The Australia Institute
Research that matters.

Off-peak hot water in the 21st century

Smarter load shifting in the NEM

In 2023, approximately 4,000 gigawatt-hours of renewable energy—around 9.3% of utility scale renewable generation—was wasted, or "curtailed". Much of this energy could be directed to off-peak hot water systems if those systems' timing could be changed from overnight to daytime peaks. Such a change could provide flexible demand for renewable energy, delivering financial savings, lower emissions, and lower gas demand.

Discussion paper

Matt Saunders – The Australia Institute
Richard Denniss – The Australia Institute
Craig Roussac – Buildings Alive

July 2024

The Australia Institute – Research that matters

Established in 1994, The Australia Institute is an independent public policy think tank with offices in Canberra, Hobart, Melbourne and Adelaide providing intellectual and policy leadership across a broad range of economic, social and environmental topics. We conduct research that drives the public debate and secures policy outcomes that make Australia better – research that matters.

The Australia Institute is funded by donations from philanthropic trusts and individuals, as well as grants and commissioned research from business, unions and non-government organisations. We do not accept donations or commissioned work from political parties. With no formal political or commercial ties, the Institute maintains its independence while advancing a vision for a fairer Australia.

Donations to our Research Fund are tax deductible, and can be made via our website or by calling the Institute:

Level 1, Endeavour House,
1 Franklin St Canberra,
ACT 2601
Tel: (02) 6130 0530
Email: mail@australiainstitute.org.au
Website: www.australiainstitute.org.au

Acknowledgement of Country

The Australia Institute recognises the ancestral connections and custodianship of Traditional Owners throughout Australia. We pay respect to Aboriginal and Torres Strait Islander cultures and to Elders past and present.

Acknowledgements

Thanks to Tom Hawking and Rod Campbell for editorial help on this report.

Summary

While Australia generates a lot of renewable energy, a significant amount of that energy is wasted. In the middle of the day, when solar panels are at their most productive, the *Australian Energy Market Operator* (AEMO) often instructs solar farms to disconnect from the grid. This "curtailment" is carried out to maintain grid stability by preventing an oversupply of electricity at a time when there is simply not enough demand for it.

Analysis of NEM data suggests that annual forced curtailment for 2023-24 was around 4,000 gigawatt-hours (GWh). This represents around 9.3% of Australia's total annual wind and utility solar generation.

A possible source of flexible demand for this generation is residential off-peak hot water. Off-peak systems account for around 30% of Australian household hot water systems. They are designed to use power overnight, a period when electricity demand has historically been lowest, but during which coal-fired generators have kept producing electricity regardless.

Today, off-peak times could be redefined, and off-peak systems reorganised to consume renewable electricity during the middle of the day, when there is an abundant supply of renewable electricity. Research by the Institute for Sustainable Futures at the University of Technology Sydney estimates that switching off-peak hot water to the middle of the day could have provided around 4,000 GWh of flexible demand in 2020—coincidentally, almost the exact level of renewable curtailment in 2023–24.

Off-peak electric hot water systems were an innovative solution to problems faced by electricity networks from the 1950s onwards. Today's problems are different, but the role of off-peak hot water systems in addressing them could be just as significant.

Introduction

> **AGL Customer:** Could you advise if it's possible to move [a] hot water system to general usage and set the timer to run 9 am–4 pm, when solar panels work? Most … days [our] solar produces 5 KW and we hardly use it.
>
> **AGL:** Unfortunately, this is something that your retailer is unable to assist you with.[1]

On AGL's "Neighbourhood" forum, customers are asking questions that Australia's governments and energy system regulators should be working on answering. The responses that these customers are actually receiving—as demonstrated by the example above—shows how lost Australia's energy system has become.

While Australia generates a lot of renewable energy, a significant amount of that energy is wasted. During the middle of the day, when the sun is shining the brightest and Australia's growing fleet of solar panels are at their most productive, the Australian Energy Market Operator (AEMO) often instructs the owners of some of Australia's solar farms to disconnect from the grid to prevent an oversupply of electricity. This practice is referred to as "curtailment", and it is done to ensure that the amount of electricity being supplied to the grid is equal to the demand at any point in time, ensuring grid stability in terms of voltage and frequency.

It is often suggested that the demand for a product is determined primarily by that product's price, and that the best way to influence demand is therefore by effecting changes in price. In reality, however, price is just one of many variables that can shape demand. Few men choose to wear ties to work because ties are cheap. Few Australians choose to snare a bargain by purchasing a left-hand drive car. The surge in demand for dog grooming services in Australia in recent years is in no way linked to a decline in the price for such services.

