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Assessing minimum water efficiency standards for plumbing products in homes and business

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ABSTRACT

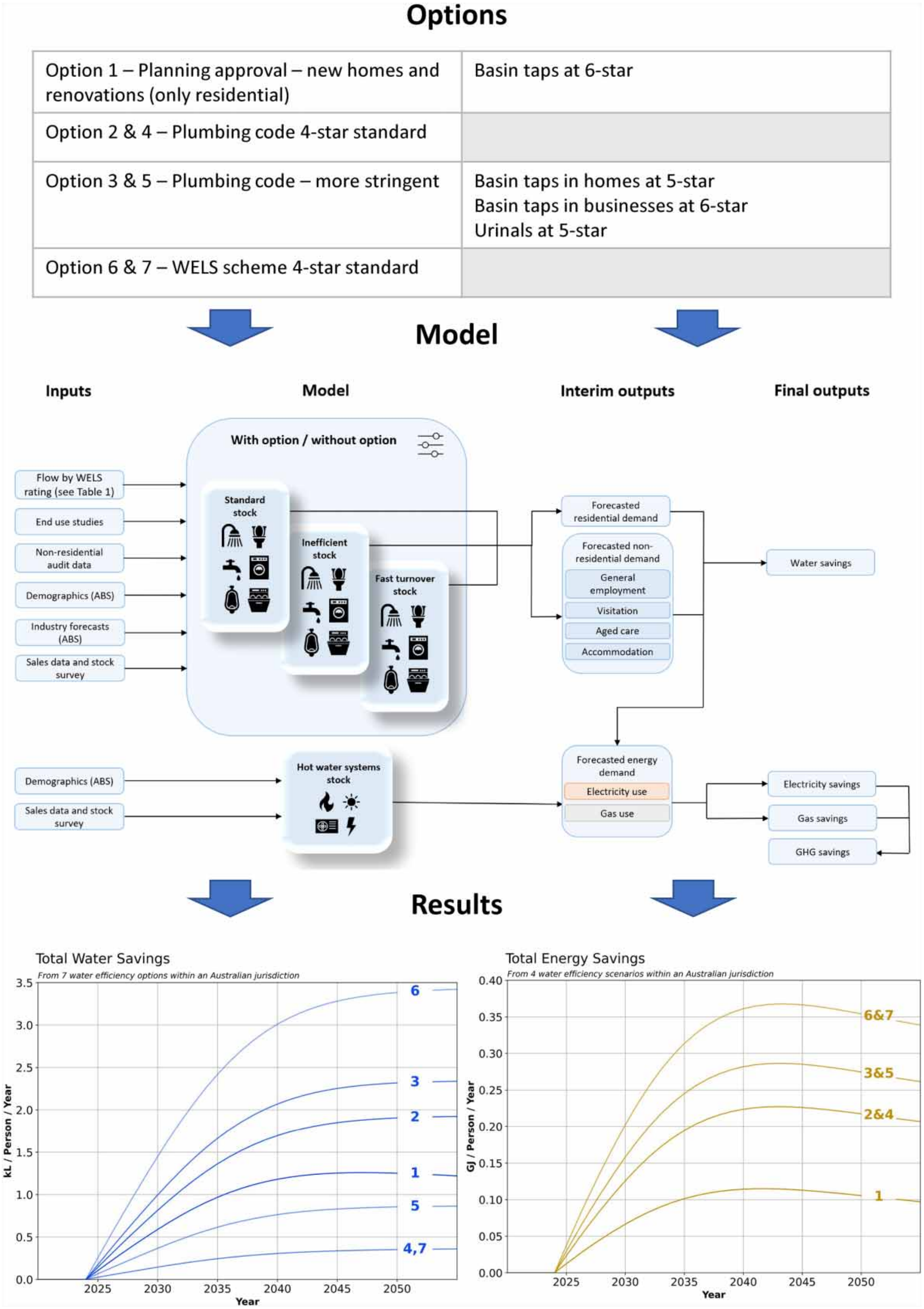
This paper describes a study that used end-use-based stock modelling to develop water, energy and greenhouse gas (GHG) savings forecasts for policy options. These options were alternative mechanisms for imposing minimum water efficiency standards on the fixtures and appliances within buildings. The study demonstrates how both residential and non-residential sub-sectors can be modelled, using demographic and industry forecasts and other available data sources, using an end-use/stock modelling approach. Specifically, the study modelled the expected water, energy and GHG savings from potential minimum water efficiency standards for plumbing products and appliances in homes and business in Australia. It discusses the relative merits of mechanisms for implementing the proposed minimum standards via: a sustainable building planning measure – such as the Building Sustainability Index (BASIX) in New South Wales; the Australian Water Efficiency Labelling and Standards (WELS) scheme; or via plumbing regulations within the National Construction Code (NCC). The paper concludes that as well as being a useful mechanism for imposing minimum standards in itself, a star-rating system such as WELS offers advantages in developing and modelling water efficiency policy options. The approach described can support decision-making on policies that improve water efficiency across building types.

Key words: end-use modelling, energy and greenhouse gas (GHG), residential and non-residential, water

HIGHLIGHTS

- Using plumbing product water efficiency ratings in demand forecasting.
- End-use-based stock modelling for residential and non-residential sectors.
- Comparing policies for fixture and appliance minimum efficiency standards.
- Estimating water, energy and GHG savings from alternative policy options.

GRAPHICAL ABSTRACT



INTRODUCTION

Policymakers in Australia and globally are facing increasing demand for water from urban areas as populations grow in many cities and towns. This is at a time when the yields from existing supplies are reducing due to the impacts of climate change. Water security is becoming a critical issue for economic, social, and environmental sustainability in many urban areas. In this context, indoor water savings from plumbing products and water-using appliances are particularly valuable from a water security perspective since indoor uses are less easily restricted during drought. With future projections of population growth, climate change and increasingly severe droughts, the potential to limit the water demand from buildings through minimum water efficiency standards is therefore a key policy lever for decision makers to examine.

