] Tech Δ is a change in technology from front loader to top loader. Behav Δ is change in behaviour, ie, when a top loader household changes from a warm wash cycle to a cold wash cycle.

[b] Sol-E = Solar-Electric Boost; Sol-G = Solar-Gas Boost; Sto-E = Electric Hot Water System with Storage; Sto-G = Gas Hot Water System with Storage; Ins-G = Instantaneous Gas Hot Water System.

At the time of analysis, the average costs applied to these evaluations were sourced from water, electricity, and gas distributors for the Frankston precinct. Water delivery and sewage disposal costs were priced at 0.36 ¢/L (0-440 L/day), and 0.43 ¢/L (441+ L/day), from South East Water (SEW 2020). Electricity costs were priced at 28.03 ¢/kWh, based on an average of United Energy (local electricity distributor for postcode 3199) market offers in January 2020 (average $/kWh, basis of 1,200 kWh/yr, single rate)(SVDP 2020a). Gas costs were priced at 8.04 ¢/kWh, based on an average of AGN Central 1 (gas coverage for postcode 3199) market offers in January 2020 (average $/kWh, basis of 17,500 kWh/yr) (SVDP 2020b).

We recognise that we have modelled household costs using an average value of available market offers for the Frankston precinct (January 2020). However, water and energy tariffs could impact a wide range of household costs, but that level of modelling is beyond the scope of the current project.

4.5 Baseline of Regional Water, Energy and GHGs for Frankston Precinct

Baseline conditions for Frankston precincts (postcode 3099) water, energy and GHG suburb totals were based on the 2016 population of 54,298 residents living across 24,438 households. Suburb totals were estimated to be: 3.1 GL/yr water use, 21.7 GWh/yr water-related electricity use, 42.5 GWh/yr water-related gas use, and 31.4 ktCO$_2$-e/yr of water-related energy GHG emissions (see Figure 4-4 for a baseline model comparison with scenario savings).

4.6 Scenario Results and Potential Savings (the prize)

Across the six technology and behaviour change scenarios, the regional model predicted that increasing efficient shower head penetration and reducing shower duration (S2) would cause the greatest reductions in water, water-related energy and GHGs across the study site. This provided an estimated annual water use reduction of -20% (-0.6 GL/yr), water-related electricity use reduction of -15% (3.3 GWh/yr), water-related gas use reduction of -38% (-16 GWh/yr), and associated GHG emissions reduction of -22% (-6.8 $ktCO_2$-e/yr) (Figure 4-4 (a-d), Table 4-10). Excluding behaviour change, the next largest combined resource reduction came from households that had the capacity to install a more efficient shower head (S1).

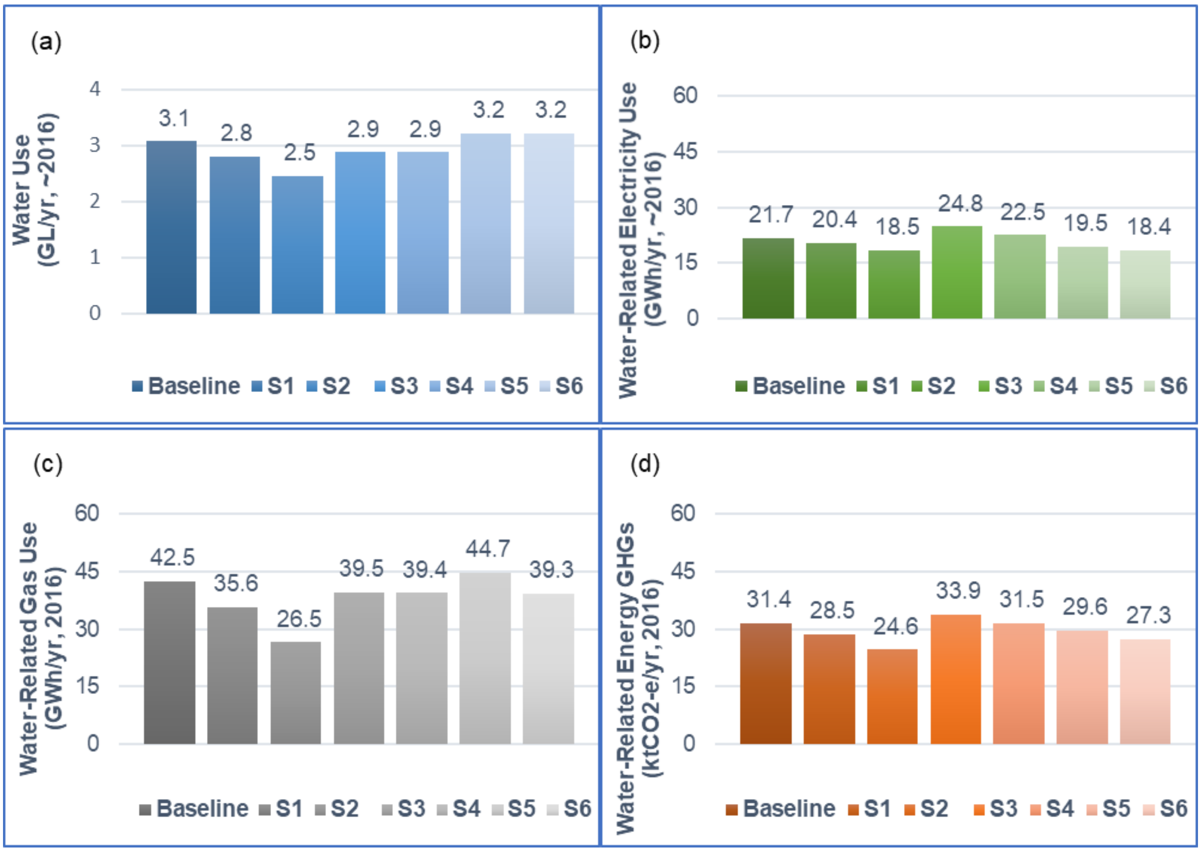

Figure 4-4: Frankston precinct baseline and scenario (S1-S6) results in annual changes for: (a) water use, (b) water-related electricity use, (c) water-related gas use, and (d) GHG emissions.[7]

Table 4-10: Scenario impacts on Frankston precincts regional water use, water-related electricity use, water-related gas use, and associated GHGs.

	Impact of Scenarios on Regional Resources in Frankston Precinct (3199)			
	Water (GL/yr)	Electricity (GWh/yr)	Gas (GWh/yr)	GHGs ($ktCO_2$-e/yr)
Scenario 1 (S1)	-0.3	-1.4	-6.9	-2.9
Scenario 2 (S2)	-0.6	-3.3	-16.0	-6.8
Scenario 3 (S3)	-0.2	+3.07	-3.04	+2.5
Scenario 4 (S4)	-0.2	+0.8	-3.1	+0.1
Scenario 5 (S5)	+0.1	-2.2	+2.2	-1.8
Scenario 6 (S6)	+0.1	-3.3	-3.2	-4.1

[7] Scenarios: S1 – every household has an efficient shower head (6.3 L/min or less); S2 – every household has an efficient shower head (6.3 L/min or less), and every shower event is a maximum of 4 min; S3 – every household uses a front loader; S4 – every household uses a front loader and washes in cold water; S5 – every household uses a top loader; and S6 every household uses a top loader and washes in cold water.

Scenario analysis of front loaders vs top loaders presented a clothes washing paradox. Replacing top loaders with front loaders reduced Frankston precincts regional water use by 6% (-0.2 GL/yr), had a mixed impact on water-related energy use from -3.6% to +0.05% (-2.3 to +0.03 GWh/yr), and increased GHG emissions by +0.4% to +8% (+0.1 to +2.5 ktCO_2-e/yr) due to the increased reliance on the electricity grid (ie, single plumbing connection) regardless of the wash cycle selection. Replacing front loaders with top loaders predictably increased Frankston precincts regional water use by +5% (+0.1 GL/yr) but reduced both water-related energy use (-0.03% to -10%, -0.02 to 6.5 GWh/yr) and GHG emissions (-6% to -13%, -1.8 to 4.1 ktCO_2-e/yr). Consequently, there are resource use trade-offs with clothes washers which need to be taken into consideration when developing policies that address both water use reduction targets and GHG emission reduction targets.

As demonstrated in previous studies, economies of scale are a factor in household resource consumption where the household size affects water and energy use per capita. Smaller occupancy households (ie, singles and families without children) were the largest consumers per capita where a combined 56% of the Frankston precinct population lived in 72% of households and consumed 61% of resources (Figure 4-5). Conversely, larger occupancy households (ie, groups and families with children) were the lowest consumers per capita where 44% of the population lived in 28% of the household stock and consumed 39% of resources.

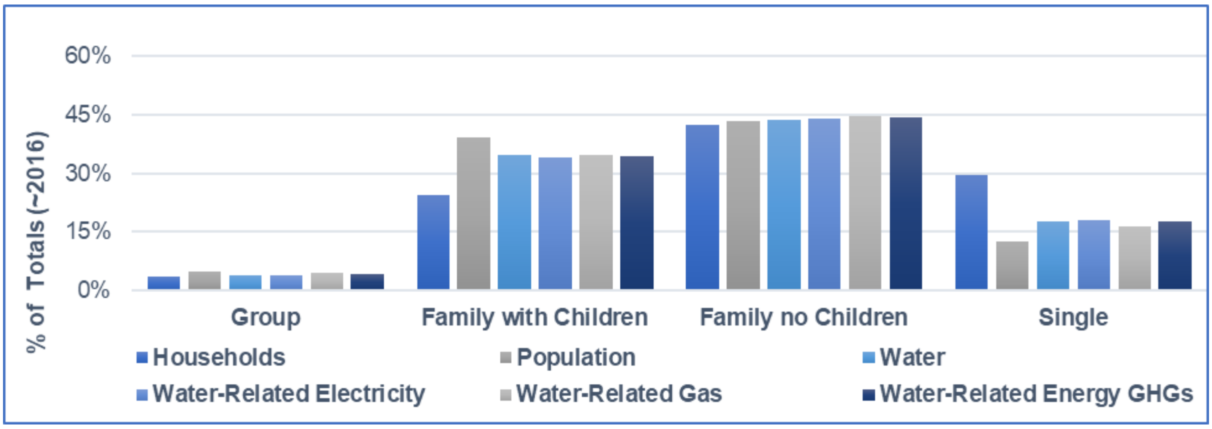

Figure 4-5: Household composition impact on regional water use, water-related energy use, and associated GHGs for the Frankston precinct (postcode boundary 3199).

5 Data and Literature Review

The aim of the data review was to revise and synthesise existing data for modelling household water-related energy focussed on two case studies in Melbourne, firstly in Reservoir (postcode 3073), secondly in the Frankston precinct (postcode 3199). The aim of the literature review was to update contemporary information on modelling analysis of water-related energy to inform subsequent phases of the project.

Water-related energy models were populated with localised data to generate a baseline of water use, water-related energy use, and associated GHGs for both Reservoir and Frankston study sites. The models were then used to estimate the impact on residential resource reduction through Scenarios 1-6 (see Sections 3.3.4, and 4.3.2 for scenario descriptions).

5.1. What Data Have We Used?

The most critical data is the distribution of households containing key technologies and behaviours that are used to quantify regional water, water-related energy, and GHGs. Key input data used in the ResWE model populates the baseline for both the Reservoir Overview Model and the Frankston Overview Model (Table 5-1). A complete list of data sources and general assumptions are provided in Appendix C.

Table 5-1: Summary of key input data.

Data	Table #	Spatial Scale	Temporal Scale	Reservoir (3073) References	Frankston (3199) References
Household Composition	Table 5-3, Table 5-4	Postcode	Census	(ABS 2020a); (ABS 2019), Table G25; (YVW 2014)	(ABS 2020b); (ABS 2017), Tables G25 and G31
Hot Water System Type	Table 5-5	SA2 Level	Year	(ABS 2014), Table 3; (ABS 2020c), Table 1; (DHHS 2008), Table 5.2.1.1	(ABS 2012b), Table 3a; (ABS 2020c), Table 1; (DHHS 2008), Table 5.2.1.1
Shower Use (technology)	Table 5-6, Table 5-7	Water utility	Year	(Ghobadi et al. 2013), Table 13; (Roberts 2017), Table 10	(Ghobadi et al. 2013), Table 13
Shower Use (behaviour)	Table 5-6, Table 5-7	Water utility	Year	(Roberts 2017), Figure 12	(Byrne and Martin 2017), Figure 5.4; (SEW 2021b)
Clothes Washing (technology)	Table 5-8	Water utility	Year	(Roberts 2017), Table 13	(Gan and Redhead 2013), Table 3
Clothes Washing (behaviour)	Table 5-8	Water utility	Season	(Gan and Redhead 2013),Table 3	
Cold Water Temperature	Table 5-9	Postcode	Month	(YVW 2015)	
Ambient Air Temperature	Table 5-9	Weather Station	3 hours	(BOM 2014)	
ResWE Model Parameters	Table C-1	Average of 5 households	Average Day	(Binks et al. 2016), Supplementary Material	

Household types and values for significantly influential water-related energy use factors were sourced from ABS datasets, utility datasets, and end use reports. For example, household composition (ABS 2020a, 2020b), hot water system type (ABS 2014, 2020c), shower use technology (Ghobadi et al. 2013; Roberts 2017), shower use behaviour (Roberts 2017; Byrne and Martin 2017; SEW 2021b), clothes washing technology (Roberts 2017; Gan and Redhead 2013), and clothes washing behaviour (Gan and Redhead 2013). In the absence of any information on key interactions between technology and behaviour of household types, it was assumed that technology and behaviour were independent.

Appliance stock specifications were sourced from State Government datasets, Australian Standards, and product specifications. For example, electric hot water systems (E3 2016b), gas hot water systems (E3 2016c), solar hot water systems (Bosch 2012), gas instantaneous hot water systems (Rinnai 2013b), hot water system set point (Standards Australia 2009), and clothes washers (E3 2016a). The remainder model input parameters were drawn from supplementary material in the study by Binks et al. (2016). Emissions factors for electricity and gas were sourced from National Greenhouse Accounts (2019).

Environmental and weather-related influences were sourced from the Bureau of Meteorology (BOM), Yarra Valley Water datasets, Commonwealth Scientific and Industrial Research Organisation (CSIRO), and Sustainable Energy Authority Victoria. For example, ambient air temperature (BOM 2014), water supply temperature (YVW 2015), indoor air temperature (CSIRO and BOM 2010), and solar hot water system fractions (George Wilkenfeld and Associates Pty Ltd 2005).

Model calibration data was sourced from end use level water use reports (Roberts, Athuraliya, and Brown 2011; Athuraliya, Roberts, and Brown 2012; Redhead et al. 2013; Gan and Redhead 2013), and space cooling/heating data from the ABS (ABS 2011a, 2014).

Measured water use, wastewater flow, electricity and gas use data were used for verifying the model (Table 5-2). Household scale water use and average household wastewater flow (utility model) were provided by the water utility, Yarra Valley Water (YVW 2014, 2017), postcode scale electricity use by electricity distributor, Jemena (Jemena 2014), and postcode scale gas use by the gas infrastructure manager, APA group (APA Group 2015).

Table 5-2: Summary of key verification data.

Data	Spatial Scale	Temporal Scale	Reference
Water Use (measured)	Household: Reservoir	Quarter	(YVW 2014)
Wastewater Flow (utility model)	Sub-catchment to household: Reservoir	Week	(YVW 2017)
Gas Use (measured)	Postcode: 3073	2 Month	(APA Group 2015)
Electricity Use (measured)	Postcode: 3073	30 minutes	(Jemena 2014)

Key data for significant factors have been outlined in: (i) household composition (Table 5-3, Table 5-4), (ii) hot water system type (Table 5-5), (iii) shower use (Table 5-6, Table 5-7), and (iv) clothes washing use (Table 5-8). Seasonal effects on model inputs (eg, cold-water temperature) were also outlined (Table 5-9). Calculation procedures can be found in Bors (2019). See Appendix C for a full list of ResWE model parameters and data sources for Table 5-3 to Table 5-9.

Table 5-3: Household composition (Reservoir, postcode 3073).

Household Composition	ResWE P#[a]	Family with Children	Family no Children	Single	Group
Number of Adults	P1	2.11	2.49	0.98	2.59
Number of Children	P2	1.78	-	-	-
% of Persons[b]	-	39%	43%	12%	6%
Total number of Persons[c]	-	50,132			
%. of Households[d]	-	24%	42%	29%	5%
Total number of Households[e]	-	20,845			

[a] See Table C-1, Appendix C for the full list of ResWE Model parameters and data sources.
[b] % of persons per household type derived from census data (ABS 2020a, 2019).
[c] Total number of persons based on census data (ABS 2020a, 2019).
[d] % of households per household type derived from census data (ABS 2020a, 2019).
[e] Total number of households based on census data (ABS 2020a), and metered water use data (YVW 2014).

Table 5-4: Household composition (Frankston precinct, postcode 3199).

Household Composition	ResWE P#[a]	Family with Children	Family no Children	Single	Group
Number of Adults	P1	1.84	2.27	0.94	3.01
Number of Children	P2	1.76	-	-	-
% of Persons[b]	-	39%	43%	13%	5%
Total number of Persons[c]	-	54,298			
%. of Households[d]	-	24%	42%	30%	4%
Total number of Households[e]	-	24,438			

[a] See Table C-1, Appendix C for the full list of ResWE Model parameters and data sources.
[b] % of persons per household type derived from census data (ABS 2020b, 2017).
[c] Total number of persons based on census data (ABS 2020b, 2017).
[d] % of households per household type derived from census data (ABS 2020b, 2017).
[e] Total number of households based on census data (ABS 2020b).

Table 5-5: Hot water system characteristics.

Hot Water System	ResWE P#[a]	Units	Electric-Storage	Gas-Storage	Gas-Instantaneous	Solar-Electric	Solar-Gas
Capacity	-	-	Medium				
Size	-	L	160	135	-	250	250
Surface Area	P16	m^2	2.47	2.12		2.58	2.58
Cold Water Temp.	P3	°C	Table 5-9				
Hot Water Temp.	P4	°C	60				
Solar Fraction	P21	-	-	-	-	Table 5-9	
Efficiency Factor	P136-P145	-	1.0204	1.3106	1.5385	1.0204	1.5385
% of Households (Reservoir)[b]	-	-	15%	33%	18%	9%	26%
% of Households (Frankston precinct)[c]	-	-	16%	42%	22%	7%	13%

[a] See Table C-1, Appendix C for the full list of ResWE Model parameters and data sources.
[b] % of households per hot water system type derived from ABS and report data. Applied sources of hot water, Table 3 (ABS 2014), added new solar hot water system installations, Table 1 (ABS 2020c). Assumed solar hot water system boost was proportional to electric vs gas sources of hot water, Table 3 (ABS 2014). Ratio of gas storage vs gas instantaneous was sourced from Table 5.2.1.1 (DHHS 2008).
[c] % of households per hot water system type derived from ABS and report data. Applied sources of hot water, Table 3a (ABS 2012b), added new solar hot water system installations, Table 1 (ABS 2020c). Assumed solar hot water system boost was proportional to electric vs gas sources of energy for hot water, Table 3a (ABS 2012b). Ratio of gas storage vs gas instantaneous was sourced from Table 5.2.1.1 (DHHS 2008).

Table 5-6: Shower use characteristics (Reservoir, postcode 3073).

Shower Use	ResWE P#[a]	Units	Value[b]	% of Households[c]
Efficient Shower head	P25, P29	L/min	6.3	69%
Inefficient Shower head	P25, P29	L/min	12	31%
Short Shower Duration	P24, P28	min	4	56%
Long Shower Duration	P24, P28	min	10	44%

[a] See Table C-1, Appendix C for the full list of ResWE Model parameters and data sources.
[b] Efficient vs inefficient shower head flowrate (weighted average of efficient shower head flowrate vs weighted average of inefficient shower head flowrate), calculated from Table 13 (Ghobadi et al. 2013). Short vs long shower duration (weighted average of short shower duration vs weighted average of long shower duration), calculated from Figure 12 (Roberts 2017).
[c] % of efficient shower head vs inefficient shower head households, Table 10 (Roberts 2017). % of short shower duration vs long shower duration households calculated from Figure 12 (Roberts 2017).

Table 5-7: Shower use characteristics (Frankston precinct, postcode 3199).