Introductory economics textbooks often assert that, all other things being equal, the price of a product is the major determinant of the quantity of demand. But outside of introductory economics textbooks, all other things are rarely equal and often it is demand that drives price, rather than vice versa. Demand for seaside hotel rooms, for example, peaks during school holidays, despite this being the period when those rooms are most expensive.

Similarly, the demand for electricity over the course of a day is shaped by a wide range of cultural and regulatory factors. In Australia, one of the major factors determining the time

[1] AGL (2024) *Managing Your Energy: Questions and discussions about managing your energy usage and saving money,* https://neighbourhood.agl.com.au/t5/Managing-Your-Energy/Moving-hot-water-from-CL1-to-general-usage/td-p/32969

of day at which households consume electricity is hot water. This, in turn, is the result of historic policy decisions to encourage the installation of off-peak hot water systems. These installations began in the 1950s and accelerated in the 1970s. These hot water systems were designed specifically to create demand for surplus coal-fired electricity. This surplus existed because power stations were designed to run continuously, despite the lack of demand for electricity in the middle of the night.

Just as government decisions on the timing of school holidays—rather than the prices of hotel rooms—are a major determinant of the timing of most family holidays, government policy decisions to encourage the installation of off-peak hot water systems have been a major determinant of the demand for electricity over the course of each day. Today off-peak hot water systems continue to run primarily at night (when the now privately-owned coal fired power stations need customers), rather than in the afternoon (where zero-emission renewable energy is often "curtailed" rather than consumed). This situation creates a unique opportunity for Australian governments to lower both greenhouse gas emissions and electricity bills—with small up-front costs.

This is the definition of a win-win opportunity, and this paper considers the size of that opportunity. The analysis draws from previous work commissioned by the Australian Renewable Energy Agency (ARENA) and presents new data on the amount of electricity generation being curtailed in Australia.[2] It finds that moving off-peak hot water to the middle of the day could consume around 4,000 GWh of electricity—a figure that coincides closely with a recent estimate of the amount renewable generation being wasted each year. This 4,000 GWh of renewable generation is also the equivalent of around 40% of the annual output of all gas-fired generators in the National Electricity Market (NEM), and allowing it to flow into the grid rather than wasted would also reduce the need for further investment in gas generation.[3]

Why are we switching off solar when the sun is shining brightest?

The Albanese Government's commitment to increasing investment in renewable energy in order to achieve net zero emissions by 2050 has been widely publicised, as has the government's target of 82% renewable generation by 2030.[4] What is not so well known, however, is that Australian Electricity Market Operator (AEMO)—the body responsible for

[2] Institute for Sustainable Futures (2023) *Domestic Hot Water and Flexibility – Prepared for ARENA,* https://arena.gov.au/assets/2023/06/uts-domestic-hot-water-and-flexibility-report.pdf

[3] Data for the 12 months to 11 June 2024, OpenNEM.org (2024) https://opennem.org.au/energy/nem/?range=1y&interval=1M&view=discrete-time

[4] Australian Energy Council (2023) *The 82 per cent National Renewable Energy Target – Where Did it Come from and How Can We Get There?* https://www.energycouncil.com.au/analysis/the-82-per-cent-national-renewable-energy-target-where-did-it-come-from-and-how-can-we-get-there/

operating Australia's National Energy Market (NEM)—insists regularly that some renewable electricity generation is switched off when the sun is shining the brightest.

Put simply, at a time when the Commonwealth Government is trying to encourage more investment in new renewable energy capacity, the electricity market operator is often instructing some renewable electricity producers to curtail the amount of power they are supplying to the grid.[5] Some of this curtailment is necessary to maintain the network's stability, which can be undermined by an oversupply of power flowing into the grid, but some is so-called "economic curtailment", where an oversupply of electricity (relative to demand) drives down the wholesale price, leaving generators with the option to either disconnect or pay to supply their electricity to the market. This phenomenon only ever occurs when the conditions for renewable energy generation are most favourable.

The basic reason behind AEMO-dictated curtailment is that at certain times of day, the amount of electricity being generated outstrips the level of demand. Electricity demand has always fluctuated over the course of the day: it often peaks in the late afternoon as children come home from school, family meals are prepared, and industrial uses of electricity are yet to shut down for the day. However, as the number of household solar panels and batteries increase, the level of externally produced electricity demanded via the NEM in the early afternoon by Australian households is declining.