This paper describes the modelling of policy options for improving the water efficiency of plumbing products and domestic water-using appliances within all property types in an Australian context. The aim of the study was to compare various means of increasing water efficiency standards and the policy mechanisms for their implementation for fixtures, fittings and household appliances (clothes and dishwashers) in homes and business.

Various policy proposals were modelled based on meeting water efficiency standards set as minimum star-ratings under the Australian and New Zealand Water Efficiency Labelling and Standards (WELS) scheme. Changes would be implemented via different mechanisms, either: a sustainable building planning measure – such as the Building Sustainability Index (BASIX) which is active in the state of New South Wales (NSW); plumbing regulations within the National Construction Code (NCC) of Australia; or via minimum standards applied directly within the WELS scheme. An end-use-based stock modelling approach was used to forecast water demand with and without the policy proposals and expected water, energy and greenhouse gas (GHG) savings.

Traditionally, water demand forecasting has been based on historic trends of per capita water consumption or multiple regression using variables that include demographics, climates, income, water price and periods of water use restrictions (Fox *et al.* 2009; Chang *et al.* 2014; Bich-Ngoc *et al.* 2022). While useful for analysing historical demand or providing baseline forecasts prior to a proposed policy or programme, these approaches are limited in projecting savings from water efficiency initiatives because of the aggregated nature of the variables (White *et al.* 2004).

Disaggregated approaches by contrast offer the advantages of modelling the water savings potential of specific water efficiency policies or programmes. End-use-based stock modelling essentially models changing patterns of end-use consumption and the decline of older stock and progressive penetration of newer, usually more efficient, water-using fixtures, fittings and appliances (Snelling *et al.* 2007). This approach to modelling requires an inventory of available data. Key challenges here include data availability and accessibility – insufficiently detailed data, and that available data/studies may focus on either one end-use or a limited geographic sample/location.

Initial approaches to collecting end-use data have included water use audits and stock surveys undertaken to gain an understanding of the stock of water-using fixtures/appliances and efficiency profiles (types and characteristics) in homes in certain regions (e.g. Roberts 2003). An early example of residential water end-use and stock modelling estimated the volume of water used for toilet flushing (toilet demand) in Australia by estimating the historical stock of single flush and various types of dual-flush toilets and forecasting the percentage of each toilet type in the stock over a 30-year period (Snelling *et al.* 2007). The model estimated potable savings since dual-flush toilets were introduced in Australia, as well as the potential savings of a nation-wide toilet retrofit programme (Snelling *et al.* 2007).

The advent of smart water metering, together with end-use disaggregation technologies has enhanced the opportunity to explore end-uses, as well as combine end-use demand with audit data covering household demographic, socio-economic and water appliance stock efficiency information (Beal & Stewart 2011).

In recent years, there has been growing interest in exploring Machine Learning and Artificial Intelligence methods for modelling (e.g. Artificial Neural Networks (ANNs) to cluster, classify and predict residential end-uses). Potential disadvantages may include their lack of explainability, the large quantity of data needed for training and validation, and generalising findings beyond the observed data range and there is still room for improvement for use in water demand forecasting (De Souza Groppo *et al.* 2019).

A key improvement described in a previous paper (Fane *et al.* 2020) was the use of efficiency rating systems, particularly the WELS star-rating scheme, as the basis for fixture/appliance stock modelling. That work (Fane *et al.* 2020) described how the modelling approach was used to estimate the reduction in water and energy use and associated GHG emissions from all improvements to plumbing fixture and appliance water use efficiency in Australia, since the introduction of the WELS scheme in 2006 and forecast to 2036. The present study expanded the modelling approach by comparing a range of potential policy options not yet implemented. Furthermore, instead of using a single set of stock models, one for each fixture and appliance type, this study also introduced different sets of end-use and stock models for non-residential sectors. This advance means that non-residential sub-sectors could be each modelled using industry specific end-use data and stock data, as well as sub-sector specific growth forecasts based on available Australian Bureau of Statistics (ABS) forecasts.

BACKGROUND

There are a number of regulatory tools or mechanisms available to mandate improved water efficiency in fixtures, fittings and domestic appliances in buildings in Australia. These mechanisms each have advantages and disadvantages with each briefly discussed in turn, below.

Sustainable building-planning measures, e.g. BASIX

State-based planning measures for sustainable building offer one avenue for increasing minimum standards. One of the strongest sustainable building measures in Australia has been the BASIX policy in NSW. This policy aims to ensure that residential buildings are being built to operate sustainably across the state. Since 2004 the BASIX policy has set minimum standards for water, energy and thermal comfort as part of the Development Approval (DA) process for building new homes and for major home renovations (NSW Government 2023). BASIX is a land planning mechanism and compliance to BASIX requirements occurs via the building certifier. The BASIX water component requires an average water savings target be met at an individual residential dwelling level. The target varies with location in the State and building type (single or multiple residential). For much of the State the target is set at the current maximum of a 40% reduction from a baseline of 247 L per person per day (L/p/d). The water saving can be met by a homeowner/developer by selecting water efficient features, including fixtures and appliances – which are committed to on the basis of their WELS rating – and/or via an alternative supply (most commonly a rain water tank). Significantly, a recent review of BASIX found that the BASIX is not currently driving more water efficient fixtures and appliances to be installed than occurs in the general market and so introducing minimum water efficiency standards for fixtures and appliances should be considered (NSW Government 2023).