Shower Use	ResWE P#[a]	Units	Value[b]	% of Households[c]
Efficient Shower head	P25, P29	L/min	6.9	59%
Inefficient Shower head	P25, P29	L/min	12	41%
Short Shower Duration	P24, P28	min	4	40%
Long Shower Duration	P24, P28	min	10	60%

[a] See Table C-1, Appendix C for the full list of ResWE Model parameters and data sources.
[b] Efficient vs inefficient shower head flowrate (weighted average of efficient shower head flowrate vs weighted average of inefficient shower head flowrate), calculated from Table 13 (Ghobadi et al. 2013). Short vs long shower duration (weighted average of short shower duration vs weighted average of long shower duration), calculated from raw shower data (SEW 2021b).
[c] % of efficient vs inefficient shower head households derived from Table 13 (Ghobadi et al. 2013). % of short vs long shower duration households calculated from raw shower data (SEW 2021b) and Figure 5.4 (Byrne and Martin 2017). It's important to note there was a large difference in % household distribution of short vs long shower duration households between raw shower data (SEW 2021b) and the mySEW study, Figure 5.4 (Byrne and Martin 2017). The raw shower data (SEW 2021b) collected for the implementation of a water efficiency program demonstrated the split between short vs long shower households was 55% (short) and 45% (long). The mySEW study, Figure 5.4 (Byrne and Martin 2017) showed the split between short vs long shower households was 17% (short) and 83% (long). A conservative approach to address the large difference in household distribution was taken and the adopted value for 40% (short shower households) vs 60% (long shower households) was chosen.

Table 5-8: Clothes washing use characteristics.

Clothes Washing	ResWE P#[a]	Units	Top Loader		Front Loader	
% of Households (Reservoir)[b]	-	-	34%		66%	
% of Households (Frankston precinct)[c]	-	-	58%		42%	
Wash Cycle	-	-	Cold	Warm	Cold	Warm
% of Households (Reservoir)[d]	-	-	73%	27%	73%	27%
% of Households (Frankston precinct)[e]	-	-	67%	33%	67%	33%
Wash Cycle Temp.	P60-P65	°C	Table 5-9	40	30	40
Wash Cycle Energy	P54-P59	kWh	0.1962	0.1962	0.1538	0.9062
Cycle Duration	P66, P67	min	75.40		220.86	
Dual Connection	P70	-	Yes		No	
Standby Energy	P68, P69	W	3.1		3.5	
Cycle Volume	P48-P53	L	117 (summer), 130 (winter)		51 (summer), 54 (winter)	

[a] See Table C-1, Appendix C for the full list of ResWE Model parameters and data sources.
[b] % of front loader vs top loader households in YVW, Table 13 (Roberts 2017).
[c] % of front loader vs top loader households in SEW, Table 3 (Gan and Redhead 2013).
[d] % of warm wash vs cold wash households in YVW, Table 3 (Gan and Redhead 2013).
[e] % of warm wash vs cold wash households in SEW, Table 3 (Gan and Redhead 2013).

Table 5-9: Cold water temperature, air temperature, other environmental influences, and seasonal end use characteristics.

Seasonal Parameters	P#[a]	Units	Month											
			J	F	M	A	M	J	J	A	S	O	N	D
Cold Water Temp.	P3	°C	21.1	22.0	23.1	18.4	15.7	12.5	12.1	11.9	13.8	14.0	16.9	15.2
Average Indoor Air Temp.	P5	°C	22.1	22.1	22.1	22.1	20.3	20.3	20.3	20.3	20.3	20.3	22.1	22.1
Ambient Air Temp.	P6	°C	20.3	21.6	20.7	15.3	12.6	9.7	10.7	11.4	14.1	13.8	15.3	17.8
Solar Fraction	P21	-	0.66	0.65	0.57	0.48	0.37	0.33	0.35	0.43	0.51	0.53	0.64	0.65
Irrigation	P102	L/day	124	111	74	49	25	0	0	0	0	25	49	99
Cooling Duration	P110	min	36	18	0	0	0	0	0	0	0	0	0	18
Heating Duration	P131	min	0	0	32	106	222	328	360	303	201	127	85	0

[a] See Table C-1, Appendix C for the full list of ResWE Model parameters and data sources.

5.2. What is New Data?

A systematic approach to investigating new sources of data for the significant factors affecting household water-related energy was taken. Significant factors for data review include: (i) household composition, (ii) hot water system type, (iii) shower use, and (iv) clothes washing use.

Household composition data has been updated through the ABS, General Community Profile and cross-referencing with ABS QuickStats at the postcode scale. There has been an increase in population and households, with a predicted increase in smaller occupancy households, thus a predicted overall increase in water use, and water-related energy use.

Appliance stock specifications for hot water systems have been sourced from State Government datasets, relevant Australian Standards, and product specifications. The distribution of hot water system types has been determined from the latest ABS data of solar hot water system installations for each case study along with the assumption that a change in hot water system is in proportion with gas vs electric sources of hot water energy. This leaves some uncertainty in assessing the overall impact of regional hot water system distribution on residential water-related energy use.

There has been an increase in the penetration of water-efficient shower heads, but the extent of the penetration in the study region is difficult to determine with the change in data collection methods. The change in households taking either long or short showers has been sourced from the most recent studies by the utilities involved in each case study area (Roberts 2017; Byrne and Martin 2017). The average shower duration in Case Study 1 (Reservoir) is reported to be lower than the previous study, however, there is an increase in shower frequency. Current model results for both case studies demonstrate that shower use will remain a significant contributor to residential water use and water-related energy use.

One of the most recent utility studies on customer water use patterns showed that the average water use per front loader was higher than previous studies. In the past, clothes washing frequency was evaluated from measured data and modelled as a function of household size. In recent work, clothes washing frequency was evaluated through digital metering data and indicated that front loaders were used more frequently than top loaders, most likely due to a difference in capacity. Thus, without more information on the difference in clothes washing frequencies, the current model results may underestimate the difference between the water use and water-related energy use for front loaders compared to top loader clothes washers.

There has been an increase in the penetration of front loader clothes washers (Roberts 2017). Front loader clothes washers use less water than top loaders. The increase in front loader clothes washer penetration will most likely leave a larger footprint if clothes washing behaviour ie, choosing a warm wash cycle increases. This is particularly important in the current climate as warm/hot wash cycles have become a recommended COVID-19 hygiene practice.

5.3. Water-Related Energy Use and GHG Emissions in Residential Households

Household water-related energy use and GHG emissions are many times more than those of the water supply and wastewater treatment systems (Kenway et al. 2019; Rothausen and Conway 2011). Within a residential household, water-related energy use can be a significant portion of total household energy use, especially in climates where there are limited space heating and cooling. Many studies quantified water-related energy use in residential households, relative to the total household energy use or relative to the total energy use of water systems (Table 5-10).

Table 5-10: Household water-related energy use and GHG emissions in perspective.

Country/Region (Reference)	Description
Australia (Binks et al. 2016)	Household water-related energy use was estimated to be 13-24% of total household energy use in Melbourne and 76-79% in Brisbane.
Europe (EU) (Bertrand, Aggoune, and Maréchal 2017)	Energy use for hot water use represents 16% of the EU household heating demand. This relative contribution is expected to increase with improving building insulation.
South East Queensland, Australia (Kenway et al. 2015)	Primary energy use for residential hot water use is over five times of total primary energy use for water supply and wastewater treatment.
United States (Sanders and Webber 2015)	Residential water heating accounts for nearly 25% of the total energy use for supplying water and steam to the residential, commercial, industrial, and power sectors.
United Kingdom (Fidar, Memon, and Butler 2010)	For providing water service to households, 96% and 87% of energy use and GHG emissions, respectively are attributable to in-house consumption, primarily related to hot water.

5.4. Impacts of Interventions on Water-Related Energy Use and GHG Emissions

Many studies retrospectively or prospectively assessed the impacts of household interventions on water-related energy use and GHG emissions (Table 5-11).

Table 5-11: Examples of assessing the impacts of interventions.

Country/Region (Reference)	Intervention	Description
Australia (Fane, Grossman, and Schlunke 2020)	Water efficiency labelling	The Water Efficiency Labelling and Standards (WELS) scheme was commenced in 2006 to mandate water efficiency labelling for indoor water-using fixtures and appliances. The savings estimated were: 112 GL in 2017-18, $A42/person in 2017-18, 231 GL in 2036-37, and 53.5 $MtCO_2$-e over 30 years. The largest economic benefits are from the energy saving from reduced water heating.
Gold Coast (Willis et al. 2010)	Alarming visual display monitors for showers	For 44 households (each installed an alarming visual display monitor locked at 40 L shower water use), it led to an average reduction of 15.40 L (27%) shower water use. A citywide implementation of the device was estimated to yield 3% and 2.4% savings in total water and energy use, respectively.
South East Queensland, Australia (Beal, Bertone, and Stewart 2012)	Replacing electric hot water systems with boosted solar hot water systems	Replacing conventional electric hot water systems with electric boosted solar hot water systems could reduce on average 737 kWh/person.yr energy use and 102 $kgCO_2$-e/person.yr GHG emissions.
Melbourne, Australia (Binks, Kenway, and Lant 2017)	Reduction of shower time	For the studied five households, a shift to four-minute showers (from the baseline of between six and 10 minutes) would lead to a reduction of energy use by 0.1-3.8 kWh/person.day.
United States (Chini et al. 2016)	Water-efficient appliances	Using average national data, a study has shown that many water-related opportunities (eg, water-efficient shower head, water-efficient faucet, heat pump water heater) are economically attractive and offer a substantial energy saving potential.
United States (US) (Sanders and Webber 2015)	Shift in residential hot water systems	In most regions of the US, shifts in residential hot water systems from electric to natural gas or solar water heating can reduce GHG emissions.
15 cities in US (Ni et al. 2012)	Grey water heat recovery	The use of multiple-function heat pump systems (to recover thermal energy from grey water for space heating and water heating) has been shown to reduce energy use and water use by 17-57.9% and 15%-34.1% respectively.

5.5. Influencing Factors on Water-Related Energy Use and GHG Emissions

Various studies assessed the impacts of different technical and non-technical influencing factors on water-related energy use and GHG emissions in residential households (Table 5-12).

Table 5-12: Examples of influencing factors on water-related energy use and GHG emissions.

Influencing Factor	Examples
Tap water temperature	In Melbourne, the variability of tap water temperature (12–28°C during summer, 9–15°C during winter) was estimated to change household energy demand for water heating by −17 to +19% (−640 to +680 kWh/hh.yr) (Bors et al. 2017). A study suggested that warming climate is expected to increase tap water temperature, and in turn reduce the energy demand for water heating (Kaufmann et al. 2013).
Demographic factor	In Beijing, a survey study has shown that per capita water-related electricity use had a positive correlation with education, but a negative correlation with family size and age (Yu et al. 2018).
Demographic, behaviour, and technological factors	For a sample of 11 US cities, a study found that water heater setpoint temperature, water heating intake temperature, heater efficiency, shower hot water percentage, household size, shower flowrate, and faucet flowrate have the highest relative effect on household water-related energy use (Abdallah and Rosenberg 2014).
Hot water system type	In Melbourne, a study evaluated the annual primary energy use for different hot water system types – electric storage (22.94 GJ), gas storage (22.70 GJ), gas instantaneous (20.85 GJ), electric-boosted solar (18.43 GJ), and gas-boosted solar (10.43 GJ) (Crawford and Treloar 2004).
Household composition	A key determinant for household resource consumption is the number and the type of occupants (children/adults) (Kenway et al. 2016).

5.6. Understanding Residential Water-Related Energy Use and GHG Emissions

Many research approaches have been developed and applied to understand different aspects of managing water-related energy use and GHG emissions (Table 5-13). They have been used for (i) quantifying the baseline water-related energy use and GHG emissions in residential household for individual household level/neighbourhood level/city level (Section 5.3); (ii) assessing the impacts of interventions on water-related energy use and GHG emissions (Section 5.4); and (iii) understanding the technical and non-technical influencing factors on water-related energy use and GHG emissions (Section 5.5).

Table 5-13: Approaches for understanding residential water-related energy use and GHG emissions management.

Approach	Examples
Mechanistic modelling	Detailed mechanistic models can be developed to quantify water-related energy use and GHG emissions under different management strategies. DeMonsabert and Liner (1998) developed a static model to analyse total energy savings associated with water conservation measures in residential end use. Fagan, Reuter, and Langford (2010) developed a dynamic modelling framework to assess environmental impacts and cost-effectiveness of different policy, design, planning, and management options in urban water systems (including residential household interventions). Kenway et al. (2013) developed a material flow analysis model to quantify water-related energy use, and associated GHG emissions and cost in households.
Life cycle assessment	Life cycle assessment (LCA) analyses the potential environmental impacts associated with products and product systems. In water-related energy and GHG emissions management, LCA has been applied to life cycle energy use and GHG emissions of residential water-using appliances (Lee and Tansel 2012), and life cycle energy use and GHG emissions of water-efficient devices and rainwater tanks (Racoviceanu and Karney 2010).
Marginal abatement cost (MAC) curve	The MAC curve visualises marginal abatement cost (cost per unit of energy saving/GHG emissions reduction) and abatement potential of management opportunities. Opportunities are prioritised based on their marginal abatement costs. MAC curve has become a popular policy tool in assessing and communicating the economics of climate change mitigation opportunities. For water-related energy and GHG management, the approach has been applied for assessing household water-related energy efficiency opportunities (Chini et al. 2016), city-scale water-related energy use management (Lam, Kenway, and Lant 2017), and city-scale water-related GHG emissions management (Lam and van der Hoek 2020).
Regression analysis	Regression models can be applied to explore statistical relationships between variables such as demographic characteristics and water-related energy use. Yu et al. (2018) conducted a face-to-face survey to collect household attributes, behaviours, water use, and energy use data in Beijing. They then applied regression methods to explore correlations between these data.
Spatial analysis	Spatial analysis makes use of statistical techniques to analyse spatial and temporal variations of data. Bors et al. (2017) analysed spatiotemporal variations of drinking water temperature in Melbourne, and its impacts on household water-related energy use.
Big data analytics	Big data analytics can be used to examine high resolution water, electricity and/or gas grid data for better understanding and modelling water and energy use, and integration of their management (Stewart et al. 2018), (Stewart et al. 2018).

6 Least Cost Analysis

6.1 Overview

An illustrative least cost analysis was performed to demonstrate the use of the MAC curve approach to identify the more cost-effective water-related energy management opportunities using the Reservoir Case study. Because a wide range of household types consistent across both the Reservoir and Frankston case studies, the results are considered equally applicable to both Reservoir and Frankston. As a large proportion of the data is also generic to Melbourne the results can also be considered an approximation (and hence scaled up) for Melbourne.

A MAC curve visualises the marginal abatement cost (ie, cost per unit of water saved/energy saved/GHG emissions reduction) and abatement potential (ie, water saving potential, energy saving potential, and GHG emissions reduction potential) of different opportunities. It prioritises opportunities based on their cost-effectiveness (ie, marginal abatement cost).

This illustrative least cost analysis for Reservoir shows how least cost analysis can be used to identify household categories for more cost-effective targeted implementation of management opportunities. The number of opportunities in the illustrative MAC curves (Figure 6-1 to Figure 6-4) are not exhaustive. These opportunities are based on the S1 scenario, in which every household with an inefficient shower head upgrades to an efficient shower head. Each opportunity involves upgrading an inefficient shower head to an efficient shower head in one of the 20 household categories (ie, 4 household compositions and 5 hot water system types). In this scenario, all the opportunities are not mutually exclusive. It means that the sum of all these opportunities is the maximum saving potential of the shower head upgrading programme in this case study region.

The key assumptions in this illustrative least cost analysis are as follows:

- The water-related energy saving includes households and water utilities.
- The GHG emissions accounting includes only the direct GHG emissions for energy supply.
- The simplified cost assessment only accounts for the initial cost of shower heads, their installation cost, water bill saving (for households), revenue loss from reduced water sales (for water utilities), and the energy cost savings at households and water utilities but does not account for the non-energy water supply and wastewater treatment cost savings at water utilities, and cost savings from deferring infrastructure upgrade.
- Three perspectives are applied. 'Community perspective' (costs and benefits at households only) accounts for energy saving, water bill saving, and energy bill saving at households. 'Utility perspective' (costs and benefits at utilities only) accounts for energy saving, energy bill savings, and revenue loss from reduced water sales at water utilities. 'Combined perspective' (costs and benefits at both households and utilities) accounts for energy saving and energy bill saving at both households and water utilities and excludes the cost impacts of reduced water use on households and water utilities.
- The total initial cost of shower heads and installation ($133/shower head) is annualised for 15 years.
- In the simplified cost assessment, energy costs are based on the latest available price data, without consideration of future potential energy price increase.

Detailed methods underpinning this least cost analysis can be found in Appendix D.

6.2 Combined Total Benefit to Water Utilities and Community

In a MAC curve, opportunities are prioritised from the most cost-effective (on the left with the lowest marginal abatement cost) to the least cost-effective (on the right with the highest marginal abatement cost). A negative marginal abatement cost implies that the opportunity results in net cost saving (ie, cost-effective). The height of each bar represents the marginal abatement cost of an opportunity, while the width represents the annual abatement potentials (ie, water saving, energy saving, GHG emissions reduction). The area of each bar is the net annual cost of an opportunity.

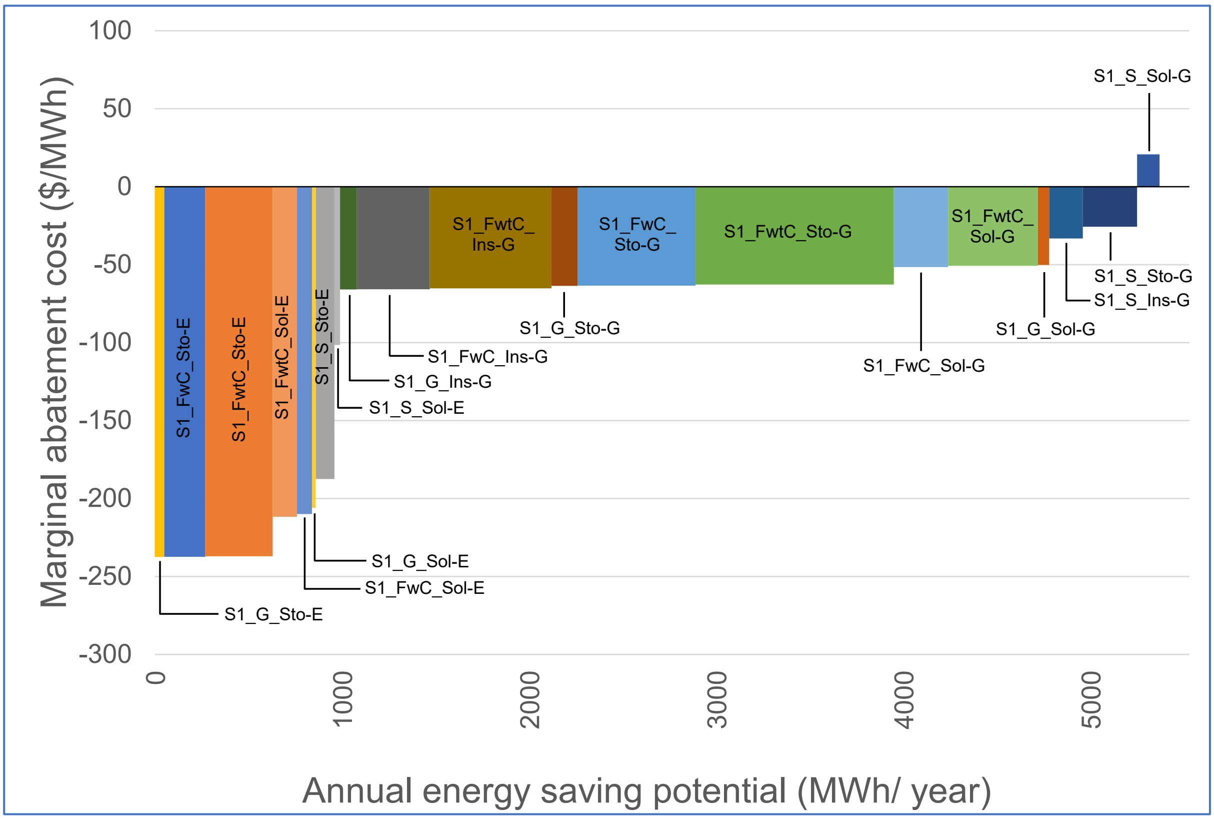

Figure 6-1: Marginal abatement cost curve for water-related energy saving in Reservoir from a 'combined perspective'. The tabulated results can be found in Appendix D.[8]

Figure 6-1 shows the water-related energy saving performance of shower head upgrade opportunity in 20 household categories for Reservoir. In terms of the marginal abatement cost, the analysis suggests that non-single household categories with an electric storage hot water system (ie, S1_G_Sto-E, S1_FwC_Sto-E, S1_FwtC_Sto-E) have lower marginal abatement costs (ie, more cost-effective). In addition, all household categories with electric hot water systems (ie, electric storage or solar electric boosted) have more attractive marginal abatement costs than any household categories with gas hot water systems (ie, gas storage, gas instantaneous, or solar gas boosted). This is mainly because of the higher unit cost of electricity (per unit of energy content), compared to that of gas. Cost saving from reducing hot water use from electric hot water systems are therefore more significant.