This is also the time of day at which large-scale solar farms are able to provide their maximum daily output. The result of this abundant supply of electricity in the early afternoon, combined with declining demand, means that wholesale electricity prices in the NEM can be close to zero or even negative at times.

While it is common to refer to the NEM as a "market", it is a complicated bureaucratic structure, governed by 1,925 pages' worth of rules and regulations and underpinned by a significant amount of legislation.[6] The privatisation and alleged deregulation of formerly publicly owned and operated electricity companies required the rhetorical creation of electricity "markets", overseen by an "operator" rather than a "regulator". However, there is no National Fruit Market in which the Fruit Market Operator can instruct farmers to stop growing peaches, nor is there a National Café Market Operator that instructs café owners where they can set up and when they have to shut down.

Despite its public portrayal as a market, many of the major decisions about the NEM continue to be made by public servants rather than investors chasing profits. Significantly, these include decisions that determine which electricity generators are required to shut down and when. These decisions are part of the AEMO's pursuit of grid stability, a

[5] Battery Storage and Grid Integration Program (2024) *Explainer: What is congestion and curtailment in the National Electricity Market (NEM)?*, https://bsgip.com/news-events/news/explainer-what-is-congestion-and-curtailment-in-the-national-electricity-market-nem/

[6] AEMO (2024) *National Electricity Rules*, https://energy-rules.aemc.gov.au/ner/572

multifaceted task that requires consideration of, among other things, short term fluctuations in supply and demand over the course of a day, scheduling of maintenance for large generators and investment in new sources of generation and transmission. The choice of sources to be curtailed can also reflect a wide range of factors including short-term capacity requirements, availability of transmission capacity, and the scheduled and unscheduled maintenance needs of other generators.

This paper is not based on the misapprehension that managing the short- and long-term requirements of the Australian electricity grid is a simple task. On the contrary, it is the complexity of the current system, and its reliance on historic bureaucratic rules, that creates opportunities for “win-win” solutions that a well-functioning market would have identified long ago.

How much solar energy is switched off when the sun is shining?

It can be difficult to make accurate estimates of how much renewable energy generation is experiencing forced curtailment. This is partly because generators of all kinds—particularly non-baseload generators—can and do voluntarily switch off if NEM spot prices make it unprofitable to continue generating. This voluntary curtailment is a normal part of market behaviour. Generators have also been known to game the market by strategically switching off to manipulate prices in their favour.[7] Nevertheless, it is widely agreed that forced curtailment does take place. This claim can be supported by simple observation of AEMO market notices.[8]

Due to the nature of the NEM, most estimates and analysis of curtailment are reported on an hourly, monthly or facility basis. For example, research published by WattClarity suggests monthly forced curtailment increased from 384 GWh a month in the first quarter of 2022 (representing 4.3% of total wind and solar generation in that quarter) to 730 GWh a year later (7.1%).[9]

For policy analysis purposes it is often more useful to discuss these issues on an annual basis since the merits of policy incentives to increase renewable or gas electricity generation investments, or large-scale investment projects more generally, are usually sold or advocated for based on annual impacts.

Analysis of NEM data supplied by AEMO shows that annual forced curtailment for the 12 months from 1 June 2023 to 31 May 2024 was 3,959 GWh, representing around 9.3% of Australia's total annual wind and utility solar generation for that 12-month period.[10] Table 1 outlines this forced curtailment data for (approximately) the financial year 2023-24, and also provides a breakdown by season, which highlights the greater curtailment in the higher solar-radiation seasons.

[7] McArdle (2023) *Increasing curtailment of Wind and Solar across the NEM,* https://wattclarity.com.au/articles/2023/06/24june-increasing-curtailment-of-wind-and-solar/

[8] McArdle (2023) *Curtailment of rooftop PV occurring in South Australia on Saturday 19th November 2022,* https://wattclarity.com.au/articles/2022/11/19nov-curtailment-of-rooftop-pv-occurring-in-sa/

[9] McCardle (2023) *Increasing curtailment of Wind and Solar across the NEM,* https://wattclarity.com.au/articles/2023/06/24june-increasing-curtailment-of-wind-and-solar/

[10] Data for the 12 months to 11 June 2024, OpenNEM.org (2024) https://opennem.org.au/energy/nem/?range=1y&interval=1M&view=discrete-time