Effective from October 2023, the existing BASIX water standards for residential buildings have been incorporated into a new State Environmental Planning Policy (Sustainable Buildings) in NSW. This policy also includes large commercial development (initially, large offices, hotels, motels and serviced apartments – although retail and industrial will be considered later) with residential. With three yearly reviews now in place, there may be an opportunity in the future to look at water efficiency standards for both new residential and non-residential development under the new Planning Policy. However, given the application of BASIX to date, the option considered in this paper considers only the development of residential buildings.

The NCC and plumbing code of Australia

The NCC of Australia combines building and plumbing construction requirements in a single code. This is comprised of the Building Code of Australia (BCA) (Volumes One and Two) see ABCB (2022a, 2022b) and the Plumbing Code of Australia (PCA) (Volume Three) see ABCB (2022c). The PCA is the code to which all plumbing and drainage works must comply for all building classes. The PCA covers both new residential and non-residential developments, as well as any replacement fixtures or fittings installed by plumbers. It covers all taps (faucets), showers, toilets and urinals. Updates to the requirements set out in the PCA, therefore, offer another approach for introducing or increasing residential and non-residential water efficiency minimum standards.

The NCC currently has no current requirements related to water efficiency beyond a maximum 9 L/min limit for outlets to showers and some tap types. There are parts of the code that could be expanded to require new (or higher) performance standards for other fixtures and fittings. Since the legislation that enacts the NCC is state controlled, each state can and does have its own additions and variations to the national code. These state-based additions might therefore be used to impose a minimum standard on plumbing products (fittings and fixtures) but not appliances installed within that state. The PCA imposes requirements on licensed plumbers. This means that if fixtures or fittings are installed by property owners there is no point of compliance versus the PCA. Despite this disadvantage, the PCA offers the advantages of impacting all installations, not just new builds and major renovations (unlike a planning policy mechanism such as BASIX). Furthermore, changes to the PCA can be state-specific and therefore do not require agreement across multiple jurisdictions (unlike below-mentioned WELS). This means any minimum standards could be targeted to the situation in a particular Australian state.

The WELS scheme

The WELS scheme is a legislated, mandatory, Federal government run scheme, which was introduced during the severe and prolonged 'Millennium Drought' in the early 2000's to improve water efficiency. The scheme requires all imported and locally manufactured indoor water-using fixtures and appliances (in defined classes) to be registered and labelled before sale or supply (Australian Government 2005). WELS labels provide water use information including a star-rating and usage information in litres per minute, litres per flush or an equivalent. The WELS scheme also imposes a minimum standard for many products. Currently this is at a 3-star level for taps, showers, toilets clothes washers and most disk washers (Australian Government 2022). For urinals it is set at 2-star. These minimum standards set a base level of water efficiency for what can be sold in the Australian (and New Zealand) market.

The WELS scheme was modelled on the successes of Australia's earlier mandatory energy-rating scheme. WELS labelling covers a range of plumbing products and appliances. These include taps, toilets, urinals, showerheads, washing machines, dishwashers and flow controllers. Other water-using devices such as irrigation and other outdoor water use equipment is covered by the complementary, voluntary 'smart-approved water-mark' scheme. WELS minimum standards build on Australia's significant development of dual-flush toilets and the subsequent regulatory minimum standard for flushing introduced in the early 1990s.

Australian State government regulations introduced for sustainable building (e.g. NSW BASIX) draw on WELS star-ratings system, as would potential ones under the PCA. Demand management programmes run by water utilities and state governments in Australia also commonly rely on WELS star-ratings for their product specifications. In essence, WELS 2-star-rated products are considered as inefficient, 3-star 'just' efficient, 4-star a step above, and 5 or 6-star highly-efficient.

Opportunity for increased minimum water efficiency standards

Within the current context of ongoing population growth and demand for water in Australia, the opportunity exists for improving water efficiency by mandating the installations of readily available water efficient products in the residential sector and various non-residential sub-sectors.

Each of the policy mechanisms for bringing in new or increased minimum standards based on minimum WELS ratings have their relative merits in terms of scope, effectiveness, and therefore varying potential savings. The approach taken to modelling and assessing the potential savings from policy options for minimum standards, follows.

METHODOLOGY

The study applied end-use and stock modelling methods to develop water use forecasts to 2050 together with resulting energy use forecasts and associated GHG emissions projections. A base case forecast to 2050 of 'no policy change' was compared to scenario simulations with each of the seven policy options that could improve water use efficiency in fixtures and appliances. This allowed savings for each potential policy to be estimated.

End-use and stock modelling creates bottom-up forecasts by starting with sales and stock survey data for each water-using product. The stock models convert sales and stock data into annual installed stock estimates by accounting for fixture and appliance lifetimes. This allows average annual flow rates, flush volumes, and water used per loads to be derived. Water use forecasts are then calculated using end-use data on frequencies of use and demographic data such as household occupancy or employee numbers in a sector.

Traditionally, stock modelling has considered aggregate groups of technologies, typically classed as efficient or inefficient. This study adopted a perspective based on the Australian WELS labelling scheme, with each stock model considering the installation of fixtures and appliances based on star-ratings. This distinction allows for estimates of the impact of policies (or programmes) that would make specific changes to star-ratings of a future cohort of product stock. As minimum water efficiency standards in Australia are to be based on WELS star-ratings, the approach allow a better interpretation for policy development. An example stock model for toilets, based on WELS star-ratings, is shown in Figure 1.