[8] S1 = Scenario 1; FwC = Family with children; FwtC = Family without children; S = Single; G = Group; Sto-E = Electric storage hot water system; Sto-G = Gas storage hot water system; Ins-G = Gas instantaneous hot water system; Sol-E = Solar electric boosted hot water system; Sol-G = Solar gas boosted hot water system.

In terms of energy saving potential, S1_FwtC_Sto-G (Family without children, using gas storage hot water system), S1_FwC_Sto-G (family with children, using gas storage hot water system) and S1_FwtC_Ins-G (family without children, using gas instantaneous hot water system) have greater water-related energy saving potential. They have a higher energy saving potential because gas hot water systems are more common in Reservoir.

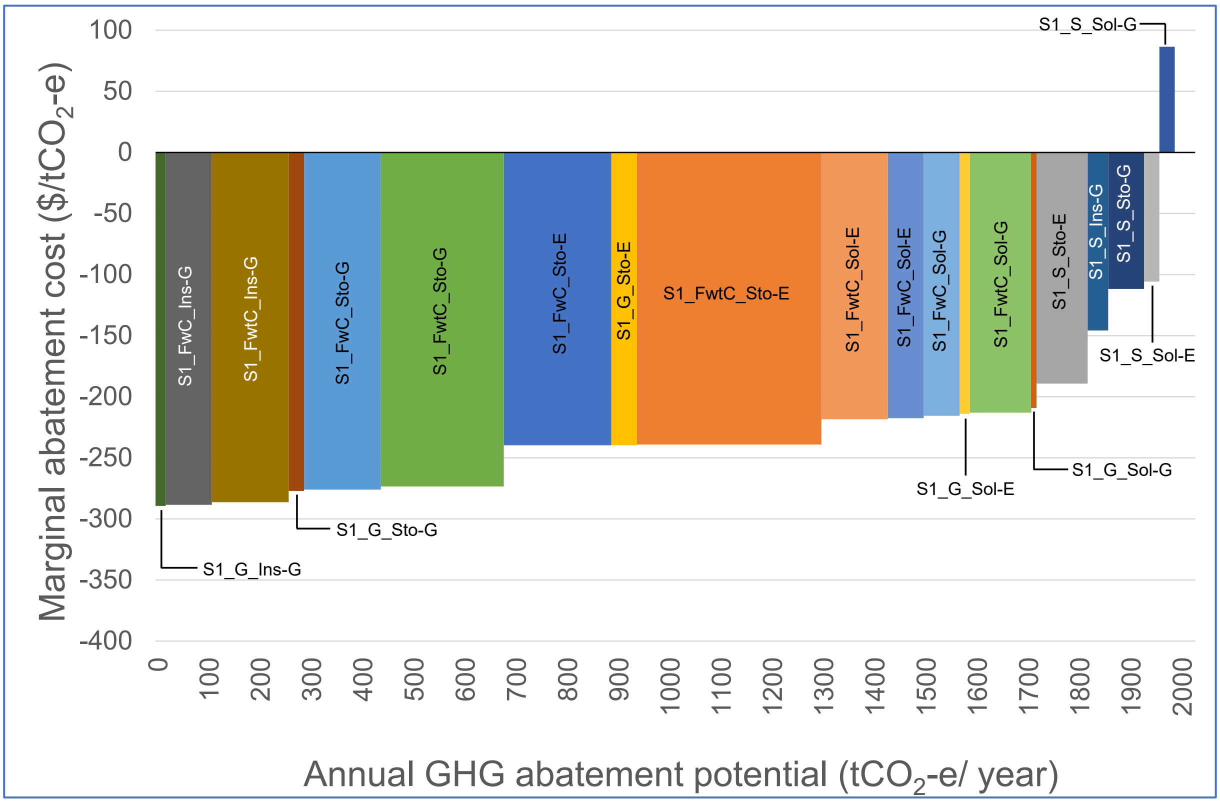

Figure 6-2: Marginal abatement cost curve for GHG emissions abatement in Reservoir from a 'combined perspective'. The tabulated results can be found in Appendix D.[9]

From the GHG emissions abatement perspective (Figure 6-2), household categories with gas hot water systems (ie, gas storage, gas instantaneous, or solar gas boosted) have lower marginal abatement costs than those with electric hot water systems (ie, electric storage, solar electric boosted). The analysis suggests that S1_FwtC_Sto-E (family without children, using electric storage hot water system), S1_FwtC_Sto-G (family without children, using gas storage hot water system), and S1_FwC_Sto-E (family with children, using electric storage hot water system) have greater GHG emissions abatement potential in the studied region.

Figure 6-3 shows the water saving performance of shower head upgrade opportunity in 20 household categories. Four opportunities (S1_G_Sto-E, S1_FwtC_Sto-E, S1_FwC_Sto-E, S1_S_Sto-E) stand out for their cost-effectiveness, while some opportunities are with greater water saving potential but lower cost-effectiveness (S1_FwtC_Sto-G, S1_FwC_Sto-G, S1_FwtC_Ins-G).

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[9] S1 = Scenario 1; FwC = Family with children; FwtC = Family without children; S = Single; G = Group; Sto-E = Electric storage hot water system; Sto-G = Gas storage hot water system; Ins-G = Gas instantaneous hot water system; Sol-E = Solar electric boosted hot water system; Sol-G = Solar gas boosted hot water system.

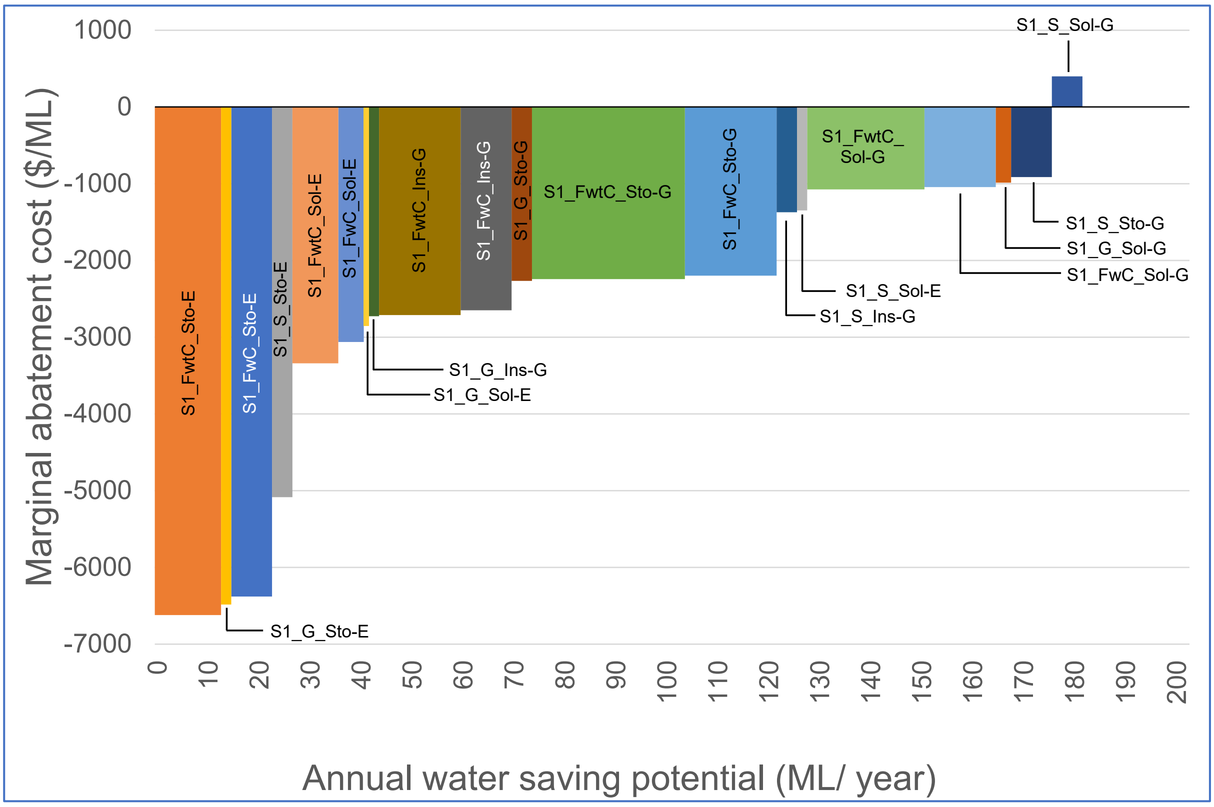

Figure 6-3: Marginal abatement cost curve for water saving in Reservoir from a 'community perspective'. The tabulated results can be found in Appendix D.[10]

6.3 Comparison of Combined Perspective, Community Perspective, and Water Utility Perspective

The previous section on water-related energy use saving, GHG emissions abatement and water saving takes a 'combined perspective' in developing the MAC curves. This accounts for the water-related energy use savings and the associated cost savings at both households and water utilities, while excludes the water bill savings at households and the revenue loss from reduced water sales at water utilities. The MAC curves can also be developed from a 'utility perspective' and a 'community perspective'. In the 'utility perspective', we only account for water-related energy use saving, associated cost saving, and reduced water sales at water utilities. In contrast, the 'community perspective' considers water and related-energy savings at households.

Figure 6-4 compares the least cost analysis results for GHG emissions abatement from the 'combined perspective' (same as Figure 6-2), the 'community perspective' and the 'utility perspective'. It clearly demonstrates that all opportunities that appear to be cost-effective from a community perspective are not favourable from a water utility perspective. This unfavourable economic viability is mainly because of the significant revenue loss from reduced water sales, and the relatively low energy intensity (and related cost) for water supply. The comparison between the three perspectives illustrates that the choice of the 'system boundary' to account for the cost and benefit can profoundly influence how opportunities are being assessed.

[10] S1 = Scenario 1; FwC = Family with children; FwtC = Family without children; S = Single; G = Group; Sto-E = Electric storage hot water system; Sto-G = Gas storage hot water system; Ins-G = Gas instantaneous hot water system; Sol-E = Solar electric boosted hot water system; Sol-G = Solar gas boosted hot water system.

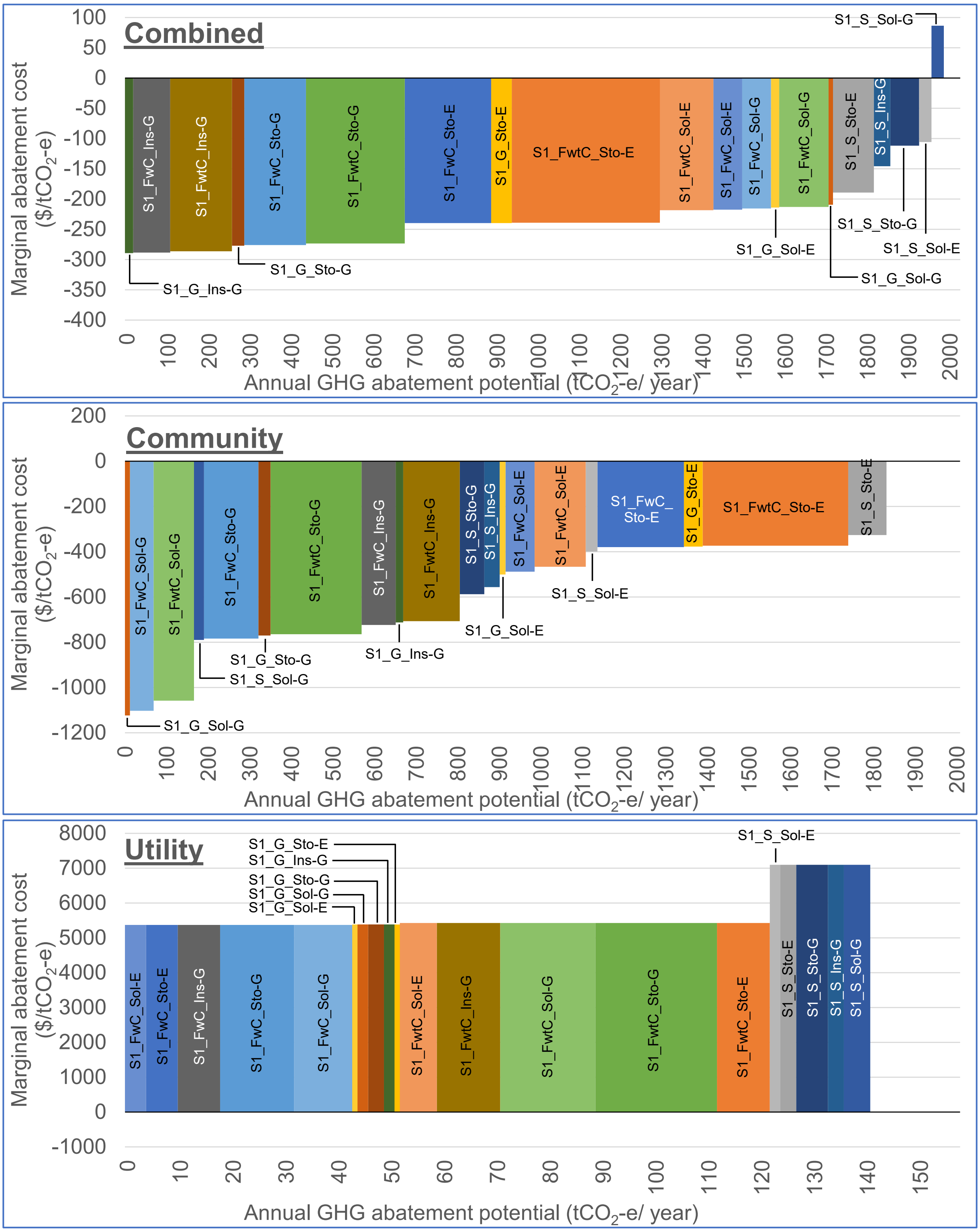

Figure 6-4: Marginal abatement cost curves for GHG emissions abatement in Reservoir from (Upper) 'combined perspective', (Middle) 'community perspective', and (Lower) 'utility perspective'.[11]

[11] S1 = Scenario 1; FwC = Family with children; FwtC = Family without children; S = Single; G = Group; Sto-E = Electric storage hot water system; Sto-G = Gas storage hot water system; Ins-G = Gas instantaneous hot water system; Sol-E = Solar electric boosted hot water system; Sol-G = Solar gas boosted hot water system.

Section 3 – Behavioural and Institutional analysis

7 Behaviour and Practice

Refer to separate Literature and Practice report: Lang, M., McCollum Coy, D., Meis-Harris, J., Smith, L. Drivers for energy reduction in the use of water in residential households: Literature and Practice Review. Melbourne, Australia: BehaviourWorks Australia, Monash Sustainable Development Institute, Monash University, September 2020.

8 Institutional Environment

8.1 Overview

This chapter outlines the initial findings of an exploratory analysis into the critical legislative, policy, regulatory and institutional dimensions seen to influence household water efficiency and water-related energy efficiency outcomes.

Specifically, this component of the broader research agenda has sought to understand the critical levers of influence for optimising water-energy efficiency outcomes for Victorian households. In this chapter we outline key findings that have emerged to date from an institutional literature and practice review process aimed at identifying opportunities for systems optimisation and the necessary governance processes required to catalyse change.

An overview of the methodology is provided alongside a series of opportunities and recommendations that the research team have identified as areas for ongoing analysis and co-development as part of the subsequent phases of this research.

While many opportunities exist, preliminary opportunities identified include:

i. A reform agenda to the State Victorian Energy Efficiency Transfer scheme to incentivise technical innovation roll-out for utilities.

ii. The development of a methodology to support the generation of emissions credits from household water-energy efficiency programs as part of the Federal Emissions Reductions Fund.

iii. Optimising rental, concession holder and social housing efficiency upgraded through segmented customer servicing outcomes for rental properties and concession holders.

Underpinning these and other opportunities identified as part of this analysis are a series of critical governance related recommendations identified as 'catalysts' for transformative change. These include:

i. Net Zero Water Cycle Governance and leadership.
ii. Institutional processes, tools and culture for scaling innovation.
iii. Forecasting and adaptive governance to respond to horizon opportunities.

These findings present important implications for state government and water utility practitioners and policy makers, in considering how water-efficiency pilot programs can be optimised for implementation at broader whole of systems scales, and in ways that enhance service provision for government, utilities and service provision outcomes for communities. Both opportunities and recommendations stemming from this initial investigation will form the basis of further research in Phases 2 and 3.

8.2 Introduction

The research team in collaboration with project partners have begun a process to develop an in-depth understanding of the enabling factors associated to residential water and energy service delivery, and identify opportunities to amend or reform these in ways that best support the optimisation of household water-related energy efficiency outcomes.

Enabling factors are widely defined to include legislative, policy, regulatory, programmatic and institutional arrangements which affect household water use and related energy, GHG emission and costs. Institutional arrangements include the roles and responsibilities of agencies, collaborative arrangements and leadership culture.

This work program aims to achieve the following outcomes:

i. A comprehensive understanding of the existing relationships between legislative, policy, regulatory, and institutional settings and programs in shaping service delivery outcomes for Victorian households overseen by DELWP, Victorian Water utilities and the regulator (and in relation to other relevant stakeholders such as community and family support services, Energy Service providers and other government departments).

ii. Identification of challenges, opportunities and critical leverage points for optimising water-energy interventions to better support household water energy saving, GHG reduction, service affordability and/or wellbeing and liveability outcomes for diverse community segments.

iii. The fostering of multi-stakeholder collaboration to develop short, medium and long-term actions which may include initiatives such as organisational practice change, institutional and technical innovation, capacity building and policy or regulatory amendments.

iv. Clarification of priority research and information needs (present at local, state and federal levels) to enable the delivery of options for improved management of water-related energy, broadly identified in Phase 1 of this project.

8.3 Phase 1: Methodology

Figure 8-1 below, illustrates the stages of ongoing investigation and collaboration between research partners. These include:

a) A review of relevant enabling environment key materials (**Systems Analysis**) – to build an illustrative understanding of the systemic properties and principles of current practice. That is, the legislative, policy, regulatory, programmatic and institutional arrangements that define current practice, and thus shape opportunities for Victorian households.

b) Discussions with key stakeholders (**Stakeholder Analysis**) from across the public sector, water and energy utilities, regulatory bodies (eg, Essential Services Commission (ESC)) and community support organisations (eg, the Brotherhood of St Lawrence and St Vincent de Paul) to understand how the enabling properties identified in step one are interpreted and translated into practice by stakeholders.

c) With research partners, identify a portfolio of opportunities and key requirements for embracing change (**Opportunities Analysis**) for continued investigation in subsequent research phases.