Table 1: Estimated curtailment of renewables in the NEM by season, 2023–24

	Total (GWh)	Five-minute max (MW)	Daily average (GWh)
Winter 2023	554	5,096	6.0
Spring 2023	1,792	8,265	19.7
Summer 2023/24	1,172	5,947	12.9
Autumn 2024	441	4,140	4.8
Total	**3,959**		

Source: Analysis of data from NEMLOG (2024) https://nemlog.com.au/show/nemfieldbyregion/1y/?field=CURTAILMENT&labels

The estimates also show that, depending on the season, up to almost 20 GWh a day of renewable generation—or around 3.6% of total daily generation—is being wasted due to forced curtailment.[11]

If some of the predictable daily fluctuations in electricity demand can be shifted to the times of day when supply is being forcibly curtailed and prices are extremely low, then it would be possible to increase overall renewable electricity generation from existing capacity. This would encourage greater investment in new renewable capacity due to higher financial returns on investment. It would also lower the emission intensity of Australia's daily electricity generation profile by reducing the reliance on coal-fired generation overnight.

The remainder of the paper outlines one way that forced curtailment could be reduced. It builds on the recent work by Denniss and Roussac on the benefits of shifting electricity demand over the course of a day by changing the way in which large commercial buildings use their heating and cooling systems.[12]

[11] Forced curtailment also occurs due to transmission constraints. See: https://wattclarity.com.au/articles/2023/05/renewable-curtailment-forced-and-not-quite-so-forced/ and https://wattclarity.com.au/articles/2023/05/australias-renewable-energy-boom-the-good-the-bad-and-the-downright-ugly/.

[12] Denniss and Roussac (2024) *Buildings as Batteries - How Buildings Can Support the Clean Energy Transition,* https://australiainstitute.org.au/report/buildings-as-batteries/

Off-peak hot water in Australia

Domestic hot water represents a considerable share of both Australia's total household energy demand and its total household emissions. According to the Institute for Sustainable Futures, using data from the former Department of Industry Science Energy and Resources (DISER), domestic hot water accounts for around 25% of household energy demand and 20% of emissions.[13] More than half of Australian households use an electric hot water system, and these account in total for around 25 GWh of daily electricity usage or 5% of total daily consumption across the NEM.[14,15]

Off-peak electric hot water systems have been a common choice for Australian households since the 1950s, particularly in NSW and Queensland. These systems work by using electricity to heat water, and they do so during the times at which electricity demand has historically been at its lowest: overnight, and usually between the hours of 10pm and 7am.[16] They were designed to create demand for coal-fired electricity throughout the night, at a time when households and industry otherwise had little use for electricity.

To encourage the uptake of these off-peak hot water systems, state-owned electricity utilities offered significantly discounted off-peak electricity tariffs, often providing as much as a 75% discount on standard prices.[17] In order to ensure that only electricity for use in off-peak hot water systems is supplied at the discounted price, off-peak systems are wired up to a separate circuit that allows the electricity distributor to switch them on and off remotely, often via a pulse of electricity at a specific frequency.[18] In return for households having little control over when their water is heated, the hot-water tanks were considerably larger than what would otherwise have been necessary.[19] The larger tanks also allow for heat loss during peak periods when the circuit is switched off. In effect, these comparatively large tanks act as large batteries, charging late at night for use during the day and evening.

[13] Institute for Sustainable Futures (2023) *Domestic Hot Water and Flexibility – Prepared for ARENA,* https://arena.gov.au/assets/2023/06/uts-domestic-hot-water-and-flexibility-report.pdf

[14] Yildiz (2023) *Electric Hot Water is a Hero of Flexible Demand. Where Does it Stand in the Age of Rooftop Solar?*, https://reneweconomy.com.au/electric-hot-water-is-a-hero-of-flexible-demand-where-does-it-stand-in-the-age-of-rooftop-solar/

[15] Institute for Sustainable Futures (2023), p.17

[16] Whirlpool Forums (2013) *How does off peak hot water work*? https://forums.whirlpool.net.au/archive/1830367

[17] Institute for Sustainable Futures (2023), p. 20

[18] The exact method of switching varies across jurisdictions.

[19] Inline Plumbing and Electrical (2024) *The Differences Between Hot Water Systems Using Off-Peak Rate vs Continuous Tariff*, https://www.inlineplumbing.com.au/off-peak-vs-continuous-tariff/

To reiterate an earlier point, if the NEM was operating as a real market, households would be free to connect actual batteries to the off-peak circuit to charge with cheap electricity and resell at higher prices at other times of the day. But as the NEM is a market in name only, such arbitrage is prevented by administrative rules.