Energy use associated with water use in fixtures and appliances is due predominately to water heating. In Australia, water heating in the residential sector uses between five and eleven times more energy than the water utility uses in providing water services to households (Blinks *et al.* 2016). For the end-uses considered in this study, a similar ratio would exist for non-residential sectors. The modelling of hot water use also took a stock modelling approach, estimating the stock of different water heater types and technologies within the region. The model included the common hot water system fuel types (electricity and gas) with widely used technologies (electric resistance, electric heat pump, gas instantaneous, gas storage, solar gas boosted,

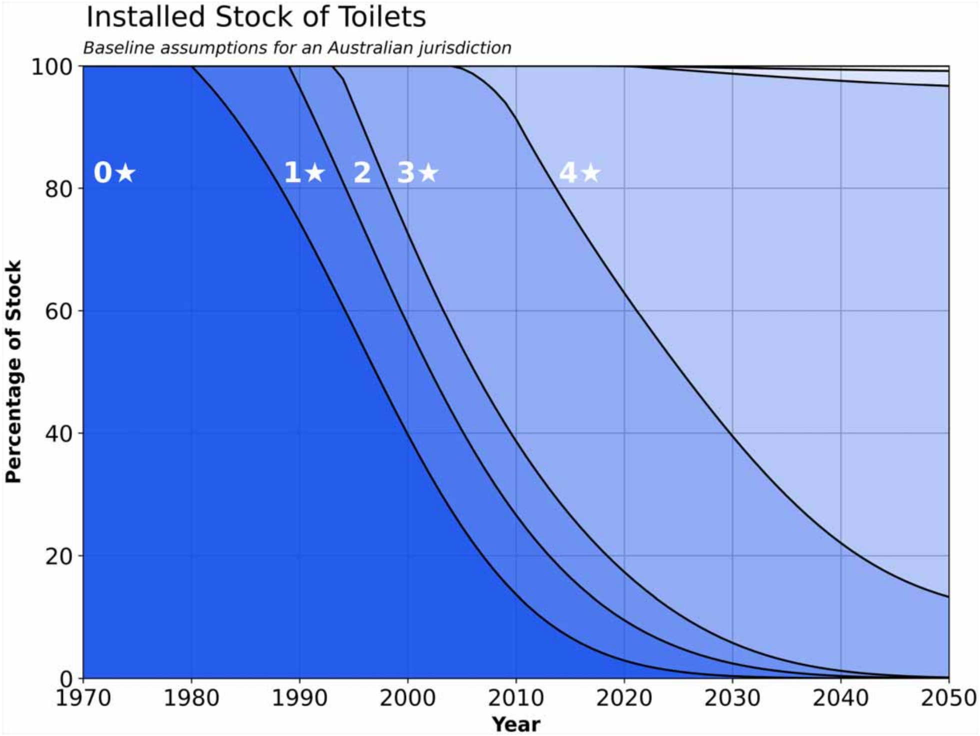


Figure 1 | Stock model for toilets.

and solar electric boosted). Due to shifting global and national trends in Australia, and a drive towards net zero GHG emissions targets, energy related to the production of hot water was assumed to be heavily favoured towards electricity into the future. The modelling assumptions closely followed that of the rapid electrification scenario in Roche *et al.* (2023), with the model from that study utilised.

The overall modelling approach is shown in Figure 2. The core model has three versions of the stock and end-use model each with six separate models within them, one for each product. The standard stock model is an update of the residential model based on a previous study that evaluated the WELS scheme (Fane *et al.* 2020). Two other versions have low turnover and less efficient stock or fast turnover with resulting more efficient stock. From the three models, five non-residential forecasts were derived. The new non-residential forecasts were: (1) Hotels/motels accommodation; (2) Aged care and hospitals accommodation; (3) 'Knowledge intensive' industries sector (covering 'high end' office employment); (4) General employment and places of study; (5) Visitation, covering both general uses (i.e. retail, public toilets, restaurants) and intensive uses (gyms, pools, etc.). This functional split allowed for different base case levels of water efficiency, different product lifetimes and, in some cases, different water use behaviours . The approach was shaped by data availability across the range of non-residential sub-sectors together with the availability of industry and sectoral forecasts (ABS 2021a, 2021b, 2021c). A key input was an analysis of water audit data from a non-residential water auditor, drawing on the previous 10 years of on the ground audit experience. This provided both stock data for some sectors and sector specific end-use estimates, where these could be expected to vary from residential end-use studies (such as Beal & Stewart 2014; Siriwardene *et al.* 2018).

A strength of an end-use and stock modelling approach for estimating water use, hot water use and subsequent energy usage is that it accounts for trends in the sales and installation of particular water-using products only. These are then reflected in the water and energy use forecasts and savings projections as that stock is assumed to remain in use for its average lifetime. This strength is supported by incorporating stock and sales data from multiple sources, together with end-use data from various studies (for example, Beal & Stewart (2014); Siriwardene *et al.* (2018)). A weakness of the approach is that factors other than the installed water efficiency of plumbing product and appliance stock are held constant. This means potential water use behaviour changes that may emerge in the future, due to societal changes or generalised experiences, such as future droughts or pandemics, are not captured in the projections. The nature of the study means that the model cannot be validated against