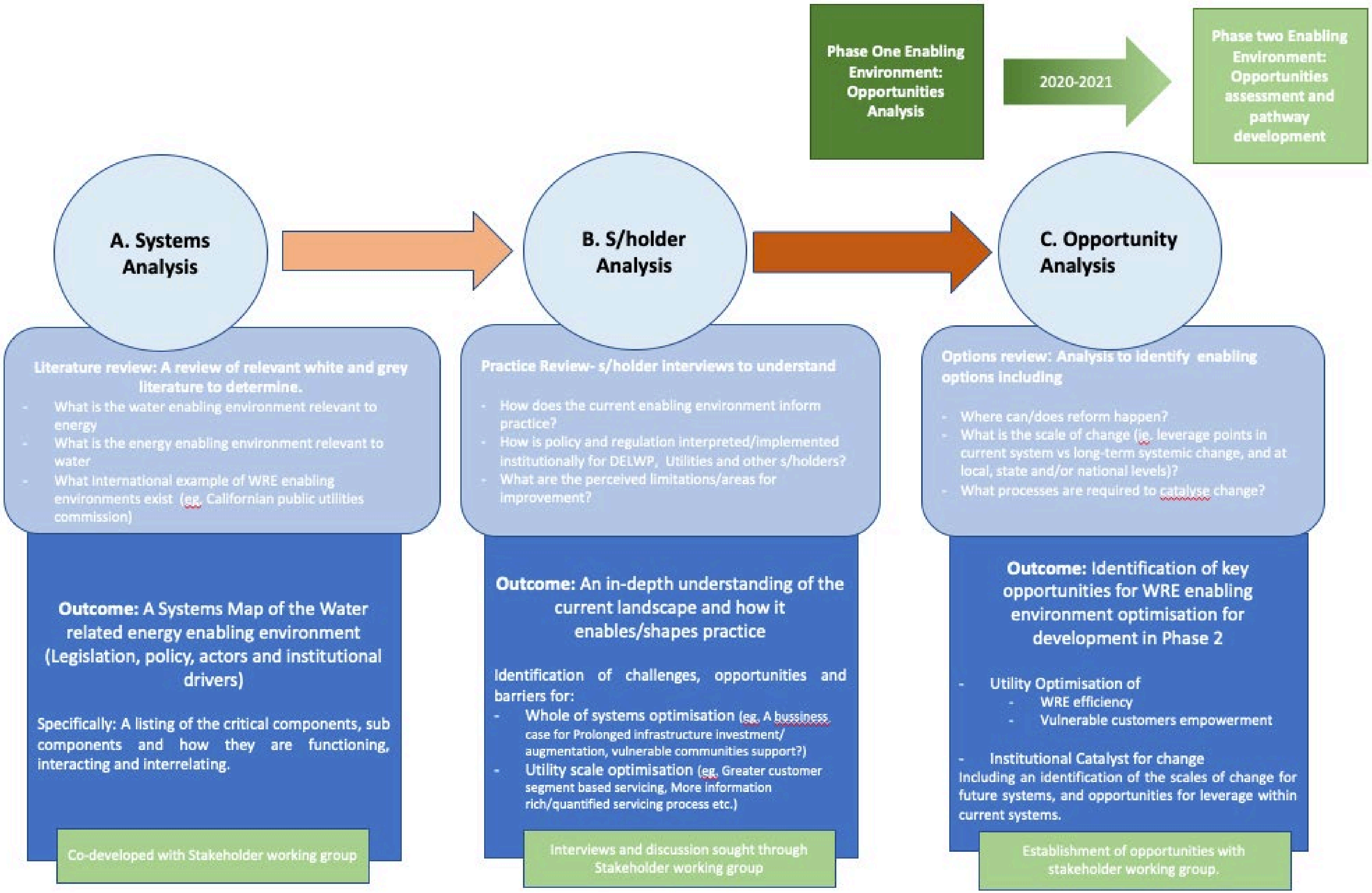

Figure 8-1: Enabling Environment Phase 1 Overview

8.4 Systems Analysis

This stage of the Phase 1 work has sought to:

a. Build an evidence base of the systems boundaries for household water-related energy outcomes, including the legislative, regulatory and institutional mechanisms that provide guidance on water-related energy programs and outcomes.

Through discussions with research partners a number of relevant materials have been identified that stipulate the conditions of the current operating environment for water sector practices and processes surrounding household water-related energy.

The table below provides an overview of relevant materials identified to date. While not comprehensive, this review provides a foundation for considering inter-organisational and sector wide processes and responsibilities shaping current practice. It is anticipated that this system mapping exercise will continue in subsequent phases as the research team and partners continue to consolidate findings and progress the above stated outcomes.

	Federal Level legislative, Policy and Regulatory Context	**State Legislative, Policy and Regulatory Context**	**Plans, Programs and Initiatives** (relevant to Metropolitan Melbourne)
Water	• The inter-governmental agreement on a National Water Initiative (2004) • The strategic water reform framework 1994 • National Water Reform 2020 Draft Report	• Ministerial Statement of Obligations (water) • Water Act 1989 • Water Industry Act 1994 • Public Administrations Act 2004 • Financial Management Act 1994 • Water for Victoria	• Schools Water Efficiency Program (DELWP) • IWM Forums
Energy/GHG Reduction (Relevant to Water sector and HH water-energy)	• Federal Emissions Reduction Fund • The National Carbon Offset Standard (NCOS) • AEMO Distributed Energy Resource Program (DER)	• Ministerial Statement of Obligations (Emissions Reduction) • Climate Change Act (2017) (including emissions reduction targets and pledges) • The Renewable Energy (Jobs and Investment) Bill 2019-VRET • Vic Renewable Energy Target (VRET) • Essential Service Commission methodologies for Vic Energy Efficiency certificates (VEEC)	• Vic Energy Efficiency Targets/VEEC scheme • Pilot Water Sector Climate Change Adaptation Action Plan • Climate Change Strategy • Renewable Energy Action Plan • The Solar Home Program • New Energy Jobs Fund • Take 2 Victoria's Climate Change Pledge
Other (eg, customer segment or concession support programs)		• Minimum efficiency standards for rental properties • State household Energy Efficiency package: upgrades to rental and low income households, including hot water upgrades	• Yarra Valley Water Energy, GHG Reduction and Water Opportunities Analysis (Chong, 2018). • WSAA Water Carbon and Environment (CCEE) task force, Customer Hot Water Heating Emissions review • Lauren, N., Tear, M. J. How can we improve energy and water programs for vulnerable households? Briefing Document. Melbourne, Australia: BehaviourWorks Australia, Monash University. Sept 2020.

8.5 Stakeholder Analysis

This stage of the Phase 1 work has sought to:

a. **Gather insights into how the observed enabling context identified from the system analysis, is interpreted and administered at varying institutional scales.**

b. **The corresponding practices and processes that emerge and the role in shaping outcomes for household efficiency.**

c. **Perspective from key stakeholders on key areas for improvement or opportunities for system optimisation.**

Subsequent discussions with personnel across partner organisations have been undertaken to develop an understanding into the way the above stated operating environment is interpreted and implemented in practice.

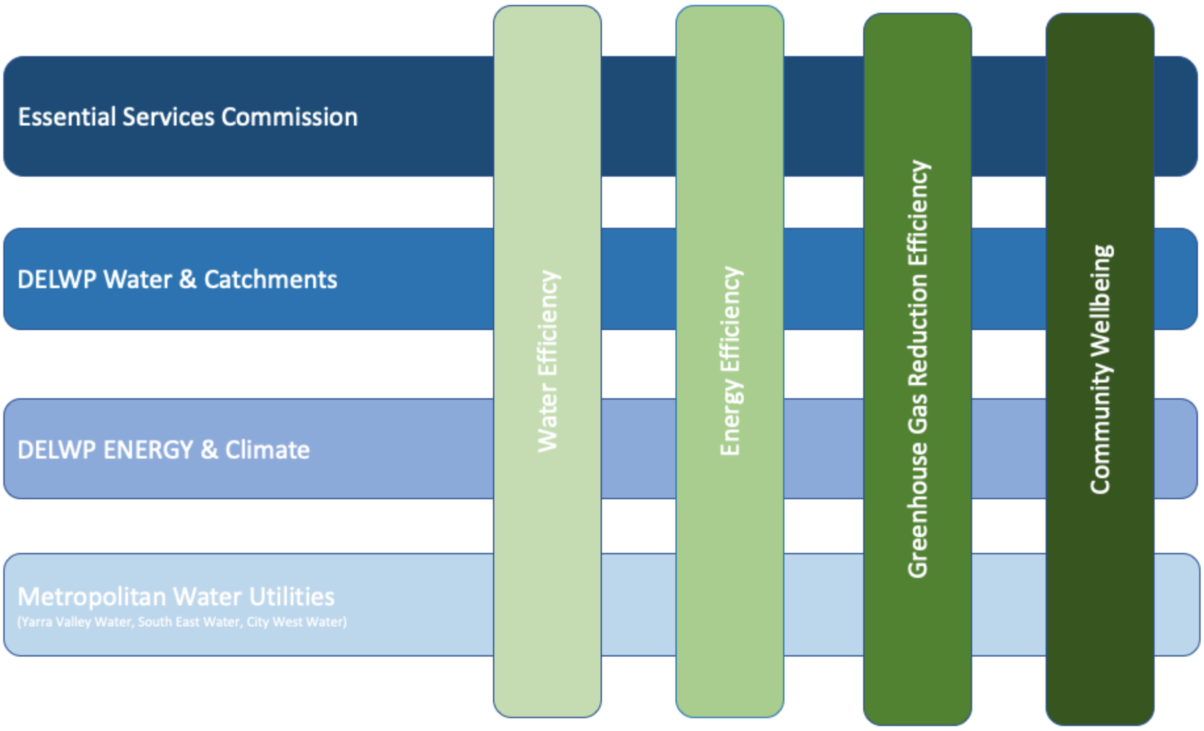

Figure 8-2: Key domains of discussion for the Phase 1 Stakeholder Analysis

As Figure 8-2 highlights, insight was sought across relevant agencies (in blue) through discussions with working groups and individual subject matter experts surrounding the four key focus areas (in green). To date 21 participants from across the four organisations have participated in group-based discussions and/or direct interviews. Discussion points have varied, at times focussed broadly on general knowledge areas of the individual or group, while in other instances on specific opportunities (see Section 8.6, Opportunity Analysis).

8.6 Opportunity Analysis

This stage of the Phase 1 work has sought to:

a. **Identify key points of leverage for system optimisation in supporting future water-related energy efficiency outcome in households.**

From this investigation, a number of opportunities have been identified that may support subsequent service delivery recommendations that emerge from this research. In the below summary, we outline three example opportunities the research team and partners have identified for ongoing consideration.

Notably, these comprise three options of a number that stakeholders have identified and have been chosen as they provide examples of interventions at different scales:

- **Opportunity 1**
  A review of Victorian Energy Efficiency Certificates (VEECs) as part of the Victorian Government's Victorian Energy Emissions Transfer (VEET) scheme.
- **Opportunity 2**
  A review of methodologies for the generation of emissions credits from household water-energy efficiency programs relating to the Federal Emissions Reductions Fund.
- **Opportunity 3**
  Assessing opportunities for water utilities to deliver segmented customer servicing outcomes for rental properties and concession holders.

Opportunity 1: A review of VEECs as part of the Victorian Government's VEET scheme

Summary of the current program, scheme or initiative.	The Victorian Energy Upgrade (VEU) program is designed to help organisations and households improve their energy demand management and reduce GHG emissions. To do this, the Victorian Government sets annual state-wide energy saving targets that results in a range of energy-efficient and other demand management products and services being made available to homes and businesses. Accredited providers that deliver these upgrades can generate VEECs which are then sold on, and the profit made is used to provide upgrades to consumers at lower costs. All large Victorian energy retailers have a liability under the VEET scheme to annually surrender VEECs, which they have either created or purchased from the competitive market. Each VEEC represents one tonne of GHG abated. The scheme's VEEC targets have been progressively increasing from 2.7 million VEECs/annum in 2009 to 5.9 million in 2017 and 6.5 million in 2020. In the last six months, the market price of VEECs varied from $8 to $20.
What is the opportunity?	Registering to become an accredited entity under the VEU scheme is of interest to Victorian utilities. The creation and sale of VEECs to underpin a business case would see a market mechanism fund large-scale water and energy efficiency programs, which would ultimately deliver multiple benefits to consumers, water utilities, the Victorian government and the environment. At present two key opportunities have been identified that could be optimised through this scheme: 1. There are multiple companies accredited to generate VEECs through replacing water heaters with solar or heat pump systems. While water heater installation is not a current nor intended business line for Victorian metropolitan utilities, it represents an opportunity for further consideration. 2. Low-flow shower heads are a pre-existing prescribed activity. Decommissioning non-low flow shower roses and installing low flow shower roses is deemed to generate 2 VEECs per unit. ESC determined that for a low flow shower head to generate VEECs, licensed plumbers must install the shower heads. Recent shower head replacement programs administered across all three metropolitan water utilities have largely exhausted opportunities for further VEECs to be claimed, however, discussions with utility personnel suggests that two immediate opportunities exist: - The uptake of water efficient shower heads in rental properties and new growth areas present opportunities for new VEECs to be generated under existing shower head replacement schemes. A recent feasibility study commissioned by Yarra Valley Water found that approximately only 57% of rental property shower heads throughout the Yarra Valley Water region are considered efficient (Chong 2018). This is reflective of the limited autonomy of tenants to be able to participate in past replacement schemes and the emphasis of Yarra Valley Water's past programs on shower head exchange, rather than specific installation and use. This opportunity is discussed in greater detail in Opportunity 3. - Recent advances in shower head technology present the opportunity for the substitution of older water efficient shower heads (with flow-rates of approximately 9 L/min) to new shower heads (at approximately 5 L/min).
What are the potential barriers or challenges?	VEECs are generated through "prescribed activities" with deemed values or specified methodologies for calculating VEECs. Under the current methodology for shower head replacement, VEECs are generated in the decommissioning of shower rose running above 9 L/min. Efficiency upgrades below this are therefore not recognised and eligible for new certificates (eg, upgrading a shower rose from 12 L to 9 L is the same as updating from 9 L to 5 L despite the increase in efficiency).

What would be needed to support these outcomes?	For the generation of certificates from a new shower head replacement scheme, there is the requirement for the existing methodology to be reviewed and upgraded to reflect current technical advancements. Suggested areas for amendments to the ESC methodology are in red: *Part 17—Low flow shower rose* *The prescribed activity is—* *(a) decommissioning a shower rose with a flow rate designated in Table 17.1A ; and* *(b) installing a product specified in subclause (2).* *(2) The specified products are the following—* *(a) a product listed on the ESC register as belonging to a product category whose category number is specified in column 1 of Table 17.1B;* *(b) an unlisted product that complies with the criteria specified in column 2 of an item in Table 17.1B.* *(3) The change in flow rate is measured by subtracting the installed product in clause 17.1(b) from clause 17.1(a), and this will form the basis of calculating energy efficiency.* *Table 17.1—Product categories* *Column 1 – Category number* *Column 2 – Criteria applying to product category* *17.1A. The removal of a shower rose that achieves a flow rate of [insert value] L.* *17.1B. A replacement shower rose complying with the requirements of AS/NZS 3662 that achieves a specified minimum star rating flow rate of [insert value]L when assessed, registered* *2) Incorporating licensed plumber certification in any targeted future shower head exchange program.* *3) Project-based activities for any future large-scale upgrade programs.* *4) Further investigation is required to determine whether and how the barriers faced by installing water efficient fixtures in tenant households could be overcome.* For optimising water-related energy outcomes, an updated activity-methodology could measure the actual reduction in flow rate and use that forms the basis of calculation. These would need to be underpinned by sufficient data on shower head flow rate and flow capacity (informed by technical and behavioural modelling) and may also have to reference the type of water heater, ie, gas vs electric, etc). Such outcomes can be supported by the future role out of digital meters, but questions surrounding data frequency (ie, half-hourly) and its reliability in producing the right resolution to quantify these efficiencies remain.
What are the potential next steps?	DELWP Energy have committed to a process to review the programs approach to additionality for cases where sectors (such as the Victorian water sector) or companies have internal targets. A Victorian Energy Upgrades Working Group has been established comprising representatives from Victorian metropolitan utilities, the ESC, key DELPW staff and the Beyond Net Zero research team. The purpose of the group is to a) Explore the role of VEECs and the likely incentives for water corporations resulting from those certificates. b) Consider a test case for the Victorian water sector's interaction with the VEU program and collate learnings with applicability for the broader sector and other project types. In accordance with these outcomes the Net Zero Water Cycle project will support these outcomes through the provision of technical data and behavioural insights from the ongoing phases of this research. This is needed to support the development of a revised methodology for shower rose replacements and to guide the future piloting of test cases.

Opportunity 2: Federal Emissions Reduction Fund Methodology Development for Utility Customer Level Offsets

Summary of the current program, scheme or initiative.	The Emissions Reduction Fund (ERF) is a voluntary scheme that aims to provide incentives for a range of organisations to adopt new practices and technologies to reduce their emissions. A number of activities are eligible under the scheme and participants can earn Australian carbon credit units (ACCUs) for emissions reductions. One ACCU is earned for each tonne of carbon dioxide equivalent (tCO_2-e) stored or avoided by a project. ACCUs can be sold to generate income, either to the government through a carbon abatement contract, or in the secondary market. Under the ERF firms will submit a sealed bid to the government's Clean Energy Regulator that quote a cost associated with reducing GHG emissions beyond some pre-determined benchmark. All bids are then ranked according to cost per unit of carbon reduction and those offering best value are funded, subject to available funds. The NCOS provides guidance on what is considered a genuine voluntary offset and sets minimum requirements for calculating, auditing and offsetting the carbon footprint of organisations or products. To achieve carbon neutrality certification under the NCOS Carbon Neutral Program, an entity must measure its carbon footprint, reduce emissions where possible and purchase NCOS eligible abatement to offset the remaining emissions. **Scope 1** covers direct **emissions** from owned or controlled sources. **Scope 2** covers indirect **emissions** from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company. **Scope 3** includes all other indirect **emissions** that occur in a company's value chain both upstream (supplies) and downstream (in use of products sold).
What is the opportunity?	Under the ERF framework water utilities currently have no obligation or incentive to do anything at the customer level (*"downstream*" of their provision of water). This is despite "downstream" GHG mitigation opportunities being a specific component of the GHG protocol and opportunity for emissions reductions at a far lower cost than traditional utility energy efficiency and renewable energy initiatives. The opportunities in relation to the ERF are two-fold. 1. Water Utilities can reduce emissions by retiring self-generated offsets that meet the NCOS. Self-generated offsets refer to offset created by or on behalf of a utility in Victoria. However, at present emissions produced by customers are not eligible for consideration as a 'self-generated offset'. 2. There is potential for utilities to join as a market participant where they bid on wholesale energy use reduction via water management. Including customer level emissions as a self-generated offset would further incentivise these objectives. However, currently there is no methodology for household efficiency programs to be included as ACCUs, and thus there is a limited incentive for water utilities to become market participants.
What would be needed to support these outcomes?	From the review process, two key critical requirements have been identified to support the above opportunity: 1. Policy change to formalise a methodology for energy efficiency projects at customer level (such as shower head and hot water service replacement) to be recognised as offsets against water authorities Scope 1 and Scope 2 emissions under the ERF. 2. Water utilities should lobby Australian Alliance for Energy Productivity to push for policy change to formalise a method for energy efficiency projects at the customer level to be recognised as offsets against water authorities Scope 1 and Scope 2 emissions under the ERF. Additional representation on the NCOS committee and COAG Energy Efficiency Committee could further the lobbying efforts for these outcomes. This could be approached at a national level through bodies such as the Water Services Association of Australia.

What are the potential barriers or challenges?	Victorian water authorities have been given guidance on offset purchasing – there are strict rules around offset purchases, which limit the opportunity for the generation and market compatibility of localised offsets (eg, distinction between overseas vs local offset). Water sector stakeholders described NCOS as unhelpful in supporting opportunity for utility generation – as international offsets are under NCOS, therefore making it difficult to justify more costly local offsets. Without more international offsets many companies could not run carbon neutral programs if just using Australian offsets, and thus NCOS are unwilling to change current market options.
What are the potential next steps?	There are some precedents for water/energy efficiency programs (eg, shower head exchanges) to be as legitimate offsets – existing methodologies could be adapted/expanded for broader industry coverage. Examples of these might include the following: • Sydney Water has created NSW accredited offsets against Scope 1 and 2 emissions through programs such as shower head exchange schemes but they did not include the customer hot water heating emissions as part of Sydney Water's footprint (only counted Scope 1 and 2). • Yarra Valley Water used shower head exchange program to offset upstream Scope 3 as well as Scope 1 and 2 emissions (but did not count hot water heating as a Scope 3 emission). Further consideration of these initiatives and how they may be subsequently developed to harness federal ERF opportunities, present a critical next step in the examination of these enablers.