Significantly for the purposes of this paper, the entire concept of off-peak hot water was developed to shift electricity demand away from afternoon and morning peaks in demand and towards periods of excess supply. Government intervention to shift the pattern of household demand for electricity was considered necessary to ensure there was sufficient overnight demand to provide grid stability following the construction of several large coal-fired baseload generators, particularly in NSW. Other demand-shifting and grid-stabilising measures at the time included keeping office and government building lights on all night, while some NSW public schools even had off-peak heating to preheat school buildings, an approach consistent with that proposed recently by Roussac and Denniss for large commercial buildings.[20]

Despite the initial success of off-peak hot water, recent developments in the NEM—particularly the strong uptake of rooftop solar by Australian households—has led to a significant decline in its use. In NSW and SA, between 15% to 25% of controlled loads (mainly off-peak off water) have become inactive or disconnected. In Queensland, one in every three solar installers advocates removing their customers' hot water from the separate off-peak circuit and connecting it to general supply,[21] on the basis that the low price households receive for exporting solar power makes it most cost-effective for households with rooftop solar to maximise self-consumption—and NEM rules prevent self-generated solar power from being diverted to off-peak hot water systems.[22] In new buildings, meanwhile, recent amendments to the National Construction Code effectively prohibit the installation of the type of electric hot water systems that were traditionally connected to off-peak circuits due to their high emissions when powered by fossil fuel sources.[23]

Despite these trends, close to three million Australian homes continue to use off-peak hot water systems to heat their water. While off-peak hot water systems were designed, and rolled out, to soak up excess night-time supply of coal fired electricity, there is no technological or economic reason that they could not be realigned to do the same for the current surplus of afternoon electricity supply: the fact that they are switched on remotely means their operation could be managed actively by an efficient energy regulator.

[20] Denniss and Roussac (2024)

[21] Yildiz (2023) *Electric Hot Water is a Hero of Flexible Demand. Where Does it Stand in the Age of Rooftop Solar?*

[22] Ibid.

[23] Institute for Sustainable Futures (2023), p.20

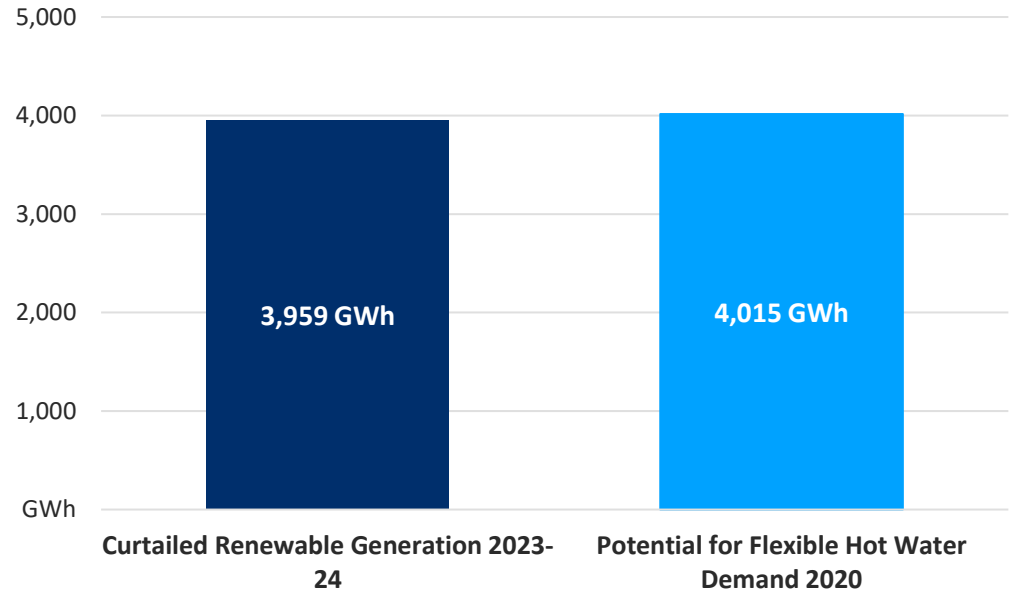
Less curtailment, more hot water

Shifting off-peak hot water heating hours to times of the day when renewable generation is at its peak is a relatively simple low-cost step towards minimising the curtailment of renewables in the NEM and reducing emissions caused by domestic hot water usage.