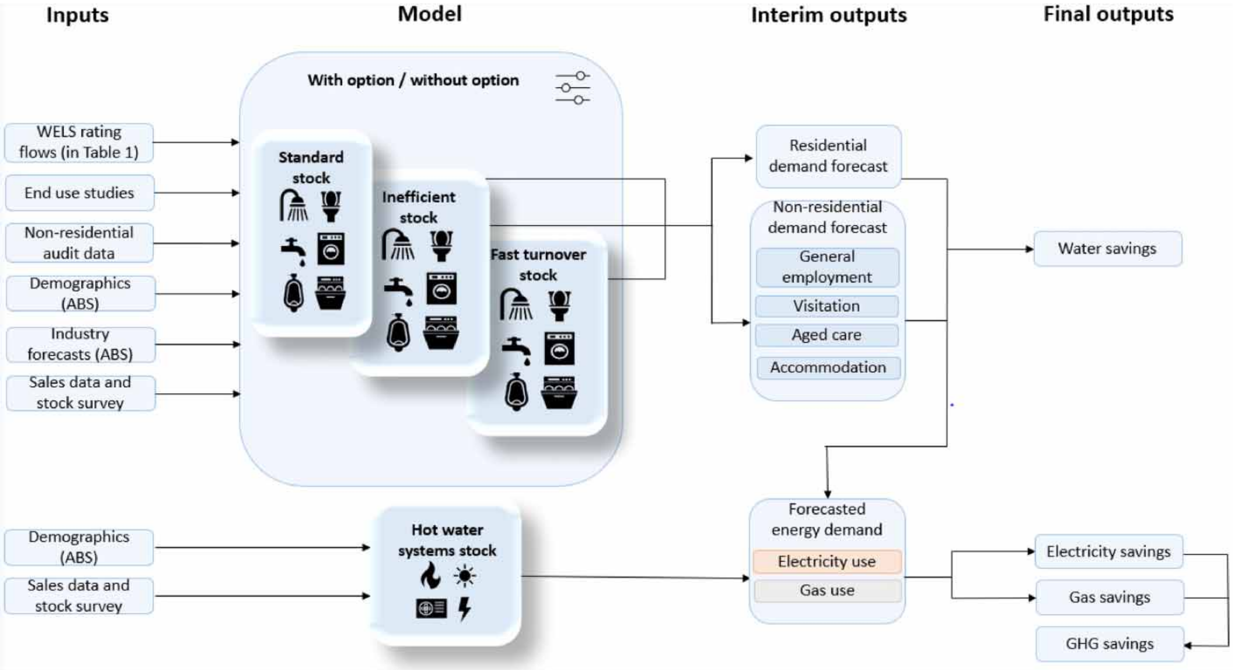


Figure 2 | Overall approach to modelling.

actual water consumption data from a state jurisdiction as a whole. This is because water consumption data at state and national levels is in aggregate and includes many significant water uses, such as outdoor irrigation, production water and evaporative cooling that are outside the scope of the policy options for indoor building water efficiency considered in the study.

Table 1 shows key assumptions used to model the water use of fixtures and appliances by their WELS rating, with water use based on average flow rate and usage behaviours.

Seven policy options/variants were considered in the study: Increased water efficiency minimum standards for plumbing fixtures and installed appliances in new residential developments via a sustainable buildings planning measure (Option 1); Increased water efficiency minimum standards via the plumbing code for all plumbing fixture installations in residential properties (with different standards levels, Options 2 and 3); Increased water efficiency minimum standards via the plumbing code for non-residential properties (again with different levels Options 4 and 5); Two options that used the WELS scheme to introduce a minimum standard (Options 6 for homes and 7 for business).

Table 2 shows the seven options modelled with the targeted WELS ratings as minimum standards. The table shows the sector (residential or non-residential) and the minimum standards modelled for the respective fixtures or appliances in terms of the WELS ratings. As compliance is a key issue requiring consideration, the assumptions include estimates for effectiveness for replaced showers and basin taps in homes under the plumbing code, due to the lack of a compliance check.

DISCUSSION AND RESULTS

The water savings results in kilolitres per person per year (kL/person/year) for each of the seven options relative to the base case are shown in Figure 3. The annual water savings were projected to increase year on year, eventually tapering off after 2040 as all inefficient stock relative to the base scenario has been replaced.

Each of the residential minimum standards options would save more than the non-residential standards. Among the residential options and overall, Option 6 (residential WELS minimum standards) would save by far the most water – 3.4 kL per person per year in 2050. Options 2 and 3 – residential plumbing code variants would also yield significant water savings, 1.9 and 2.3 kL per person per year in 2050, respectively. Residential sustainable building planning – Option 1 would save the least among the residential options at 1.3 kL per person per year in 2050 due to less uptake when compared to plumbing code and WELS mechanisms.

Table 1 | Summary of end-use and WELS rating data and assumptions used in the water demand modelling

	Shower	Tap	Toilet	Washing machine	Dishwasher	Urinal
Fixture/appliance water consumption						
WELS star-rating	L/min	L/min	L/flush	L/use	L/use	L/flush
0 Star	15.0	8.0	12.0		32.1	10.0
1 Star	12.8	6.4	7.2	156.7	24.9	4.0
1.5 Star				140.8	18.8	
2 Star	10.2	5.4	6.5	125.9	17.9	2.5
2.5 Star				112.1	16.2	
3 Star	8.1	4.1	5.7	99.4	15.1	2.0
3.5 Star				87.9	13.7	
4 Star	6.9	3.8	4.4	77.5	13.8	1.5
4.5 Star				68.2	12.4	
5 Star	5.5	3.0	3.0	59.8	11.7	1.0
5.5 Star					10.7	
6 Star		2.3	2.5		10.1	0.8
Behavioural assumptions						
Frequency (/person/day)	0.9	NV[a] Basin: 6.33 Sink: 2.37	4.33			
Frequency (/household/week)		V[a] Sink: 5.9–10.1		3.95–4.88	3.30–4.09	
Duration (minutes/use)	6.8	NV[a] Basin: 0.38 Sink: 0.38				

[a]Kitchen and laundry sinks are separated into volumetric (V) and non-volumetric (NV) usage. Non-volumetric usage is considered similar to bathroom basin usage with daily per person frequency and duration assumptions. Volumetric usage is independent of the tap flowrate or duration, assuming the activity is to fill an object. This occurs with an assumed frequency per household per week and a fixed volume.

Among the non-residential options, Option 5 – minimum standards via the plumbing code would save the most at 0.9 kL per person per year in 2050. Options 4 and 7 (with their less stringent standards – via the plumbing code or WELS) would save half that volume at 0.4 kL per person per year.