Opportunity 3: Segmented Servicing for concession tenant household water-energy efficiency

Summary of current program / initiatives.	Recently, the Victorian Government has announced a $797 million program to support rental, social housing and concession holders with energy and water efficiency upgrades. Budget allocations include $112 million to seal windows and doors, and upgrade heating, cooling and hot water in 35,000 social housing properties. Minimum efficiency standards for rental properties will also be introduced to reduce energy bills for tenants, and improve living conditions for renters in over 320,000 (Approx.) identified poor-quality residences across Victoria. Furthermore, many Victorians will be supported with a one-off $250 payment for eligible concession card holders, (including anyone receiving JobSeeker, youth allowance or pension payments), designed to support an estimated 950,000 Victorian households who would otherwise struggle with bill payments.
What is the opportunity?	Significant opportunities exist to offer additional and ongoing support to concession holders, rental and vulnerable community members through residential water and energy efficiency programs. A recent study into energy and water programs for vulnerable Australian households, conducted by Behaviourworks Australia, revealed that programs that include retrofitting, appliance upgrades, consumer advice and pricing schemes stand to deliver multiple benefits beyond water and energy efficiency outcomes for communities. These range from improved health and wellbeing outcomes, financial stability and perceptions of control (Lauren, Tear and Smith 2020, Chong 2018). Water utilities, community support organisations, and relevant government agencies also stand to benefit, through optimising efficiency programs in light of these recent state government initiatives. For example, concession customers and those in rental properties are customer segments that have traditionally been hard to reach in utility household efficiency programs such as shower rose replacement schemes. A recent explorative study commissioned by Yarra Valley Water found that 43% of tenant customer shower heads (over 100, 000) were still inefficient in their region, costing customers on average an additional $67 in water and $40-$100 in electricity per shower head each year (equivalent of 14 kL in water and 100-500 kg CO_2-e / shower head/year) (Chong 2018). Notably each shower head also represents two VEECs that water utilities could generate, thus representing a substantial opportunity for improved servicing outcomes (as presented in Opportunity One). Water-energy efficiency programs also present some potential to reduce state government funded concessions for water and energy bills provided by the Victorian Department of Health and Human Services (DHHS). Chong (2018) found that in 2016/17, almost 660,000 of Yarra Valley Water's residential bills included a concession payment, in total valued at approximately $48 million. It is estimated that about 165,000 (or greater than 20%) of Yarra Valley Water's residential customers receive these concessions (Chong 2018). However, subsequent discussions with key personnel as part of this analysis revealed that as concession repayments require customers to self-register, there are many thousands of concession card holding residents that currently are not receiving concession support with their bills, despite their eligibility. Chong's (2018) findings reveal that owner occupiers, paying fixed water and sewage system charges (in addition to varied use charges) presented little opportunity for concessions savings, as the concession allocated for these fixed charges (Approx. $66.83) was near the concession cap of $78. Tenants however, only pay usage charges, with landlords having responsibility for fixed system charges. Therefore, reducing water use would also translate to a reduction in the concession paid. Notably, Chong (2018) concluded that for the Yarra Valley Water region water saving for concession tenants alone presented limited potential for reducing concessions paid (eg, supporting 1/3 of tenant concession customers to save 50 litres of water per day would produce savings on water bill concessions equating to approximately $300,000 per year). Limited from these considerations however, are the added potential savings at the broader metropolitan or state-wide scale, concessions savings associated to energy and gas bills (not just water bills) and the added impact of eligible concession card holders yet to register for bill concessions. Further quantification of these dimensions is needed to

	understand the extent of these opportunities in relation to water-related energy interventions. This initial analysis points to a substantive opportunity for optimising water-energy and GHG efficiency outcomes through an emphasis on segmented customer servicing that focusses specifically on concession holders in rental properties. Implicit here is the need for greater coordination between stakeholders including water and energy utilities, community welfare and support services (including those in social housing support), real estate agents and relevant state government departments such as DELPW, DELPW Energy and DHHS.
What are the potential barriers or challenges?	From the review of materials and subsequent stakeholder discussions, it seems there is general support across organisations for segmented servicing outcomes in water and energy efficiency programs. However, several barriers were identified as having limited progress in this area to date, which included: i. Institutional arrangements and resourcing being not supportive of cross-agency collaboration, creating knowledge gaps and resource intensive delivery outcomes which hinder more segmented servicing opportunities. ii. Short-term program cycles for water and energy efficiency, which limits avenues for cross-stakeholder coordination and opportunities for long-term customer engagement and participation. iii. Limited community input and community sector participation in the early design phases of programs, which lead to program delivery outcomes that lack contextual sensitivity and understanding of existing experiences, needs and capacities.
What would be needed to support these outcomes?	From their review, Lauren, Tear and Smith (2020) describe the following objectives as critical to the success of water efficiency programs that have been targeted at vulnerable customers: i. The need for alignment of organisational factors (eg, objectives, partnerships, funding) and adaptive management from the outset of the project. ii. For recruitment and engagement to be established through personal relationships and networks to build trust and understanding. iii. Specific behavioural and technical interventions that are tailored to the experiences and needs of particular community sub-sections. These need to be underpinned by appropriate servicing arrangements to ensure their uptake and ongoing functionality. iv. Servicing solutions that foster ongoing engagement through empowering community segments with education, enable ease of participation, and regular engagement in a compassionate manner. These requirements present the need for governance processes that enable water and energy service providers to work collaboratively with state government departments, community development partners and community networks over a long-term basis to develop segmented servicing arrangements that better support uptake and engagement for 'hard to reach community members'. Critical to these requirements are appropriate legislative, regulatory and institutional arrangements that can enable adequate resourcing for the establishment of these processes.
What are the potential next steps?	Inter-agency support networks or working groups are required to determine an appropriate course of action for the coordination and further quantification of community level, utility and state government level opportunities (such as those described above) and resource channels for enabling outcomes in the face of recent state government budgetary allocations. While many stakeholders noted the value of "shared-risk" based technical innovation networks such as the "intelligent water network" and similar programs led by the Water Services Association of Australia, few noted similar cross-sectoral networks that sought to establish socio-institutional outcomes to further customer delivery capabilities. One participant noted the potential for the Thriving Communities Partnership to play a role "given water utilities and many energy utilities are members".

8.7 Recommendations for Phase 2: Catalysts for Change

Harnessing opportunities such as those identified above will require ongoing collaboration between the broader research partners, their stakeholders and communities. From this analysis, key considerations emerged stemming across opportunities as important catalysers for change. In relation to specific opportunities, these present areas for further consideration in Phases 2 and 3 of this research.

Theme	Considerations
Net Zero Water Cycle Governance	There is currently a gap in agency or leadership for the co-management of water and energy. Determining which agency has leadership for water-related energy efficiency and who pays for what remains a challenge. This will require ongoing co-development between key stakeholders across water, energy and community sectors, and the establishment of appropriated institutional arrangements to guide these development processes. Notably, there are a number of ways this could be pursued. Some participants noted the potential role water utilities could play as a boundary spanning organisation with enriched capabilities for facilitating cross-sectoral integration. However, there is currently little incentive (regulatory, legislative or otherwise) for utilities to address downstream (or supply end) emissions. This comes amidst recent calls for the reform of the National Water Initiative (NWI) to play closer attention to climate related impacts (PC 2021) and institutional reforms warranting attention at a national scale. The Phase 2 and 3 recommendations associated outlined here provide examples of leverage points within the current system for pursuing integrated or "whole of water cycle" governance outcomes for water-related energy. Notably a range of stakeholders would need to participate to address some of the opportunities identified.
Scaling Innovation	The emergent findings of this research point to opportunities for optimised, water and energy efficiency, GHG reduction, economic viability and community wellbeing when quantified, evaluated and delivered at a whole of system (or state-wide) scale. Critical to these considerations is the need for pilot programs and initiatives to be scaled across different contexts, to offer benefits at a whole of system, metropolitan, state or even national scale. Many stakeholders described aspects for future consideration in relation to these challenges, which included: - A question of who finances and who pays, particularly given the relationship between outcomes for greater public benefit (achieved at scale), compared to those for specific benefit to a utility or utility customer, which might support an initial pilot program (eg, utility shower rose rebate scheme). - Challenges in how to mobilise under resourced or less resourced stakeholders, in particular non-metropolitan Victorian utilities or local governments with a more limited remit of service delivery capacities. - A need for cross-organisational and cross-agency processes for data and information sharing and common methodologies for quantifying benefits and risk. - Ensuring a desired policy state that simultaneously drives wide-spread role out while also supporting ongoing participation and engagement with low-income households and community sector support groups to ensure interventions are fit for purpose.

Theme	Considerations
	- Tools and governance to support shared investment and shared risk models which can foster the buy-in and participation of key stakeholders across regions. Initiatives such as intelligent water networks, and national level working groups such as those facilitated through the Water Services Association of Australia were seen as effective avenues to enhance systems wide optimisation through knowledge sharing and advocacy. Critical to these processes is a need to address both technical as well as socio-cultural (including cross sectoral) requirements.
Forecasting: The need to see, respond and adapt to horizon opportunities	While it is anticipated that a number of technical and behavioural insights are likely to emerge from this research, a key question remains in how to ensure a strategic agility amongst stakeholders to ensure practitioners and policy makers are able to mobilise and respond to emerging 'horizon' opportunities in order to embed new practices across scales. Opportunity 3 identified above provides a notable example, in considering how the behavioural and technical insights generated from Phase 2 and 3 of this research could best support the Victorian Governments investment in energy efficiency upgrades for social housing, renters and concession holders. As our preliminary analysis suggests, water utilities, energy utilities and welfare support providers (including DHHS) stand to benefit from coordinated servicing arrangements, however, to date limitations in institutional structures and a siloed governance culture has limited opportunities for integrated outcomes. Ensuring a greater flexibility in the institutional environment to best enable these outcomes will require ongoing examination in subsequent research phases. Critical to these outcomes is the need to consider the interlinkages of internal processes of water utilities with those of partners in energy utilities, community service providers and corresponding governing agencies and processes to build alignment in desired outcomes and coordination in adaptive response procedures.

Section 4 – Conclusions and Recommendations

9 Conclusions

This study has identified a number of significant gaps in the co-ordinated management of water-related energy and GHG emissions. These include:

Gap 1 – **Technical data and knowledge of energy and carbon efficiency through the entire water cycle.** There is a lack of recent data relevant to the management of household water-related energy. Specific high value datasets (eg, water end use breakdown and related socio-demographics) has not been identified despite a shift to higher intensity water metering. This is very important to compare across "utility-scale" and "household/community"-scale management options.

Gap 2 – **Understanding of Behaviour**. Knowledge of the behaviour changes necessary for customers – or customer segments – to adopt new techniques or systems, and how utilities can interface in ways which help achieve efficiencies while simultaneously improving affordability and wellbeing, do not seem to have been considered. With the growth in data measuring devices and computer processing capability utilities have new possibilities that have not existed previously. This creates the opportunity to meet each customer's needs and values specifically while supporting their use of less water and energy. Further, very little is currently understood (and very little data exists) addressing socio-demographic factors influencing water use. This is a major omission which needs attention.

Gap 3 – **Organisational/policy**. There is a lack of action (ie, leadership) for combined efficiency across water and the related energy impact that it has. Within utilities and State agencies, it appears to be a "nobody's problem, problem" ie, there is no organisation with responsibility for programs of efficiency across water, energy, GHG, affordability and liveability. In brief, we have identified that an efficient shower head has a payback period of about one year, after which the saving is about $150+ a year (Yarra Valley Water pers comm). So why are people not doing it? We need to find new creative ways to inform, incentivise, and enable change and we need a policy and regulatory framework that supports this rather than delays it.

Gap 4 – **Definitions**. A wide range of terms are being used, often with inconsistent meaning and application. These include "carbon neutral", "energy neutral", "net zero energy", "net zero carbon", "100% renewable". Added to this is the "scope of the water cycle" which the GHG (or energy) management goal applies to. Most goals in this domain relate to "organisations" (eg, a Net Zero water utility). This is quite distinct to the aim of a "Net Zero" Water Cycle (or City) which is also only very loosely defined currently.

This project has identified points of leverage which can start to address these gaps and specifically address the problem of rising water and energy costs. It offers a new efficiency and customer-focussed opportunity to reduce consumption of both water and related energy.

9.1 Rationale for Progressing the Project

The following reasons summarise the rationale for progressing to Phases 2 and 3 of the residential project.

- **It would represent a shift towards a (i) customer-centric solutions** and **(ii) more customised/tailored management of water end use**. The planned intervention (even if limited to shower systems management) represents an option to go well beyond the semi-standard water efficiency programs of the past. By integrating technology and behaviour management, and drawing on demographic and household-specific information, options will be created for customers to simultaneously address their costs of both water and energy.

- **It is clear that efficiency solutions represent least cost from a community perspective**. For example, based on the analysis of the shower head replacement program (Scenario 1) efficiency was demonstrated as the lowest cost strategy to the Melbourne/Victorian community compared with other GHG mitigation schemes currently within the Pledge. Consequently, there is a strong business case for the program if a customer centric perspective is taken.
- **It would add value to the planned digital meter roll-out.** Current planning for the digital meter roll-out is not expected to provide end use breakdown. This means it would have limited value for understanding water-related energy unless strategic additional capacities or details are included (eg, selected sites need the capability for end use breakdown).
- **The program would simultaneously contribute significantly towards goals articulated by the State of Victoria** (eg, (i) a zero emissions climate ready economy and community, (ii) safe, sustainable and productive water resources, particularly improved security, and (iii) reliable, sustainable and affordable energy services. It gives a clear pathway to achieve this without trading water impacts for energy impacts (eg, additional desalination for water security would come at a high energy use impact) or vice-versa (eg, many energy development options require additional water eg, for cooling). Noting that potential unintended consequences (eg, potential GHG emissions from internally-heated front-loading clothes washers and dishwashers) require detailed consideration in Phase 2.
- **It would bring forward the argument relating to trade-offs between management of water, energy, GHG, cost or wellbeing** and hence enable a future set of water management plans to have much clearer goals in this domain.
- **It would help inform future water strategies for Melbourne toward "integrated resources strategies"** (for example, there are still separate water, sewerage, energy and GHG strategies, in future these are anticipated to be more integrated at the highest level).
- **It would, if scaled up, cost-effectively offset Melbourne's next water augmentation and delay needs for energy upgrades.** This would be achieved if applied at scale (eg, at all of suburb scale), and expanded to all of Melbourne and Victoria scale (after Phase 3).
- **Create new areas of trans-disciplinary work across the water-energy sector and spanning institutional, social and physical science components.**
- **Find new optimal solutions and strengthen the rationale for investment pathways**. It would achieve this by enabling systematic analysis for multiple/co-benefits resource efficiency across sectors.
- **It would create a strong research-industry government partnership.** This would help accelerate (a) the generation of timely and industry relevant data and knowledge, and (b) rapid application of the knowledge into relevant policy and implementation options.
- **It would put information into the public domain and help drive innovation.** This would support movements beyond the current infrastructure dominated thinking as the prime solution to problems.

An important aim of the technical and modelling analysis was to quantify water-related energy, identify key data and options to focus on in Phase 2. It is clear that shower systems represent the largest fraction of water-related energy (approximately 50%) and a large share of related GHG emissions. Clothes washers (9%) and dishwashers (7%) also comprise a significant fraction of water-related energy and because of their larger dependence on electricity (much of which is currently produced by coal-fired power) also account for a large share of water-related GHG emissions. Systems losses (eg, pipe and storage as well as hot water system efficiency) are also high (estimated as 17%) noting uncertainty around losses estimates is higher than other end uses.

9.2 Key Recommendations

Recommendation 1: The project should progress to Phase 2 (optimisation of options). Phase 1 has demonstrated a compelling case, showcasing opportunities to reduce water related energy in households, using robust scientific rigour. Specifically, during Phase 2 (and 3) the project should keep in mind system-wide impacts (eg, energy load shifting, water asset implications, and social and wellbeing implications, not just water and energy efficiency). This could include hot water as an energy storage option enabling more renewables into the energy supply side. Wherever possible the project outcomes should inform the Metropolitan Urban Water System Strategy currently being developed by the water utilities. Finally, a cornerstone of the project is the enabling of systematic and long-term behaviour change and the project can play a significant role in achieving circular economy outcomes.

Recommendation 2: Phase 2 optimisation of options should focus on Shower Systems, Clothes Washer Systems, Dishwasher Systems and related losses. Phase 1 has identified these are the areas where GHG reduction, residential cost saving, energy efficiency saving, and water-based benefits are collectively greatest. For example, as demonstrated in case study 1 (Reservoir), shifting the entire population to 6.3 L/min shower heads and 4 minute shower duration has the potential to save 12 GWh/yr energy, 0.4 GL water (and wastewater) and reduce 4.3 kt CO_{2-e} (in the suburb). If applied across all of Melbourne, it would save an estimated 61 GL/yr in water savings and 619 ktCO_{2-e}.

The optimisation of options should integrate technical and behavioural opportunities to understand the singular and combined influence of each. The optimisation of options in Phase 2 should consider in detail the impacts and opportunities for vulnerable/disadvantaged groups to ensure the solutions improve overall wellbeing and affordability.

Recommendation 3: Phase 2 should undertake small scale pilots with the aim of implementing preferred interventions during Phase 3 at a suburb-scale. Interventions in Phase 3 are intended at the scale of the entire suburb, initially in Reservoir and followed by Frankston. A third case study in Greater Western Water's jurisdiction could be considered but has not been scoped in this proposal. During Phase 2, small scale pilots (eg, a shower head exchange of ~100 to 500 households) is anticipated led by partnering utilities and with associated digital meter installation. This will enable and support a related monitoring program (led by the research partners) to capture key data (eg, with Amphiro unit installation) and quantify impacts on energy and GHG emissions.

Recommendation 4: Further analysis and, if appropriate, changes to the enabling environment should be pursued throughout Phases 2 and 3. Appropriately supportive enabling environments are absolutely key to achieving sustained and state-wide benefits of this research. Preliminary reviews suggest there are opportunities for appropriate changes in these areas. For example, the project presents an opportunity to explore a shift towards a situation that would allow water utilities to claim wider community value of such initiatives (ie, wider than a utility-focus alone).

Recommendation 5: The opportunities of Water in a Net Zero GHG city should be progressively articulated and documented. This recommendation recognises that this project creates opportunities for far greater changes than to the VEEC (Victorian energy efficiency certificates) program in the area of shower head efficiency. If all the opportunities present in residential water management which can save water, energy and GHG emissions are considered, there is a very large scope for change – however, changes to the enabling environment are necessary for this to occur. An even greater role of the water sector in net zero cities could be created if utilities are also given scope to influence water-related energy in the industrial and commercial sectors, and in landscape-level cooling. However, this opportunity, how it is defined, managed and regulated, needs far better description which will explored in Phase 2.

9.3 Institutional Enabling Environment Recommendations

9.3.1 Net Zero Governance, Leadership and Institutional Reform Processes

There is currently a gap in agency or leadership for the co-management of water and energy. This will require ongoing co-development between key stakeholders across water, energy and community sectors, and the establishment of appropriate institutional arrangements to guide these development processes. To support these outcomes Phases 2 and 3 of this research could support the following initiatives:

Recommendation 6: The ongoing review of VEEC/VEET regulatory measures and the piloting of a program to test new methodologies to support technical innovation upgrades in household appliance stock. Phase 2 could support a cross sector working group with the ongoing development of a program that pilots a methodology calculating VEECS associated to water efficient shower head exchange. This will utilise behavioural and household technical insights to quantify shower head flow rate, with behavioural variables such as flow use and time (etc). This will fill important scientific gaps relevant to regulation.

Recommendation 7: Advocacy and cross-sector collaboration to support the development of an ERF methodology for household appliance upgrades. Phase 2 could support the creation of a method that water utilities can follow in order to claim ACCU's for down-stream emissions such as those relating to household water use. This will require stakeholder collaboration and policy advocacy via a national working group. As a driver for incentivising these outcomes, many stakeholders have acknowledged the potential for Phases 2 and 3 to investigate policy options and opportunities that encourage water utilities to report customer water use emissions in their annual reporting. This presents the opportunity to promote supply-end (or "downstream") emissions reductions initiatives in line with utilities commitments to transitioning to a low carbon economy, and thus present an incremental enabling path.

Recommendation 8: Supporting intergovernmental practice for a customer–centric approach to water energy servicing. Phase 2 could support the development of a working group or initiative to develop the principles for customer centric leadership and practice. A key focus of this will be in how to ensure value maximisation in ways that align with communities' wellbeing outcomes. Both institutional and leadership culture will be a key requirement to ensuring a motivation for each stakeholder to deliver outcomes that focus centrally on the wellbeing of communities.

9.3.2 Scaling Innovation to support whole of system or state-wide benefits and outcomes

A key challenge relating to the outputs of this research and other related initiatives lies in the question of how to achieve optimised outcomes at scale. Phase 2 could support the following outcomes:

Recommendation 9: A Working group to support best practice Household Appliance Stock Regulation and Policy. Stakeholders acknowledged the requirement for ongoing advocacy for institutional regulatory and policy measures that span household residential water appliance stock, to ensure the upkeep of appliance standards in line with technical proficiencies and innovation. This is necessary to ensure that efficiencies generated from the findings of this research are not undermined by broader market processes. Phase 2 and 3 of this research could support these initiatives through the establishment of a cross sector sub-group to pursue these outcomes. A working group could be developed around water appliances including considering the enabling environment to support efficiency measures which do not undermine savings from related proposed measures, etc. Another building sector opportunity could relate to house efficiency assessment at point-of-sale (of households).