As shown in Table 1 above, is it estimated that for the financial year 2023–24, around 3,959 GWh of renewable electricity supply was curtailed by the regulator. Coincidentally, the Institute for Sustainable Futures at the University of Technology Sydney recently modelled the NEM under a range of scenarios to assess the impacts of switching off-peak hot water to the middle of the day peak renewable output—and concluded that, under its most conservative scenario, off-peak hot water systems could have provided around 4,015 GWh of flexible demand in 2020.[24]

To be clear, curtailment of renewable energy supply can occur for reasons other than excess supply—for example, insufficient transmission capacity. The objective of comparing these two figures is to demonstrate their similar orders of magnitude—a similarity shown clearly in Figure 1 below—and that there is considerable scope for using curtailed renewable generation to produce hot water. The available data shows clearly that using off-peak hot water to create new demand for daytime solar supply has significant potential to reduce curtailment. This, in turn, would reduce the emission intensity of the NEM and increase investment in (and returns on) renewable electricity capacity.

Figure 1: Curtailed renewable generation vs flexible hot water electricity demand



Source: Analysis of data from NEMLOG (2024) & Institute for Sustainable Futures (2023)

[24] Institute for Sustainable Futures (2023) *Domestic Hot Water and Flexibility – Prepared for ARENA,* https://arena.gov.au/assets/2023/06/uts-domestic-hot-water-and-flexibility-report.pdf

Figure 1 makes clear that there is significant potential for reducing the amount of renewable energy that is curtailed by shifting electric off-peak hot water demand from overnight to the early hours of the afternoon. However, the design of the NEM, and other system requirements, mean such a shift is not without some difficulties.

Nevertheless, the Institute for Sustainable Futures have modelled the potential impact to 2050 that refining policy and providing incentives to further encourage the uptake of off-peak hot water and found it was an efficient way to match demand and supply across the NEM. Their research estimates that by 2040, off-peak electric hot water could provide around 50GWh a day, or 18,300 GWh a year, of flexible demand and storage to help stabilise the grid.[25] The higher amount of renewable generation that this would permit could save up to $6 billion in household electricity and energy costs, including expensive gas-fired hot-water.[26]

[25] Institute for Sustainable Futures (2023) *Domestic Hot Water and Flexibility – Prepared for ARENA,* Table7, p. 40, https://arena.gov.au/assets/2023/06/uts-domestic-hot-water-and-flexibility-report.pdf

[26] Roche (2023) *Electric Water Heaters Could Do Work of 2 million Home Batteries – and Save Billions*, https://reneweconomy.com.au/electric-water-heaters-could-do-work-of-2-million-home-batteries-and-save-billions/

Conclusion

The so-called National Electricity Market is not a market in any traditional sense—but then again, electricity is not a traditional product. It is an essential service that plays a critical role in Australia's economy and climate goals.

Electricity prices are not like those of other products. A rental tenant living in a house with a gas oven and an off-peak hot water system can do little to change their consumption choices when the relative prices of different forms of energy change. That said, while concerns about the likely inefficiency of privatising the electricity system have been made clear over the decades, the architects of National Competition Policy pressed ahead regardless and, in turn, delivered the distorted and inefficient rules that currently require the curtailment of low cost, zero emission electricity today.[27,28]

Off-peak electric hot water systems were an innovative solution to the changing circumstances in the rapidly evolving state-based electricity networks in Australia from the 1950s onwards. While the problems faced by the electricity system of the 2020s are different to those faced in the 1950s, off-peak hot water systems could again play an important role in addressing those problems.

Just as large commercial buildings have the potential to shift a significant amount of the electricity they use for heating and cooling to times of day when there is an abundance of renewable energy,[29] off-peak hot water systems also represent a significant opportunity to shift household electricity demand. If off-peak hours were moved away from the time of day dominated by coal-fired electricity and towards the time of day when the sun is shining brightest, curtailment of solar power supply could be reduced significantly.

[27] Richardson (2013) *Electricity and Privatisation - What Happened to Those Promises?* https://australiainstitute.org.au/report/electricity-and-privatisation-what-happened-to-those-promises/

[28] Quiggin (2014) *Electricity Privatisation in Australia a Record of Failure*, https://johnquiggin.com/2014/02/20/electricity-privatisation-in-australia-a-record-of-failure/

[29] Denniss and Roussac (2024) *Buildings as batteries: How buildings can support the clean energy transition*, https://australiainstitute.org.au/report/buildings-as-batteries/