That savings from fixture and appliance minimum water efficiency standards are higher in the residential sector than the non-residential sector(s) is expected. As a proportion of total water use in Australia, households use about twice as much water as all industries excluding agriculture combined (see ABS 2022). Non-residential water usage also includes a higher proportion of end-uses such as outdoor irrigation, production water and cooling that were outside of the scope of the policy options considered in this study.

Table 3 shows the annual projected per capita water, energy and GHG emissions savings for the years, 2030, 2040 and 2050. As snapshots, these per capita results can be compared to average per capita projections in particular regions, and would be of interest from a utility planning perspective. These results again demonstrate that the greatest savings – across water, energy and GHG emissions – would be achieved via the WELS mechanism (Options 6 and 7). However, the more stringent plumbing code option (combining Options 3 and 5) is close in terms of water savings - 3.3 kL compared to 3.7 kL per person per year in 2050, despite the anticipated compliance issue with some property owners. The relative advantages of the mechanisms are addressed in the conclusions section.

The previous study (Fane *et al.* 2020) which evaluated all water savings made through water efficiency gains on fixtures and appliances since the introduction of the WELS scheme in Australia in 2006, found savings in 2030 equivalent to 6.9 kL per person. For energy savings and GHG emissions avoidance, the previous study found the impact of all programmes and policies including WELS to be 0.69 gigajoules (GJ) and 81.84 kg carbon dioxide equivalent (CO_2-e) per person respectively. The

Table 2 | Summary of target and minimum WELS star-rating for the seven options

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Scenario description							
Target sector	Residential	Residential	Non-Residential	Residential	Non-Residential		
Mechanism	Sustainable Building measure	Plumbing Code	Plumbing Code	Plumbing Code	Plumbing Code	WELS	WELS
Minimum WELS star-rating							
Showers	4	4[a]	4[a]	4	4	4	4
Toilet	4	4	4	4	4	4	4
Washing Machine	4					4	
Dishwasher	4					4	
Basin taps	6	4[b]	5[b]	4	6	4	4
Laundry and kitchen Sink	4	4[b]	4[b]	4	4	4	4
Urinals				4	5		4

[a]50% effectiveness for replacements.
[b]75% effectiveness for replacements.

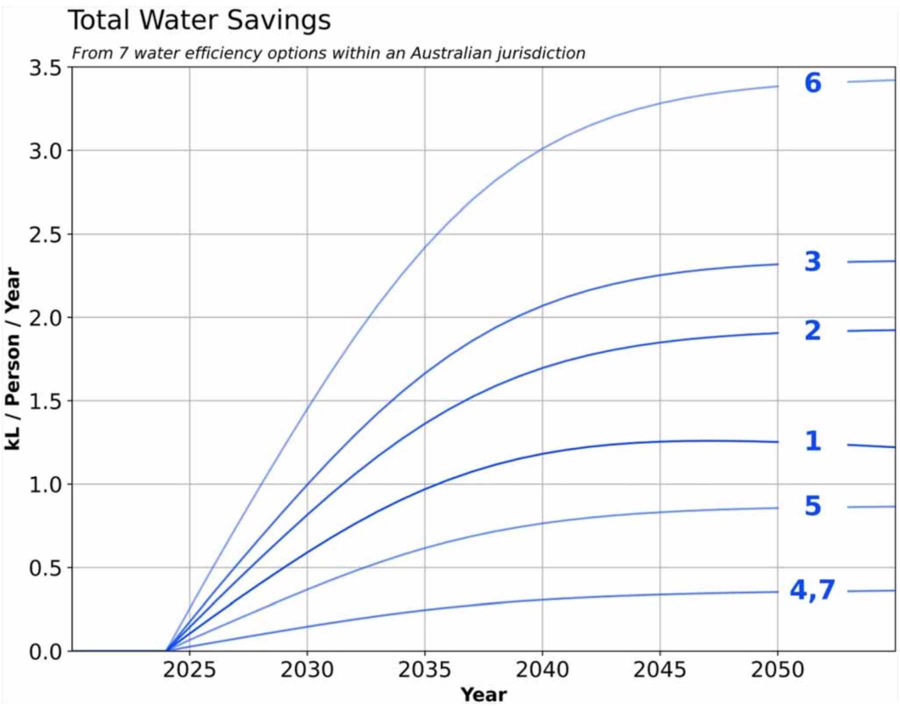


Figure 3 | Total water savings, by policy option.

comparison to the current study shows the policy options considered would make material additional savings on top of efficiency gains already made in Australia to date.

Figure 4 shows the energy savings (mostly from hot water) and Figure 5 the GHG emissions savings results again from reduced hot water and (to a lesser extent) utility energy use for combinations of the options evaluated relative to the base case. The energy and GHG emissions savings follow water savings, in terms of comparing the policy options. Interestingly, while the water savings continue to grow, the energy and GHG savings both peak. The energy savings peak in the early 2040s

Table 3 | Water, energy, and GHG savings results – 2030, 2040, 2050

Scenario	2030	2040	2050
Water savings (kL/Person/Year)			
Sustainable building measure *(Option 1)*	0.6	1.2	1.3
Plumbing code *(Options 2 & 4)*	1.0	2.0	2.3
Plumbing Code + *(Options 3 & 5)*	1.4	2.8	3.2
WELS *(Options 6 & 7)*	1.6	3.3	3.7
Energy savings (GJ/Person/Year)			
Sustainable building planning	0.07	0.11	0.11
Plumbing code	0.13	0.22	0.22
Plumbing code +	0.16	0.28	0.27
WELS	0.20	0.36	0.35
Greenhouse gas savings (kg CO_2-e/Person/Year)			
Sustainable building planning	3.9	4.8	4.2
Plumbing code	7.4	9.4	8.5
Plumbing code +	9.3	11.9	10.8
WELS	11.9	15.2	13.9

as rapid electrification sees heat pump technologies becoming dominant over gas hot water heating and resistance electric systems (Roche *et al.* 2023).