Recommendation 10: Stakeholder communications and engagement strategy for Integrated resources citizenry. Phase 2 and 3 should work with research partners to develop a more coordinated communication strategy to drive community wide literacy building and establish a societal culture for water-energy efficiency derived from values on GHG reduction, community wellbeing and bill saving.

Victoria's experiences of the millennium drought and the enabling environment that resulted around this has left a lasting legacy of both literacies and capacities for water efficiency practices throughout Victorian households. Supporting broader system-wide processes of transition towards an integrated resources efficiency (ie, Water-energy efficiency planning and management) will require an active community engagement and support for these outcomes. To support the shift of Victoria to a carbon neutral economy (and Net Zero water sector), there is now a need to extend the literacies and capacities of Victorian residents beyond water saving as a drought prevention measure to consider the integrated dimensions of household water, energy and waste (resource flows) and the environmental, social and economic benefits of integrated efficiency measures. Within the enabling Environment Water Utilities and DELWP there has been little coordination to date on addressing these community literacies for building outcomes. These are important because a rich community literacy and salience for household water efficiency provides a key enabler for utilities to justify service delivery upgrades to the ESC.

9.3.3 Forecasting: The need to see, respond and adapt to horizon opportunities.

The institutional, regulatory and policy environment must remain adaptive and agile to respond to opportunities that can support technical and behavioural interventions (such as new appliance roll-outs) across Victorian households. Phase 2 and 3 should support the following outcomes:

Recommendation 11: Supporting concession, low-income and rental households. With recent reforms to residential tenancy requirements, a substantive opportunity exists to enhance household water-energy outcomes for concession, rental and low-income households. Phase 2 and 3 should seek to respond to this opportunity to ensure implementation is underpinned by best practice household water energy efficiency knowledge. Next steps should include developing a richer quantification of the potential savings opportunity for supporting concession rental customers with household Water- energy efficiency outcomes. This should be quantified not just in terms of water utility bills, but broadly at a system level to consider water and energy concessions payments for the concession holder whether registered to receive concessions or not. Developing this level of quantification will also require a greater coordination between state government departments, water and energy utilities and community support providers which the project could seek to foster through a high-level (and ongoing) steering group.

9.4 Behavioural

The key focus of this phase was to identify behaviours and behavioural interventions for reducing household water-related energy use. There is minimal research that specifically examines water-related energy behaviour so this report also draws on evidence from behavioural interventions that aim to reduce consumption of energy or water. In the academic literature, the most frequently targeted water-related energy behaviours are showering, clothes washing and dishwashing. These behaviours are also emphasised in existing water-saving campaigns in Victoria. Water-related energy use is also addressed through a range of retrofit programs that increase installations of efficient appliances, particularly hot water systems and low-flow shower heads.

The academic literature is not sufficiently advanced to make firm recommendations about effective interventions. Similarly, practitioners stated that there are few available examples of program evaluations that measure behaviour change, particularly long-term behaviour change. However, some broad approaches were consistently identified in both the rapid review and the practice review as being the best-practice approach to reducing household water-related energy use. These include: using social norms, providing individual feedback about water and energy use, targeting programs to specific populations, including communities in designing interventions, and delivering a coordinated suite of interventions. These approaches inform the recommendations for the Net Zero Strategy that are outlined below.

Recommendation 12: Develop a strategy that combines multiple approaches but evaluates the contributions of individual interventions. While combined approaches are identified as best practice by both the academic literature and practitioners, delivering programs in combination makes it difficult to establish the contribution of individual interventions to total reductions in water-related energy use. Rigorous pilot testing of individual interventions, and staged introduction of different interventions would help to establish an evidence base to help make decisions about the most effective combination of interventions.

Recommendation 13: Select digital metering installations that allow water authorities to provide individualised feedback to households. Digital metering trials are currently underway to determine the most effective options for installation in Victorian households. In addition to the effectiveness of the meters themselves, the potential for digital meter data to develop behavioural interventions should be considered when selecting meters. Digital metering data has the potential to allow water authorities to develop interventions such as gamification of water use and comparing households with other households in their communities. These interventions may produce more behaviour change than simply providing feedback about individual household water use.

If digital metering data does not allow analysts to differentiate the precise end uses of water, additional pilots of hot water metering may add useful data.

Recommendation 14: Establish positive social norms around water-related energy use. Positive social norms can be generated in various ways. Digital metering allows for comparing high-using households with similar lower-using households. Trusted champions within specific communities can model behaviours that reduce water-related energy use. Gamification programs that include school or community-level competition build positive social norms by showcasing and publicly rewarding households that reduce their consumption. Water-related energy saving education programs can include education about how to encourage others to reduce their consumption.

Recommendation 15: Continue and enhance the two-pronged approach to household segmentation. The available academic literature highlights the importance of targeting high consuming households. The current approach in Victorian water conservation, employed in the Make Every Drop Count campaign, takes this approach one step further by targeting households with high discretionary water use, which is high use of water that is easy to reduce. The highest discretionary water use is in long showers so targeting high discretionary use also targets water-related energy use. While the global literature focuses only on high-consuming households, Victoria also has a range of programs that provide targeted support to low-income households. This dual approach should be continued because it enables water authorities to save the largest volume of water at the least cost by targeting households with high discretionary water use, while also supporting households who have high needs rather than high use. Further segmentation could include differentiation of groups according to criteria such as culture, education, religion, or attitudes to water-related energy use.

Recommendation 16: Co-design programs with vulnerable communities. Although there are few examples of evaluated co-designed programs to draw on, the academic literature and some practitioners recommend designing interventions with community members. This is particularly relevant for close knit communities and those with households that face additional barriers to reducing their water-related energy use, such as difficulty accessing energy efficient appliances.

Recommendation 17: Emphasise the energy-saving benefits of water-related energy use reductions. Water-related energy use has generally been framed as a water-saving strategy. Emphasising energy-saving has multiple potential benefits. First, the financial benefits of reducing energy use are greater than those for reducing water use. Second, energy is not subject to the cycles of drought and rain that affect water-saving programs. Third, emphasising the energy-saving benefits of water-related energy may assist in developing partnerships with energy companies, government departments, and non-government organisations with an interest in energy affordability.

9.5 Data and Monitoring

Recommendation 18: Stronger demographic data and analysis is needed in Phase 2. During the study it became clear that very little demographic data is available (eg, even for water end use, there is relatively little information on how that end use is partitioned within different socio-demographic groups). Even less data are available on disadvantaged or vulnerable groups. In order to ensure “no one is left behind” Phase 2 should greatly strengthen this understanding.

Recommendation 19: Demographic data such as the number of people per household to accompany household scale water or energy use data. Raw water use data provided at the household scale could not be used to verify model results due to a lack of information on the number of people in the household (ie, without the number of people in the house, the household information could not be used to verify either per capita or household scale inputs and outputs).

Recommendation 20: Collect data from a larger number of customers and wider representation of socio-economic groups. The sample size of end use characterisation reports has an indeterminate effect on modelling inputs and outputs due to a lack of information on socio-economic data on the participants (eg, 500 to 2000 persons per water distribution region without information on their socio-economic background, scaled up to represent the water use consumption patterns of 2 million persons).

Recommendation 21: Suburb-scale verification data (water use, electricity use, natural gas use) should be sourced. Alternatively, analysis boundaries shifted to represent time-scale metering of bulk water electricity and gas flows.

Recommendation 22: Improved access to current and historical digital meter data collected by utilities would be important. This recommendation has two aims. Firstly, improved end use characterisation. End use characterisation was sourced from graphs in industry reports. The use of data derived from a graph vs access to the measured data may have impacted the modelling results. Secondly, model calibration and verification. Access to suburb scale water and energy use data is needed for model calibration and verification to continue to improve the accuracy of modelled estimates in water and water-related energy use.

Recommendation 23: Data access, and creation of primary data (including use of metered data) needs to be accelerated. Relatively little new data was identified during the study particularly in key areas of water end use breakdown. This is particularly important when considering the digital meter data. In addition to improved data access agreements (potentially complex with the diverse partnership involved in the project) a secondment of researchers to the participating water utilities may help with data access and flow. In Phase 2 there will be a need to bring together diverse water, energy and socio-demographic data in order to fully realise the potential of this project. Many are currently managed in different stakeholder groups (water utility, energy utility, ABS, etc). More specific planning for data management (including intersections with digital metering data) should be included in Phase 2.

9.6 Modelling Analysis and Monitoring

Recommendation 24: Improve understanding of potential intervention impacts on wellbeing, affordability in different socio-economic groups. It is not yet well understood how an efficiency intervention would impact wellbeing in different socio-economic groups. It is important to ensure that wellbeing is not adversely impacted of any socio-demographic group and rather that choice to support affordability is offered to all groups within the community.

Recommendation 25: Phase 2 to include detailed design of a monitoring program responding to clear aims and objectives of the program. This could include nested design of suitable (a) digital metering at resolution sufficient to partition water end uses, (b) together with potential for specific monitoring of hot water flows, household electricity and gas usage, and (c) shower and other end use specific data.

Recommendation 26: Simulate a range of new technologies particularly heat pump systems. A range of new technologies should be analysed for impact on household performance. The stronger uptake of new hot water system types including heat pumps should be simulated in order to determine their potential influence.

Recommendation 27: The scale of analysis (or multiple scales of analysis) would benefit from clarification together with agreement on "who will use the data and models of the project". This project has operated across a wide range of scales from households to whole of state. In order for analysis across a range of scales (and commensurate sensitivity and uncertainty analysis) clarification of key scales of analysis would help. For example, if state-wide (say rather than Melbourne-wide) analysis data is important, then additional data to represent areas outside greater Melbourne would improve analysis considerably.

9.7 Least Cost Analysis and Optimisation

The least cost analysis in Phase 1 demonstrated that individual household characteristics such as household composition and hot water system type can significantly influence the cost effectiveness, water-related energy use saving potential, and GHG emission abatement potential of a shower head program. Consequently, it affects priorities for intervention. Another key determining factor is the perspective - whether an opportunity is viewed (and costed) from either a (i) utility, or (ii) community, or (iii) combined perspectives.

Recommendation 28: To capture spatially-explicit data for different socio-demographic groups. There are significant data gaps to capture the variations of the water use behaviour and household stock of different socio-demographic groups, and to also differentiate them spatially. This prevents spatial-explicit modelling of the impacts of household characteristics (eg, baseline water use behaviour, household composition, hot water system type) on water-related energy use and GHG emissions. Collection and compilation of high-resolution smart water metering data, energy use data, and demographic data is needed to address this gap.

Recommendation 29: There is a need to move the dialogue around community engagement more strongly towards integrated resources management (and less about drought).

Recommendation 30: Analyse additional household characteristics and intervention options using improved data. Improved data would enable advanced modelling of the impacts of interventions in different household categories, in addition to household composition and hot water system type modelled in Phase 1 based on average data.

Recommendation 31: Model interventions that target a wider range of behavioural changes. The model is best to link the cost of behaviour change programs to the extent of behaviour changes, consequentially the water-related energy saving and GHG emissions abatement potential. This can be an agent-based model that utilises empirical data from pilot studies on behaviour change.

Recommendation 32: Undertake high resolution least cost analysis. Once the prerequisites of acquiring high resolution data and enhancing modelling capacity are satisfied, higher resolution least cost analysis can be conducted to provide a comprehensive comparison of interventions with consideration of uncertainty. This can maximise the cost-effectiveness of an intervention program, through identifying targeted groups that have higher certainty to achieve potential cost saving, water-related energy use saving, and GHG emissions abatement. In addition, other cost benefits such as treatment cost saving and deferring system augmentation are to be considered to future least cost analysis. Ultimately the least cost data and other data should be incorporated into some form of decision support such as multi-criteria analysis. This should include analysis from the perspectives (community vs water utility) to identify interventions. This can be used to propose incentive mechanisms that work best for all stakeholders.

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Appendix A: Method for Creating the Regional Water-Related Energy Model

This appendix provides a summary of the regional ResWE model simulation design. Details of calculation procedures, the simulation process (including the creation of input/output statistics), file conversions, and MATLAB files for processing regional model outputs can be found in Bors (2019).

Table A-1 details the significant factors that were utilised to capture end use variability of different household types to quantify water use, water-related energy use and associated GHGs across a region. Table A-2 details the simulation layout of all 320 household types (ie, 4 household compositions x 5 HWS types x 4 shower use x 4 clothes washing use). Table C-1 in Appendix C provides an example of the 145 input parameters required to model 1 of the 320 household types with references to input tables, calculation procedures (in Bors (2019)) and sources of data.

The "Regional" water-related energy model was used to create the "overview" models of each suburb used in the case studies for this project. This was undertaken to quickly incorporate updated quantification of resources flows with improved data on suburb-scale household, demographic and hot water system type and other data. Appendix B.1 provides further details.

Table A-1: Legend of significant water-related energy factors used to determine household types.

#	Significant Factor	Variant	#	Significant Factor	Variant
HC (1)	Household Composition	Family with children household	SU (1)	Shower Use	Efficient Shower head – Short Shower Duration
HC (2)	Household Composition	Family without children household	SU (2)	Shower Use	Efficient Shower head – Long Shower Duration
HC (3)	Household Composition	Single Household	SU (3)	Shower Use	Inefficient Shower head – Short Shower Duration
HC (4)	Household Composition	Group Household	SU (4)	Shower Use	Inefficient Shower head – Long Shower Duration
HWS (1)	Hot Water System	Electric – Storage	CW (1)	Clothes Washing	Top Loader – Warm Wash Cycle
HWS (2)	Hot Water System	Gas – Storage	CW (2)	Clothes Washing	Top Loader – Cold Wash Cycle
HWS (3)	Hot Water System	Gas – Instantaneous	CW (3)	Clothes Washing	Front Loader – Warm Wash Cycle
HWS (4)	Hot Water System	Solar – Electric Boost	CW (4)	Clothes Washing	Top Loader – Cold Wash Cycle
HWS (5)	Hot Water System	Solar – Gas Boost	-	-	-

Table A-2: Regional ResWE model simulation process for 320 household types (HT-1 to HT-320).

	HC (1)	HC (2)	HC (3)	HC (4)
HWS (1)	SIMULATION 1	SIMULATION 2	SIMULATION 3	SIMULATION 4
	[HT-1] SU (1): CW (1)	[HT-17] SU (1): CW (1)	[HT-33] SU (1): CW (1)	[HT-49] SU (1): CW (1)
	[HT-2] SU (1): CW (2)	[HT-18] SU (1): CW (2)	[HT-34] SU (1): CW (2)	[HT-50] SU (1): CW (2)
	[HT-3] SU (2): CW (1)	[HT-19] SU (2): CW (1)	[HT-35] SU (2): CW (1)	[HT-51] SU (2): CW (1)
	[HT-4] SU (2): CW (2)	[HT-20] SU (2): CW (2)	[HT-36] SU (2): CW (2)	[HT-52] SU (2): CW (2)
	[HT-5] SU (3): CW (1)	[HT-21] SU (3): CW (1)	[HT-37] SU (3): CW (1)	[HT-53] SU (3): CW (1)
	[HT-6] SU (3): CW (2)	[HT-22] SU (3): CW (2)	[HT-38] SU (3): CW (2)	[HT-54] SU (3): CW (2)
	[HT-7] SU (4): CW (1)	[HT-23] SU (4): CW (1)	[HT-39] SU (4): CW (1)	[HT-55] SU (4): CW (1)
	[HT-8] SU (4): CW (2)	[HT-24] SU (4): CW (2)	[HT-40] SU (4): CW (2)	[HT-56] SU (4): CW (2)
	[HT-9] SU (1): CW (3)	[HT-25] SU (1): CW (3)	[HT-41] SU (1): CW (3)	[HT-57] SU (1): CW (3)
	[HT-10] SU (1): CW (4)	[HT-26] SU (1): CW (4)	[HT-42] SU (1): CW (4)	[HT-58] SU (1): CW (4)
	[HT-11] SU (2): CW (3)	[HT-27] SU (2): CW (3)	[HT-43] SU (2): CW (3)	[HT-59] SU (2): CW (3)
	[HT-12] SU (2): CW (4)	[HT-28] SU (2): CW (4)	[HT-44] SU (2): CW (4)	[HT-60] SU (2): CW (4)
	[HT-13] SU (3): CW (3)	[HT-29] SU (3): CW (3)	[HT-45] SU (3): CW (3)	[HT-61] SU (3): CW (3)
	[HT-14] SU (3): CW (4)	[HT-30] SU (3): CW (4)	[HT-46] SU (3): CW (4)	[HT-62] SU (3): CW (4)
	[HT-15] SU (4): CW (3)	[HT-31] SU (4): CW (3)	[HT-47] SU (4): CW (3)	[HT-63] SU (4): CW (3)
	[HT-16] SU (4): CW (4)	[HT-32] SU (4): CW (4)	[HT-48] SU (4): CW (4)	[HT-64] SU (4): CW (4)
HWS (2)	SIMULATION 5	SIMULATION 6	SIMULATION 7	SIMULATION 8
	[HT-65] SU (1): CW (1)	[HT-81] SU (1): CW (1)	[HT-97] SU (1): CW (1)	[HT-113] SU (1): CW (1)
	[HT-66] SU (1): CW (2)	[HT-82] SU (1): CW (2)	[HT-98] SU (1): CW (2)	[HT-114] SU (1): CW (2)
	[HT-67] SU (2): CW (1)	[HT-83] SU (2): CW (1)	[HT-99] SU (2): CW (1)	[HT-115] SU (2): CW (1)
	[HT-68] SU (2): CW (2)	[HT-84] SU (2): CW (2)	[HT-100] SU (2): CW (2)	[HT-116] SU (2): CW (2)
	[HT-69] SU (3): CW (1)	[HT-85] SU (3): CW (1)	[HT-101] SU (3): CW (1)	[HT-117] SU (3): CW (1)
	[HT-70] SU (3): CW (2)	[HT-86] SU (3): CW (2)	[HT-102] SU (3): CW (2)	[HT-118] SU (3): CW (2)
	[HT-71] SU (4): CW (1)	[HT-87] SU (4): CW (1)	[HT-103] SU (4): CW (1)	[HT-119] SU (4): CW (1)
	[HT-72] SU (4): CW (2)	[HT-88] SU (4): CW (2)	[HT-104] SU (4): CW (2)	[HT-120] SU (4): CW (2)
	[HT-73] SU (1): CW (3)	[HT-89] SU (1): CW (3)	[HT-105] SU (1): CW (3)	[HT-121] SU (1): CW (3)
	[HT-74] SU (1): CW (4)	[HT-90] SU (1): CW (4)	[HT-106] SU (1): CW (4)	[HT-122] SU (1): CW (4)
	[HT-75] SU (2): CW (3)	[HT-91] SU (2): CW (3)	[HT-107] SU (2): CW (3)	[HT-123] SU (2): CW (3)
	[HT-76] SU (2): CW (4)	[HT-92] SU (2): CW (4)	[HT-108] SU (2): CW (4)	[HT-124] SU (2): CW (4)
	[HT-77] SU (3): CW (3)	[HT-93] SU (3): CW (3)	[HT-109] SU (3): CW (3)	[HT-125] SU (3): CW (3)
	[HT-78] SU (3): CW (4)	[HT-94] SU (3): CW (4)	[HT-110] SU (3): CW (4)	[HT-126] SU (3): CW (4)
	[HT-79] SU (4): CW (3)	[HT-95] SU (4): CW (3)	[HT-111] SU (4): CW (3)	[HT-127] SU (4): CW (3)
	[HT-80] SU (4): CW (4)	[HT-96] SU (4): CW (4)	[HT-112] SU (4): CW (4)	[HT-128] SU (4): CW (4)
HWS (3)	SIMULATION 9	SIMULATION 10	SIMULATION 11	SIMULATION 12
	[HT-129] SU (1): CW (1)	[HT-145] SU (1): CW (1)	[HT-161] SU (1): CW (1)	[HT-177] SU (1): CW (1)
	[HT-130] SU (1): CW (2)	[HT-146] SU (1): CW (2)	[HT-162] SU (1): CW (2)	[HT-178] SU (1): CW (2)
	[HT-131] SU (2): CW (1)	[HT-147] SU (2): CW (1)	[HT-163] SU (2): CW (1)	[HT-179] SU (2): CW (1)
	[HT-132] SU (2): CW (2)	[HT-148] SU (2): CW (2)	[HT-164] SU (2): CW (2)	[HT-180] SU (2): CW (2)
	[HT-133] SU (3): CW (1)	[HT-149] SU (3): CW (1)	[HT-165] SU (3): CW (1)	[HT-181] SU (3): CW (1)
	[HT-134] SU (3): CW (2)	[HT-150] SU (3): CW (2)	[HT-166] SU (3): CW (2)	[HT-182] SU (3): CW (2)
	[HT-135] SU (4): CW (1)	[HT-151] SU (4): CW (1)	[HT-167] SU (4): CW (1)	[HT-183] SU (4): CW (1)
	[HT-136] SU (4): CW (2)	[HT-152] SU (4): CW (2)	[HT-168] SU (4): CW (2)	[HT-184] SU (4): CW (2)
	[HT-137] SU (1): CW (3)	[HT-153] SU (1): CW (3)	[HT-169] SU (1): CW (3)	[HT-185] SU (1): CW (3)
	[HT-138] SU (1): CW (4)	[HT-154] SU (1): CW (4)	[HT-170] SU (1): CW (4)	[HT-186] SU (1): CW (4)
	[HT-139] SU (2): CW (3)	[HT-155] SU (2): CW (3)	[HT-171] SU (2): CW (3)	[HT-187] SU (2): CW (3)
	[HT-140] SU (2): CW (4)	[HT-156] SU (2): CW (4)	[HT-172] SU (2): CW (4)	[HT-188] SU (2): CW (4)
	[HT-141] SU (3): CW (3)	[HT-157] SU (3): CW (3)	[HT-173] SU (3): CW (3)	[HT-189] SU (3): CW (3)
	[HT-142] SU (3): CW (4)	[HT-158] SU (3): CW (4)	[HT-174] SU (3): CW (4)	[HT-190] SU (3): CW (4)
	[HT-143] SU (4): CW (3)	[HT-159] SU (4): CW (3)	[HT-175] SU (4): CW (3)	[HT-191] SU (4): CW (3)
	[HT-144] SU (4): CW (4)	[HT-160] SU (4): CW (4)	[HT-176] SU (4): CW (4)	[HT-192] SU (4): CW (4)
HWS (4)	SIMULATION 13	SIMULATION 14	SIMULATION 15	SIMULATION 16
	[HT-193] SU (1): CW (1)	[HT-209] SU (1): CW (1)	[HT-225] SU (1): CW (1)	[HT-241] SU (1): CW (1)
	[HT-194] SU (1): CW (2)	[HT-210] SU (1): CW (2)	[HT-226] SU (1): CW (2)	[HT-242] SU (1): CW (2)
	[HT-195] SU (2): CW (1)	[HT-211] SU (2): CW (1)	[HT-227] SU (2): CW (1)	[HT-243] SU (2): CW (1)
	[HT-196] SU (2): CW (2)	[HT-212] SU (2): CW (2)	[HT-228] SU (2): CW (2)	[HT-244] SU (2): CW (2)
	[HT-197] SU (3): CW (1)	[HT-213] SU (3): CW (1)	[HT-229] SU (3): CW (1)	[HT-245] SU (3): CW (1)
	[HT-198] SU (3): CW (2)	[HT-214] SU (3): CW (2)	[HT-230] SU (3): CW (2)	[HT-246] SU (3): CW (2)
	[HT-199] SU (4): CW (1)	[HT-215] SU (4): CW (1)	[HT-231] SU (4): CW (1)	[HT-247] SU (4): CW (1)
	[HT-200] SU (4): CW (2)	[HT-216] SU (4): CW (2)	[HT-232] SU (4): CW (2)	[HT-248] SU (4): CW (2)
	[HT-201] SU (1): CW (3)	[HT-217] SU (1): CW (3)	[HT-233] SU (1): CW (3)	[HT-249] SU (1): CW (3)