Figure 5 shows a peak in GHG emissions savings earlier than the energy peak. This difference is driven by assumptions about the rapid decarbonisation of the electricity grid in Australia and the growth of renewable energy. The Federal Government's national target for Australia is for 83% of electricity to be renewable by 2030 in line with the step change scenario in Australian Energy Market Operator's (AEMO) Integrated System Plan (AEMO 2022).

The estimates for water, energy and GHG savings in Figures 3–5 can be valued to give the benefits side of a cost–benefit analysis of the option. Benefits would be considered with expected costs of the policies due to administration and some price premiums for higher rated products.

CONCLUSIONS

The end-use and stock modelling showed the potential water, energy and GHG savings from minimum water efficiency standards for plumbing products and household appliances in homes and business in Australia. The results showed that the application of minimum water efficiency standards would achieve better results if applied to all installations than new developments only. The plumbing code is a good mechanism and increased standards would yield significant savings. However, the savings via WELS would be higher still.

Considering issues beyond potential savings, a minimum water efficiency standard based on the plumbing code has the significant advantage that it does not require agreement across jurisdictions. It might also be used to target minimum standards at high levels based on the local situation and water security needs. Yet the issue of compliance remains more easily addressed under WELS, by increasing the standards of water-using fixtures and appliances at the point of sale, rather than relying on the plumbing code. In the Federal context of Australia, a State Government policymaker looking to introduce minimum standards for water efficiency in buildings in their jurisdiction would need to judge not just the potential water savings and cost–benefit analysis of each option but also what argument might be reached at a federal level.

Overall, the study shows the value of WELS star-ratings as a tool for policy development and for modelling forecasts of impacts. The approach also shows for the first time the potential use of sub-sector specific information in modelling and forecasting water demand and associated energy and GHG emissions savings.

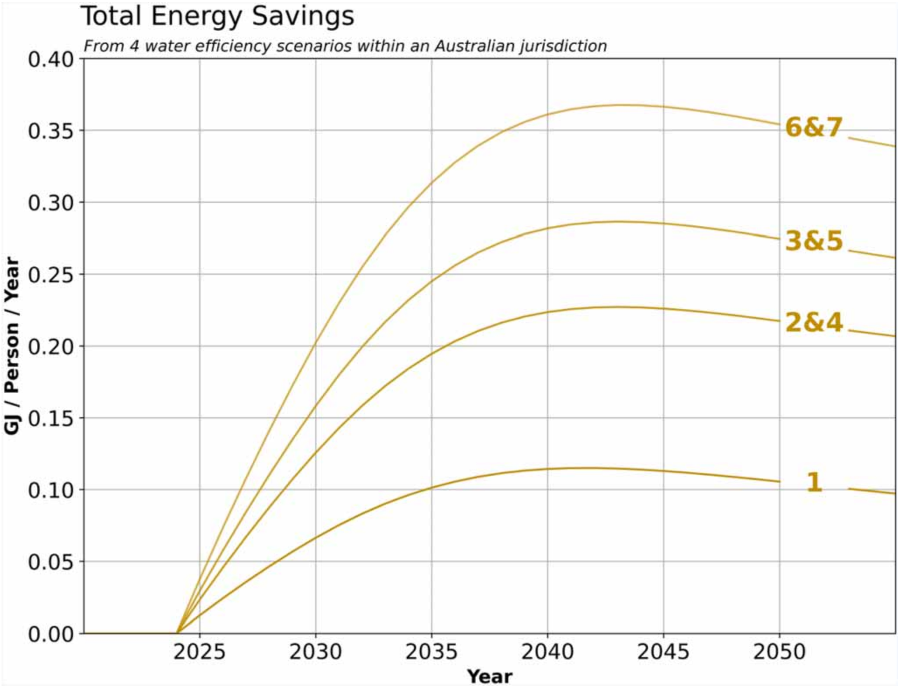


Figure 4 | Total energy saving, by policy option combinations.

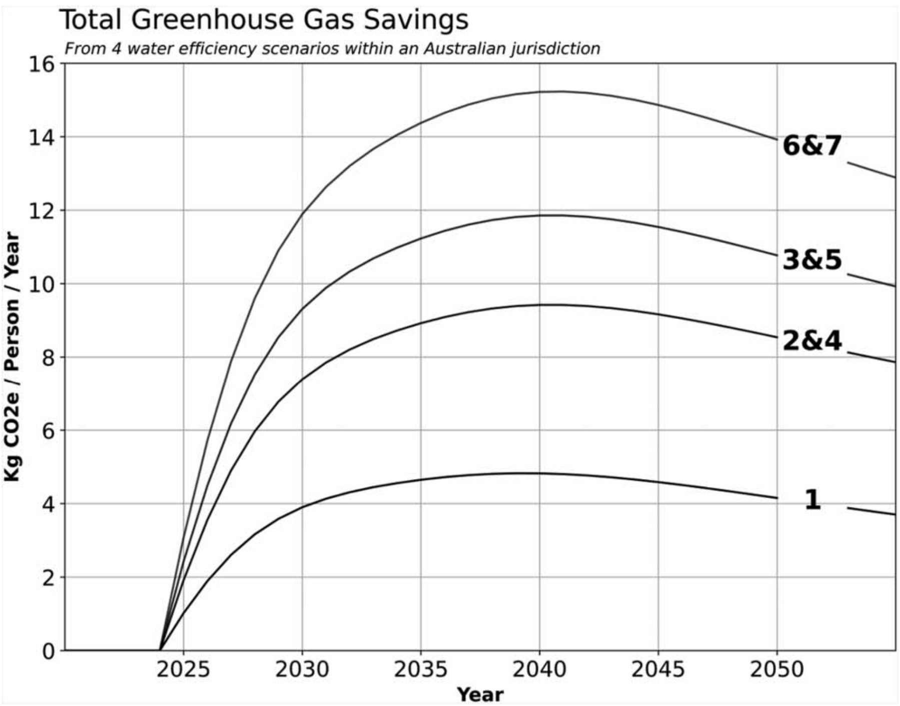


Figure 5 | Total GHG savings (kg CO_2-e), by policy option combinations.