	[HT-202] SU (1): CW (4)	[HT-218] SU (1): CW (4)	[HT-234] SU (1): CW (4)	[HT-250] SU (1): CW (4)
	[HT-203] SU (2): CW (3)	[HT-219] SU (2): CW (3)	[HT-235] SU (2): CW (3)	[HT-251] SU (2): CW (3)
	[HT-204] SU (2): CW (4)	[HT-220] SU (2): CW (4)	[HT-236] SU (2): CW (4)	[HT-252] SU (2): CW (4)
	[HT-205] SU (3): CW (3)	[HT-221] SU (3): CW (3)	[HT-237] SU (3): CW (3)	[HT-253] SU (3): CW (3)
	[HT-206] SU (3): CW (4)	[HT-222] SU (3): CW (4)	[HT-238] SU (3): CW (4)	[HT-254] SU (3): CW (4)
	[HT-207] SU (4): CW (3)	[HT-223] SU (4): CW (3)	[HT-239] SU (4): CW (3)	[HT-255] SU (4): CW (3)
	[HT-208] SU (4): CW (4)	[HT-224] SU (4): CW (4)	[HT-240] SU (4): CW (4)	[HT-256] SU (4): CW (4)
HWS (5)	**SIMULATION 17**	**SIMULATION 18**	**SIMULATION 19**	**SIMULATION 20**
	[HT-257] SU (1): CW (1)	[HT-273] SU (1): CW (1)	[HT-289] SU (1): CW (1)	[HT-305] SU (1): CW (1)
	[HT-258] SU (1): CW (2)	[HT-274] SU (1): CW (2)	[HT-290] SU (1): CW (2)	[HT-306] SU (1): CW (2)
	[HT-259] SU (2): CW (1)	[HT-275] SU (2): CW (1)	[HT-291] SU (2): CW (1)	[HT-307] SU (2): CW (1)
	[HT-260] SU (2): CW (2)	[HT-276] SU (2): CW (2)	[HT-292] SU (2): CW (2)	[HT-308] SU (2): CW (2)
	[HT-261] SU (3): CW (1)	[HT-277] SU (3): CW (1)	[HT-293] SU (3): CW (1)	[HT-309] SU (3): CW (1)
	[HT-262] SU (3): CW (2)	[HT-278] SU (3): CW (2)	[HT-294] SU (3): CW (2)	[HT-310] SU (3): CW (2)
	[HT-263] SU (4): CW (1)	[HT-279] SU (4): CW (1)	[HT-295] SU (4): CW (1)	[HT-311] SU (4): CW (1)
	[HT-264] SU (4): CW (2)	[HT-280] SU (4): CW (2)	[HT-296] SU (4): CW (2)	[HT-312] SU (4): CW (2)
	[HT-265] SU (1): CW (3)	[HT-281] SU (1): CW (3)	[HT-297] SU (1): CW (3)	[HT-313] SU (1): CW (3)
	[HT-266] SU (1): CW (4)	[HT-282] SU (1): CW (4)	[HT-298] SU (1): CW (4)	[HT-314] SU (1): CW (4)
	[HT-267] SU (2): CW (3)	[HT-283] SU (2): CW (3)	[HT-299] SU (2): CW (3)	[HT-315] SU (2): CW (3)
	[HT-268] SU (2): CW (4)	[HT-284] SU (2): CW (4)	[HT-300] SU (2): CW (4)	[HT-316] SU (2): CW (4)
	[HT-269] SU (3): CW (3)	[HT-285] SU (3): CW (3)	[HT-301] SU (3): CW (3)	[HT-317] SU (3): CW (3)
	[HT-270] SU (3): CW (4)	[HT-286] SU (3): CW (4)	[HT-302] SU (3): CW (4)	[HT-318] SU (3): CW (4)
	[HT-271] SU (4): CW (3)	[HT-287] SU (4): CW (3)	[HT-303] SU (4): CW (3)	[HT-319] SU (4): CW (3)
	[HT-272] SU (4): CW (4)	[HT-288] SU (4): CW (4)	[HT-304] SU (4): CW (4)	[HT-320] SU (4): CW (4)

Appendix B: Method for Creating the Overview Model

Summary of the overview (suburb) water-energy-GHG-cost models

An "overview" model (of water-energy-GHG and costs) was created for the case study suburbs of "Reservoir" and "Frankston". The University of Queensland's existing Residential Water-Energy (ResWE) model has been used to generate the water use, and water-related energy use inputs to create the Overview Model (See B.1). Data and information have been compiled for the key factors of influence (eg, household stock, hot water system type, shower systems and clothes washers), and used to update the Overview Model for each case study.

The Overview Model has been used to:

- Quantify existing water use, related energy use, GHG emissions, and costs. This has set the baseline performance of a specified area and provided useful information on customer benefits.
- Run various scenarios. This helped identify the reduction potential for water use, water-related energy use, and GHG emissions for various interventions. This is important for guiding later phases of research including interventions seeking to change behaviour, and more detailed investigations on key options. Additionally, this has helped understand the order of magnitude influence of potential interventions in relation to potential asset deferrals.
- Identify data gaps. This has provided direction on the data necessary to improve resource use predictions. Moreover, this has provided direction data collection refinements for piloting interventions in later phases of the research.
- Provide key data inputs into the household module for the Overview Model tool.

Overview Model Description

The Overview Model (Figure B-1), a first-generation tool, can be used to: (i) quantify existing residential water use, water-related energy use, associated GHGs, and costs for a given suburb, (ii) understand the order of magnitude influence of potential intervention measures, and (iii) estimate the impacts of city scale interventions.

A MMFA result library is used to store a collection of result sets from running the static MMFA model known as ResWE, with many different combinations of input parameters (ie, household composition, technology, behaviour, environment, and cost). The result sets are in terms of water use, water-related energy use, water-related GHG and related costs for different household groups.

Multiple scenarios are defined (ie, baseline, interventions) by selecting (discrete) inputs for household composition, technology, behaviour, environment, and cost input parameters, and specifying the regional distribution of different household groups in a suburb. In the household module, the scenario inputs and the MMFA result library are used to estimate regional residential total water use, water-related energy use, water-related energy GHGs and related costs. In the utility module, the regional residential total water use is used to estimate the energy use, GHG and related cost of water delivery and sewage disposal. Summing up the results from the household module and the utility module gives the baseline (Function 1) and saving potential of interventions (Function 2). The city module enables a rough estimation by scaling-up the results from suburb level to city level based on proxies such as population (Function 3).

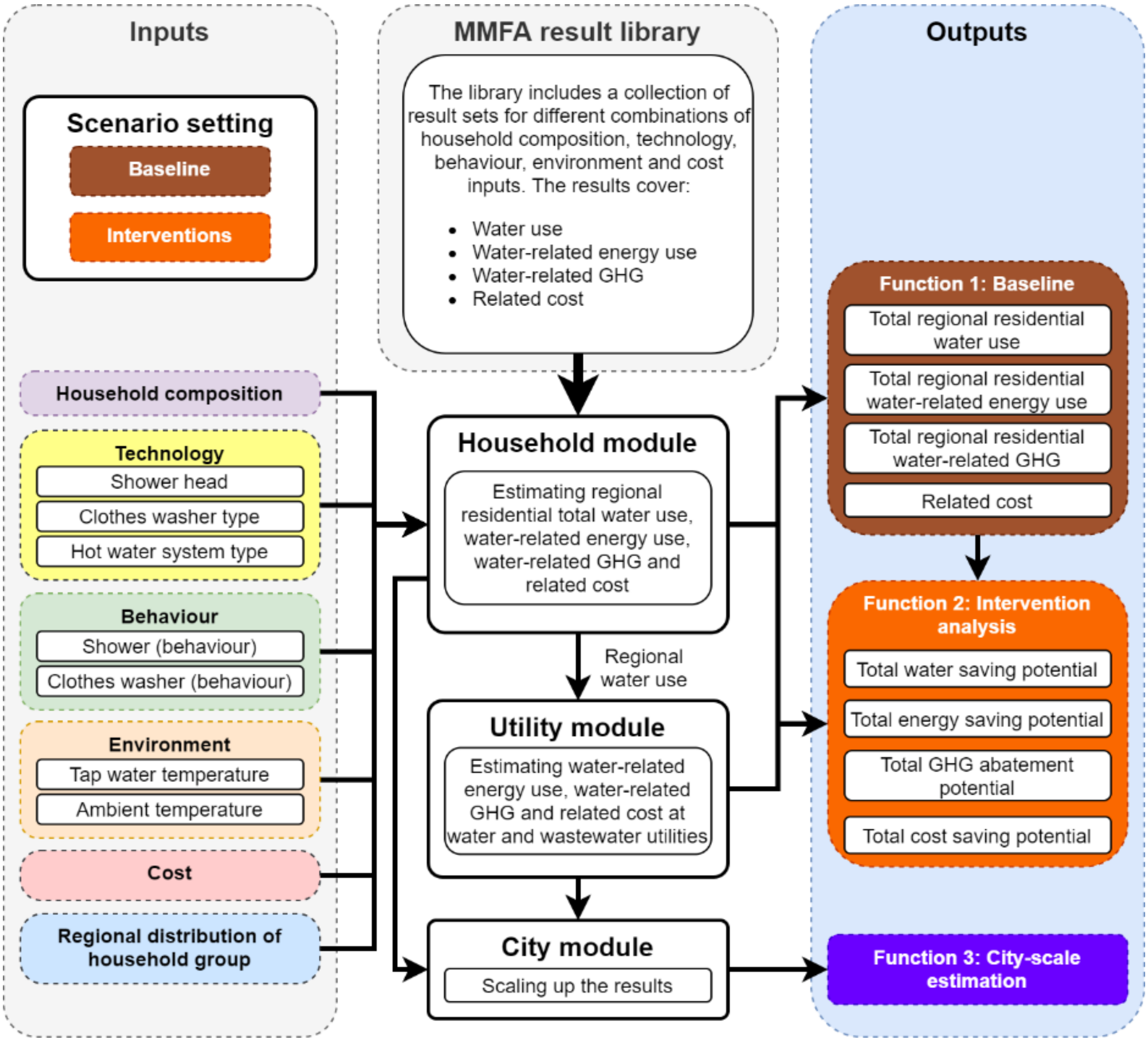

Figure B-1: Overview Model concept being developed for the Net Zero Water Cycle Project.

B.1 Summary of the Regional Water-Energy-GHG-costs model

Detailed information on the regional water-related energy model is presented in Appendix D of Bors (2019). Section D.1 lists the modelling assumptions and key determinants of household water-related energy use (ie, household composition, HWS type, shower use and clothes washing use). These were used to model the residential impact on regional water, water-related energy, and associated emissions. Section D.2 provides details of the regional ResWE Mathematical Material Flow Analysis Model (MMFA) model which was used for simulation. Section D.3 provides details of the calculation processes for key model parameters with specific assumptions and modelling simplifications. Section D.4 lists the issues addressed during the verification data clean-up whilst section D.5 contains water-related energy use results for the base case of household water-related energy use for each of the 16 combinations of shower use and clothes washing use.

Appendix C: Data List

Table C-1 references calculation procedures, sources of data, and a data list of the 145 input parameters required to model each of the 320 household types used to characterise water use, water-related energy use, and GHGs for Reservoir.

Table C-1: ResWE model data sources as a basis for the Overview Model.

P#	Unit	Description	Value	Source
Household Input Parameters				
P1	[-]	Number of adults per household	Table 5-3 Table 5-4	(ABS 2020a); (ABS 2019), Table G25; (YVW 2014)
P2	[-]	Number of children per household	Table 5-3 Table 5-4	(ABS 2020b); (ABS 2017), Tables G25 and G31
P3	[°C]	Temperature cold water	Table 5-9	(YVW 2015); (Bors 2019), Appendix D.
P4	[°C]	Temperature hot water at HWS	Table 5-5	(Standards Australia 2009); (Standards Australia 2015); (Rinnai 2013a)
P5	[°C]	Average indoor temperature	Table 5-9	(CSIRO and BOM 2010); (Bors 2019), Appendix D.
P6	[°C]	Ambient air temperature at HWS storage	Table 5-9	(BOM 2014); (Bors 2019), Appendix D.
P7	[m]	Ave. length of wastewater pipes	9.00	(Binks et al. 2016)[a]
P8	[m/s]	Velocity of wastewater	0.14	(Binks et al. 2016)[a]
P9	[m]	Radius of wastewater pipe	0.07	(Binks et al. 2016)[a]
P10	[W/m²°K]	Heat coefficient of wastewater pipe	2.00	(Binks et al. 2016)[a]
P11	[m]	Average length of hot-water pipes (storage to tap)	9.40	(Binks et al. 2016)[a]
P12	[m/s]	Velocity of hot water	1.70	(Binks et al. 2016)[a]
P13	[m]	Radius of hot-water pipe	0.01	(Bosch 2012)[a]
P14	[W/m²°K]	Heat coefficient of hot-water pipe	2.00	(Binks et al. 2016)[a]
P15	[W/m²°K]	Heat coefficient of hot-water storage	0.50	(Binks et al. 2016)[a]
P16	[m²]	Surface of hot water storage	Table 5-5	(E3 2016b); (E3 2016c); (Bosch 2012); (Bors 2019), Appendix D.
P17	[-]	Split of hot water storage: share of gas use	Table 5-9	N/A
P18	[-]	Number of stand times in hot water pipes	2.69	(Binks et al. 2016)[a]
P19	[m]	Thickness of hot-water pipe	0.001	(Binks et al. 2016)[a]
P20	[-]	Switch: hws standard (0) / solar heat (1)	0 or 1	N/A
P21	[-]	Share of solar hot water on total hw	Table 5-9	(LG Electronics 2017); (George Wilkenfeld and Associates Pty Ltd 2005), Tables 7 and 9; (Bors 2019), Appendix D.
P22	[-]	Part of hot water continuous system for total hot water	Balance of P21	
P23	[-]	share of gas use for continuous hw system	0 or 1	N/A
Shower Use Input Parameters				
P24	[min]	Flow duration per shower for adults	Table 5-6 Table 5-7	(Roberts 2017), Figure 12; (Byrne and Martin 2017), Figure 5.4
P25	[L/min]	Flowrate per showers for adults	Table 5-6 Table 5-7	(Ghobadi et al. 2013), Table 13; (Roberts 2017), Table 10
P26	[-]	Number of showers per adult per day	0.90	(2013), Table 7.4
P27	[°C]	Temperature of showers for adults	38.64	(Binks et al. 2016)[a]
P28	[min]	Flow duration per shower for child	Table 5-6	(Roberts 2017), Figure 12; (Byrne and Martin 2017), Figure 5.4

			Table 5-7	
P29	[L/min]	Flowrate per showers for child	Table 5-6 Table 5-7	(Ghobadi et al. 2013), Table 13; (Roberts 2017), Table 10
P30	[-]	Number of showers per child per day	0.29	(Binks et al. 2016)[a]
P31	[°C]	Temperature of showers for child	35.50	(Binks et al. 2016)[a]
P32	[-]	Fraction of instantaneous shower heating	0.00	N/A
P33	[-]	Split of instant. Shower: share of gas use	0.00	N/A
Bath Use Input Parameters				
P34	[L]	Volume per bath per adult	0.00	(Binks et al. 2016)[a]
P35	[-]	Number of baths per adult per day	0.00	(Binks et al. 2016)[a]
P36	[°C]	Temperature of baths for adults	0.00	(Binks et al. 2016)[a]
P37	[L]	Volume per bath per child	89.28	(Binks et al. 2016)[a]
P38	[-]	Number of baths per child per day	0.36	(Binks et al. 2016)[a]
P39	[°C]	Temperature of baths for child	37.00	(Binks et al. 2016)[a]
P40	[-]	Fraction of instantaneous bath heating	0.00	N/A
P41	[-]	Split of instant. Bath share of gas use	0.00	N/A
Clothes Washing Use Input Parameters				
P42	[-]	Number of cycles cold top per day	(Bors 2019), Table D-9, Appendix D.	
P43	[-]	Number of cycles warm top per day	(Bors 2019), Table D-9, Appendix D.	
P44	[-]	Number of cycles hot top per day	0.00	N/A
P45	[-]	Number of cycles cold front per day	(Bors 2019), Table D-9, Appendix D.	
P46	[-]	Number of cycles warm front per day	(Bors 2019), Table D-9, Appendix D.	
P47	[-]	Number of cycles hot front per day	0.00	N/A
P48	[L]	Volume per cycle cold top	Table 5-8	(Gan and Redhead 2013), Table 13
P49	[L]	Volume per cycle warm top	Table 5-8	(Gan and Redhead 2013), Table 13
P50	[L]	Volume per cycle hot top	0.00	N/A
P51	[L]	Volume per cycle cold front	Table 5-8	(Gan and Redhead 2013), Table 13
P52	[L]	Volume per cycle warm front	Table 5-8	(Gan and Redhead 2013), Table 13
P53	[L]	Volume per cycle hot front	0.00	N/A
P54	[kWh]	Energy per cycle cold top (excl. water heating)	Table 5-8	(E3 2016a)
P55	[kWh]	Energy per cycle warm top (excl. water heating)	Table 5-8	(E3 2016a)
P56	[kWh]	Energy per cycle hot top (excl. water heating)	0.00	N/A
P57	[kWh]	Energy per cycle cold front (excl. water heating)	Table 5-8	(E3 2016a)
P58	[kWh]	Energy per cycle warm front (excl. water heating)	Table 5-8	(E3 2016a)
P59	[kWh]	Energy per cycle hot front (excl. water heating)	0.00	N/A
P60	[°C]	Temperature cold cycle top	P3	(YVW 2015)[b]
P61	[°C]	Temperature warm cycle top	Table 5-8	(Flower 2009)
P62	[°C]	Temperature hot cycle top	0.00	N/A
P63	[°C]	Temperature cold cycle front	Table 5-8	(Flower 2009)
P64	[°C]	Temperature warm cycle front	Table 5-8	(Flower 2009)
P65	[°C]	Temperature hot cycle front	0.00	N/A
P66	[min]	Duration average cycle top	Table 5-8	(E3 2016a); (Bors 2019), Appendix D.
P67	[min]	Duration average cycle front	Table 5-8	(E3 2016a); (Bors 2019), Appendix D.
P68	[W]	Standby energy top	Table 5-8	(Binks et al. 2016)[a]
P69	[W]	Standby energy front	Table 5-8	(Binks et al. 2016)[a]
P70	[-]	Connected to hot+cold (0) or only cold (1) water	Table 5-8	(E3 2016a); (Bors 2019), Appendix D.
Tap Use Input Parameters				

P71	[-]	Number hand wash per person per day	3.93	(Binks et al. 2016), max calibration
P72	[L]	Volume per hand wash	1.40	(Binks et al. 2016), max calibration
P73	[°C]	Temperature hand wash	P3	(YVW 2015)[b]
P74	[-]	Number teeth brush per person per day	2.00	(Binks et al. 2016), max calibration
P75	[L]	Volume teeth brush	2.46	(Binks et al. 2016)[a]
P76	[°C]	Temperature teeth brush	P3	(YVW 2015)[b]
P77	[-]	Number shave per adult per day	0.92	(Binks et al. 2016), max calibration
P78	[L]	Volume per shave	2.50	(Binks et al. 2016), max calibration
P79	[°C]	Temperature shave	P3	(YVW 2015)[b]
P80	[-]	Number dish wash (by hand) per hh per day	0.96	(Binks et al. 2016)[a]
P81	[L]	Volume dish wash (by hand)	8.57	(Binks et al. 2016)[a]
P82	[°C]	Temperature dish wash (by hand)	50.24	(Binks et al. 2016)[a]
P83	[-]	Number clothes wash (by hand) per hh per day	0.08	(Binks et al. 2016)[a]
P84	[L]	Volume per clothes wash (by hand)	14.00	(Binks et al. 2016)[a]
P85	[°C]	Temperature clothes wash (by hand)	38.00	(Binks et al. 2016)[a]
P86	[-]	Number cleaning per hh per day	0.07	(Binks et al. 2016)[a]
P87	[L]	Volume per cleaning	10.95	(Binks et al. 2016)[a]
P88	[°C]	Temperature of cleaning	39.72	(Binks et al. 2016)[a]
P89	[-]	Number other use per person per day	(Bors 2019), Table D-10, Appendix D.	
P90	[L]	Volume other use	1.40	(Athuraliya, Roberts, and Brown 2012)
P91	[°C]	Temperature other use	P3	(YVW 2015)
P92	[-]	Fraction of instantaneous tap water heating	0.00	N/A
P93	[-]	Split of instant. Taps share of gas use	0.00	N/A
Dishwasher Use Input Parameters				
P94	[-]	Number of cycles dishwasher per day	(Bors 2019), Table D-11, Appendix D.	
P95	[L]	Volume per cycle dishwasher	12.52	(Binks et al. 2016)[a]
P96	[kWh]	Energy per cycle dishwasher (excl. water heating)	0.72	(Binks et al. 2016)[a]
P97	[°C]	Temperature dishwasher cycle	58.33	(Binks et al. 2016)[a]
P98	[min]	Duration average cycle dishwasher	100.33	(Binks et al. 2016)[a]
P99	[W]	Standby energy dishwasher	2.20	(Binks et al. 2016)[a]
P100	[-]	Connected to hot+cold (0) or only cold (1) water	1.00	(Binks et al. 2016)[a]
Outdoor Use Input Parameters				
P101	[L]	Pool volume per day	0.00	N/A
P102	[L]	Irrigation per day	Table 5-9	(Gan and Redhead 2013), Fig. 6; (ABS 2013d); (YVW 2014); (Bors 2019), Appendix D.
P103	[min]	Duration pool filtration per day	0.00	N/A
P104	[kW]	Power of pool filter	0.00	N/A
Toilet Use Input Parameters				
P105	[-]	Number of toilet flushes per person per day	3.93	(Binks et al. 2016), max calibration
P106	[L]	Volume per toilet flush	4.43	(Binks et al. 2016), max calibration
Kettle Use Input Parameters				
P107	[-]	Number of kettle boils per person per day	1.51	(Binks et al. 2016)[a]
P108	[L]	Volume per boil	0.76	(Binks et al. 2016)[a]
Air-conditioning Use Input Parameters				
P109	[L/min]	Water use aircon evap.	1.10	(Binks et al. 2016)[a]
P110	[min]	Duration use aircon evap.	Table 5-9	(Binks et al. 2016)[a]; (ABS 2011a), Table 11; (ABS 2014), Table 5; (Bors 2019), Appendix D.
P111	[W]	Energy used aircon evap.	843.00	(Binks et al. 2016)[a]
P112	[W]	Standby energy aircon evap.	2.00	(Flower 2009)
P113	[min]	Duration use aircon rest	0.00	N/A
P114	[W]	Energy used aircon rest	0.00	N/A
P115	[W]	Standby energy aircon rest	0.00	N/A
Other Energy Use Input Parameters				

P116	[min]	Duration use cooking	64.47	(Binks et al. 2016), max calibration
P117	[W]	Energy used cooking	7385.80	(Binks et al. 2016), 90th per. calibration
P118	[W]	Standby energy cooking	3.20	(Binks et al. 2016)[a]
P119	[min]	Duration use fridge	1440.00	(Binks et al. 2016)[a]
P120	[W]	Energy used fridge	66.82	(Binks et al. 2016)[a]
P121	[W]	Standby energy fridge	0.00	N/A
P122	[min]	Duration use TV	171.25	(Binks et al. 2016)[a]
P123	[W]	Energy used TV	201.64	(Binks et al. 2016)[a]
P124	[W]	Standby energy TV	3.28	(Binks et al. 2016)[a]
P125	[min]	Duration use light	3723.50	(Binks et al. 2016)[a]
P126	[W]	Energy used light	32.11	(Binks et al. 2016)[a]
P127	[W]	Standby energy light	0.00	(Binks et al. 2016)[a]
P128	[min]	Duration use PC	786.55	(Binks et al. 2016)[a]
P129	[W]	Energy used PC	60.70	(Binks et al. 2016)[a]
P130	[W]	Standby energy PC	4.60	(Binks et al. 2016)[a]
P131	[min]	Duration use heating	Table 5-9	(Binks et al. 2016); (ABS 2011a), Table 9; (Bors 2019), Appendix D.
P132	[W]	Energy used heating	7576	(Binks et al. 2016)[a]
P133	[W]	Standby energy heating	2.20	(Binks et al. 2016)[a]
P134	[-]	Split of cooking energy: share of gas use	0.91	(Binks et al. 2016)[a]
P135	[-]	Split of heating energy: share of gas use	1.00	(Binks et al. 2016), max calibration
Parameters for Supply				
P136	[-]	Efficiency fact. for hw storage electrical	1.0204	(Flower 2009)
P137	[-]	Efficiency fact. for hw storage gas	1.3106	(Flower 2009)
P138	[-]	Efficiency fact. for instant. hw gas	0.00	N/A
P139	[-]	Efficiency fact. for hw cloth washer	1.05	(Binks et al. 2016)
P140	[-]	Efficiency fact. for hw dish washer	1.05	(Binks et al. 2016)
P141	[-]	Efficiency fact. for hw kettle boil	1.05	(Binks et al. 2016)
P142	[-]	Efficiency fact. for heating water outdoor pool	1.05	(Binks et al. 2016)
p143	[-]	Efficiency fact. for instant. hw electrical	0.00	N/A
p144	[-]	Efficiency fact. for hw continuous electrical	0.00	N/A
p145	[-]	Efficiency fact. for hw continuous gas	1.5385	(Flower 2009)

[a] Average of input parameters for Melbourne households (*n=5*) in Binks et al. (2016). [b] Assumed temperature is equal to cold water supply temperature, parameter P3.

Appendix D: Method and Results for the Least Cost Analysis

The least cost analysis involves quantifying the **Abatement Potential** (ie, water saving potential, energy saving potential, and GHG emissions reduction potential) and the **Marginal Abatement Cost** (ie, cost per unit of water saved/energy saved/GHG emissions reduction) of each opportunity. The abatement potentials and the marginal abatement costs are then used to develop the MAC curve, where opportunities are prioritised based on their marginal abatement cost.

Abatement Potential

At the household level, various abatement potentials (ie, water saving potential, energy saving potential, GHG emissions reduction potential) of management opportunities can be quantified using the ResWE model (see Section 3.3). In the illustrative least cost analysis for Reservoir (Section 5), 20 household categories for the S1 scenario were modelled. Each household category represents an opportunity, and each has a set of the abatement potentials (ie, water, energy, GHG emissions).

At the utility level, energy saving potential and GHG emissions reduction potential were estimated based on the water saving potential at household, and the energy intensity and GHG emissions intensity for providing water and wastewater services by utilities.

For each opportunity, its total energy saving potential/GHG emissions reduction potential is the summation of the household saving and the utility saving (for the 'combined perspective').

Marginal Abatement Cost

The equations for deriving the marginal abatement cost are:

Marginal Abatement Cost = Annualised Net Cost/Annual Abatement Potential

Annualised Net Cost = Total Initial Cost/Opportunity Lifespan + Total Annual Ongoing Cost

where

- *Annual Abatement Potential* can be water saving potential (ML/yr), energy saving potential (MWh/yr), or GHG emissions reduction potential (tCO_2-e/yr) of an opportunity.
- *Total Initial Cost* is the total initial capital cost of implementing an opportunity (eg, cost of shower heads and their installation cost).
- *Opportunity Lifespan* is the useful lifespan of an opportunity. It is used to linearly annualised the *Total Initial Cost* over the assessment period.
- *Total Annual Ongoing Cost* is annual cost saving (eg, energy bill saving), annual maintenance cost (where applicable), or any other annual cost/saving in the operation phase of an opportunity.

This illustrative least cost analysis is based on a simplified cost assessment using key data (Table D-1). More detailed costing is possible with consideration of factors such as discount rate, non-linear depreciation, projected energy price changes. Once the marginal abatement costs for all opportunities are derived, all the opportunities are ranked from the one with the lowest marginal abatement cost to the one with highest marginal abatement cost. They are then populated on to the

MAC curve from the opportunity with the lowest marginal abatement cost (starting from the left) to the one with the highest (all the way to the right).

As an example ('combined perspective'), the marginal abatement cost of GHG emissions abatement for the opportunity S1_fwc_Sto-E (Family with children, using electric storage hot water system) can be derived as follows.

Annualised Net Cost
= (Number of new efficient shower head installed X unit cost of shower head and installation)/Useful lifespan of a shower head + (Annual energy cost saving at household + Annual energy cost saving at water utility)
= (739 x $132.8)/15 years + (-$55,042) + (-$2,885)   = -$51,384

Marginal Abatement Cost of GHG Emissions Abatement
= Annualised Net Cost/ (GHG abated from household energy saving + GHG abated from water utility energy saving)
= -$51,384/ (208 tCO_2-e +6 tCO_2-e)   = -$240/$tCO_2$-e

Table D-1: Key utility inventory data

Item	Value	Year	References
Energy intensity for water supply (Yarra Valley Water)	0.056 MWh/ML	2017/18	Yarra Valley Water Annual Report 2017/18
Energy intensity for water supply (Melbourne Water)	0.297 MWh/ML	2019/20	Melbourne Water Annual Report 2019/20
Energy intensity for wastewater collection (Yarra Valley Water)	0.036 MWh/ML	2017/18	Yarra Valley Water Annual Report 2017/18
Energy intensity for wastewater treatment (Melbourne Water)	1.170 MWh/ML	2019/20	Melbourne Water Annual Report 2019/20
GHG emissions factor for energy use (Yarra Valley Water)	0.858 tCO_2-e/MWh	2019/20	Yarra Valley Water Annual Report 2017/18
GHG emissions factor for energy use (Melbourne Water)	0.484 tCO_2-e/MWh	2019/20	Melbourne Water Annual Report 2019/20
Electricity unit price - water utility[12]	$0.230/kWh	2019/20	Melbourne Water 2016 Price Submission

[12] Estimated based on the "Melbourne Water 2016 Price Submission" report. In the report, the expected total electricity cost and purchase grid electricity for Melbourne Water in 2019/20 are $45.7M (in 2015/16 real dollars) and 209,479 MWh. The price term was adjusted to 2019/20 term using Consumer Price Index from ABS (ie, CPI: 108.6 (Jun-16), CPI: 114.4 (Jun-20)).

Table D-2: Annual energy saving potential and marginal abatement cost in Reservoir from a 'combined perspective' (corresponding to Figure 6-1)

Household category	Abbreviation	Annual energy saving potential (MWh/year)	Marginal abatement cost ($/MWh)
S1: Group: Elec Storage HWS	S1_G_Sto-E	47.08	-237.47
S1: Family with children: Elec Storage HWS	S1_FwC_Sto-E	216.47	-237.37
S1: Family no children: Elec Storage HWS	S1_FwtC_Sto-E	363.52	-237.04
S1: Family no children: Solar - E.Boost HWS	S1_FwtC_Sol-E	134.21	-211.71
S1: Family with children: Solar - E.Boost HWS	S1_FwC_Sol-E	76.79	-209.95
S1: Group: Solar - E.Boost HWS	S1_G_Sol-E	15.61	-205.95
S1: Single: Elec Storage HWS	S1_S_Sto-E	95.95	-187.48
S1: Single: Solar - E.Boost HWS	S1_S_Sol-E	30.70	-101.51
S1: Group: Gas Cont. HWS	S1_G_Ins-G	86.12	-65.89
S1: Family with children: Gas Cont. HWS	S1_FwC_Ins-G	391.52	-65.78
S1: Family no children: Gas Cont. HWS	S1_FwtC_Ins-G	653.40	-65.19
S1: Group: Gas Storage HWS	S1_G_Sto-G	139.43	-63.59
S1: Family with children: Gas Storage HWS	S1_FwC_Sto-G	633.21	-63.44
S1: Family no children: Gas Storage HWS	S1_FwtC_Sto-G	1055.73	-62.74
S1: Family with children: Solar - Gas.Boost HWS	S1_FwC_Sol-G	287.02	-51.55
S1: Family no children: Solar - Gas.Boost HWS	S1_FwtC_Sol-G	484.86	-50.73
S1: Group: Solar - Gas.Boost HWS	S1_G_Sol-G	59.69	-50.15
S1: Single: Gas Cont. HWS	S1_S_Ins-G	176.43	-33.19
S1: Single: Gas Storage HWS	S1_S_Sto-G	285.78	-25.65
S1: Single: Solar - Gas.Boost HWS	S1_S_Sol-G	119.72	20.77

Table D-3: Annual GHG abatement potential and marginal abatement cost in Reservoir from a 'combined perspective' (corresponding to Figure 6-2)

Household category	Abbreviation	Annual GHG abatement potential (tCO_2-e/year)	Marginal abatement cost ($/$tCO_2$-e)
S1: Group: Gas Cont. HWS	S1_G_Ins-G	19.61	-289.36
S1: Family with children: Gas Cont. HWS	S1_FwC_Ins-G	89.27	-288.48
S1: Family no children: Gas Cont. HWS	S1_FwtC_Ins-G	148.76	-286.33
S1: Group: Gas Storage HWS	S1_G_Sto-G	32.00	-277.12
S1: Family with children: Gas Storage HWS	S1_FwC_Sto-G	145.53	-276.04
S1: Family no children: Gas Storage HWS	S1_FwtC_Sto-G	242.22	-273.44
S1: Family with children: Elec Storage HWS	S1_FwC_Sto-E	214.35	-239.72
S1: Group: Elec Storage HWS	S1_G_Sto-E	46.64	-239.71
S1: Family no children: Elec Storage HWS	S1_FwtC_Sto-E	360.37	-239.12
S1: Family no children: Solar - E.Boost HWS	S1_FwtC_Sol-E	130.08	-218.43
S1: Family with children: Solar - E.Boost HWS	S1_FwC_Sol-E	74.10	-217.54
S1: Family with children: Solar - Gas.Boost HWS	S1_FwC_Sol-G	68.62	-215.62
S1: Group: Solar - E.Boost HWS	S1_G_Sol-E	15.02	-214.05
S1: Family no children: Solar - Gas.Boost HWS	S1_FwtC_Sol-G	115.46	-213.06
S1: Group: Solar - Gas.Boost HWS	S1_G_Sol-G	14.31	-209.14
S1: Single: Elec Storage HWS	S1_S_Sto-E	95.04	-189.28
S1: Single: Gas Cont. HWS	S1_S_Ins-G	40.18	-145.76
S1: Single: Gas Storage HWS	S1_S_Sto-G	65.58	-111.78
S1: Single: Solar - E.Boost HWS	S1_S_Sol-E	29.46	-105.78
S1: Single: Solar - Gas.Boost HWS	S1_S_Sol-G	28.76	86.45

Table D-4: Annual water saving potential and marginal abatement cost in Reservoir from a 'community perspective' (corresponding to Figure 6-3)

Household category	Abbreviation	Annual GHG abatement potential (tCO_2-e/year)	Marginal abatement cost ($/$tCO_2$-e)
S1: Family no children: Elec Storage HWS	S1_FwtC_Sto-E	13.01	-6621.10
S1: Group: Elec Storage HWS	S1_G_Sto-E	1.72	-6483.91
S1: Family with children: Elec Storage HWS	S1_FwC_Sto-E	8.05	-6379.64
S1: Single: Elec Storage HWS	S1_S_Sto-E	3.54	-5084.70
S1: Family no children: Solar - E.Boost HWS	S1_FwtC_Sol-E	8.51	-3340.18
S1: Family with children: Solar - E.Boost HWS	S1_FwC_Sol-E	5.26	-3062.27
S1: Group: Solar - E.Boost HWS	S1_G_Sol-E	1.13	-2851.97
S1: Group: Gas Cont. HWS	S1_G_Ins-G	2.08	-2726.57
S1: Family no children: Gas Cont. HWS	S1_FwtC_Ins-G	15.71	-2711.44
S1: Family with children: Gas Cont. HWS	S1_FwC_Ins-G	9.72	-2649.08
S1: Group: Gas Storage HWS	S1_G_Sto-G	3.91	-2265.97
S1: Family no children: Gas Storage HWS	S1_FwtC_Sto-G	29.53	-2242.78
S1: Family with children: Gas Storage HWS	S1_FwC_Sto-G	18.28	-2198.01
S1: Single: Gas Cont. HWS	S1_S_Ins-G	4.27	-1371.47
S1: Single: Solar - E.Boost HWS	S1_S_Sol-E	2.31	-1347.78
S1: Family no children: Solar - Gas.Boost HWS	S1_FwtC_Sol-G	22.91	-1073.82
S1: Family with children: Solar - Gas.Boost HWS	S1_FwC_Sol-G	14.18	-1043.73
S1: Group: Solar - Gas.Boost HWS	S1_G_Sol-G	3.04	-986.03
S1: Single: Gas Storage HWS	S1_S_Sto-G	8.03	-913.19
S1: Single: Solar - Gas.Boost HWS	S1_S_Sol-G	6.23	399.32