In the future, the modelling approach used for the study will be applied to demand forecasting for cities and towns. At that scale the approach can also be used to estimate potential water, energy and GHG savings from demand management programmes such as rebates and retrofits with specific WELS-rated products. Municipal demand forecasting will require the expansion of the model to cover non-WELS-rated end-uses such as outdoor irrigation, production water and cooling. At this scale validation of the forecast with customer metered data and sewage flow data will also be possible.

DATA AVAILABILITY STATEMENT

All relevant data are available online, as listed in the references below.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Australian Building Codes Board (ABCB) 2022a *National Construction Code 2022 Volume one – Building Code of Australia Class 2 to 9 buildings*, NCC.

Australian Building Codes Board (ABCB) 2022b *National Construction Code 2022 Volume two – Building Code of Australia Class 1 and 10 buildings*, NCC.

Australian Building Codes Board (ABCB) 2022c *National Construction Code 2022 Volume three – Plumbing Code of Australia*, NCC.

Australian Bureau of Statistics (ABS) 2021a *Counts of Australian Businesses, Including Entries and Exists June 2016 to June 2021*. Available from: https://www.abs.gov.au/statistics/economy/business-indicators/counts-australian-businesses-including-entries-and-exits/latest-release (accessed April 2023).

Australian Bureau of Statistics (ABS) 2021b *Labour Force and Employment; Employment and Unemployment for Australia Detailed*. Available from: https://www.abs.gov.au/statistics/labour/employment-and-unemployment (accessed April 2023).

Australian Bureau of Statistics (ABS) 2021c *Retirement-and-Retirement-Intentions-Australia*. Available from: https://www.abs.gov.au/statistics/labour/employment-and-unemployment/retirement-and-retirement-intentions-australia/latest-release (accessed April 2023).

Australian Bureau of Statistics (ABS) 2022 *Water Account Australia*. Available from: https://www.abs.gov.au/statistics/environment/environmental-management/water-account-australia (accessed December 2023).

Australian Energy Market Operator (AEMO) 2022 *Integrated System Plan for the National Electricity Market, Australian Energy Market Operator*.

Australian Government 2005 *Water Efficiency Labelling and Standards Act 2005*. Australian Government, Canberra, Australia.

Australian Government 2022 *WELS Regulator Communication – Standard Amendments*. Depart of Water Agriculture and Environment

Beal, C. D. & Stewart, R. A. 2011 *South East Queensland Residential End Use Study: Final Report. Technical Report #47*. Urban Water Security Research Alliance.

Beal, C. D. & Stewart, R. A. 2014 *South East Queensland Residential End-Use Study: Stage 2 Final Report and Summary of Water Consumption Trends From 2010 to 2014*. Griffith University, Queensland, Australia.

Bich-Ngoc, N., Prevedello, C., Cools, M. & Teller, J. 2022 Factors influencing residential water consumption in Wallonia, Belgium. *Utilities Policy* **74**, 101281.

Binks, A., Kenway, S., Lant, P. & Head, B. 2016 Understanding Australian household water-related energy use and identifying physical and human characteristics of major end uses. *Journal of Cleaner Production* **135**, 892–906.

Chang, H., Praskievicz, S. & Parandvash, H. 2014 Sensitivity of urban water consumption to weather and climate variability at multiple temporal scales: The case of Portland, Oregon. *International Journal of Geospatial and Environmental Research* **1**, 1. Article 7.

de Souza Groppo, G., Costa, M. A. & and Libânio, M. 2019 Predicting water demand: A review of the methods employed and future possibilities. *Water Supply* **19**, 2179–2198.

Fane, S., Grossman, C. & Schlunke, A. 2020 Australia's water efficiency labelling and standards scheme: Summary of an environmental and economic evaluation. *Water Supply* **20** (1), 1–12.

Fox, C., McIntosh, B. & Jeffrey, P. 2009 Classifying households for water demand forecasting using physical property characteristics. *Land Use Policy* **26**, 558–568.

NSW Government 2023 *BASIX Review Stage one, Prepared for NSW Department of Planning and Environment by UTS Institute for Sustainable Futures*.

Roberts, P. 2003 *Appliance Stock and Usage Patterns Survey*. Yarra Valley Water, Melbourne.

Roche, D., Dwyer, S., Rispler, J., Chatterjee, A., Fane, S. & White, S. 2023 *Domestic Hot Water and Flexibility. Report Prepared for ARENA by UTS Institute for Sustainable Futures*.

Siriwardene, N., Do, J., Radion, A. & Westcott, J. 2018 Where is water being used in Melbourne households? Residential End Use Measurement Study (REUMS) insights.

Snelling, C., Turner, A., Riedy, C., White, S. & Cummings, S. 2007 Where does the water go? Best practice stock modelling for water using appliances. *Water Practice and Technology* **2** (4), wpt200707.

White, S., Milne, G. & Riedy, C. 2004 End use analysis: Issues and lessons. *Water Supply* **4** (3), 57–66.

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