Benefit Analysis of Load-Flexibility from Consumer Energy Resources: Final Report

Prepared by Energeia for the
Australian Energy Market Commission

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Executive Summary

Background

This study explores how key consumer energy resource (CER) technologies can be utilised to provide consumer and system benefits through accessing value directly from the system. It also investigates the current impact optimised CER would have on consumer retail bills. Using CER flexibly to provide system benefits aims to provide lower-cost solutions for market and grid requirements, such as reducing network peak demand and providing energy into the wholesale market, with the aim of lowering the overall costs of energy to all consumers.

Scope and Approach

The Australian Energy Market Commission (AEMC) engaged Energeia to develop an estimate of the system benefits of unlocking flexible CER to 2050, as well as the associated retail bill impacts for consumers responding to the needs of the system. The system benefits modelled within this report were developed with the AEMC to advise future reforms related to CER.

The above analysis was conducted using a fit-for-purpose Microsoft Excel-based modelling tool that estimated the material costs and benefits of flexible CER for the system and for consumers. The modelling included the most significant types of flexible loads and consumer segments, which were outlined in the Methodology Report[1] across the National Electricity Market (NEM) to 2050.

Energeia worked closely with the AEMC to deliver the following scope and approach that aimed to support the AEMC with modelling to use in future reforms:

- **Develop and Agree Upon Key Inputs, Assumptions, and Methodology** – Energeia developed key modelling inputs and assumptions based around CER flexibility, including technical parameters, operational profiles, and adoption to 2050.
- **Develop CER Flexibility Optimisation Tool** – Energeia developed a CER flexibility model to estimate retail bill impacts and system cost impacts, including wholesale, ancillary services, transmission, distribution, and carbon emissions.
- **Determine Allocation of Benefits** – Energeia researched and analysed current virtual power plant (VPP) offers to estimate the average level of CER utilisation and the impact on the consumer's bill of orchestration of CER to provide system benefits.
- **Validate Reporting with Key Stakeholders** – Energeia presented the delivered research, analysis, and results to key AEMC stakeholders and revised them based on feedback received, before being documented in this report.

Value of Flexible Load

Energeia's analysis determined the incremental system benefits of CER flexibility to 2050, considering an expected sharing of benefits across supply chain participants.

Total Market Benefits if CER Flexibility is Unlocked

Energeia scaled the calculated net benefits per device by consumer segments modelled using a consensus view[2] of device adoption rates and flexible program participation rates. It is worth noting that the Australian Energy Market Operator's (AEMO's) Inputs and Assumptions Report (IASR) 2023

[1] Energeia, Benefit Analysis of Load-Flexibility from Consumer Energy Resources: Methodology Report (2023), https://www.aemc.gov.au/sites/default/files/2023-08/CER%20Flexibility%20Modelling%20Methodology%20Paper%20-%20FINAL.pdf

[2] The consensus view referred to throughout this report considers Energeia's consolidation of respected industry publications, primarily the E3 Residential and Commercial Baseline Studies (2022), the AEMO ISP Step Change Inputs and Assumptions (2023), and the E3 'Smart' Demand Response Capabilities report (2022)

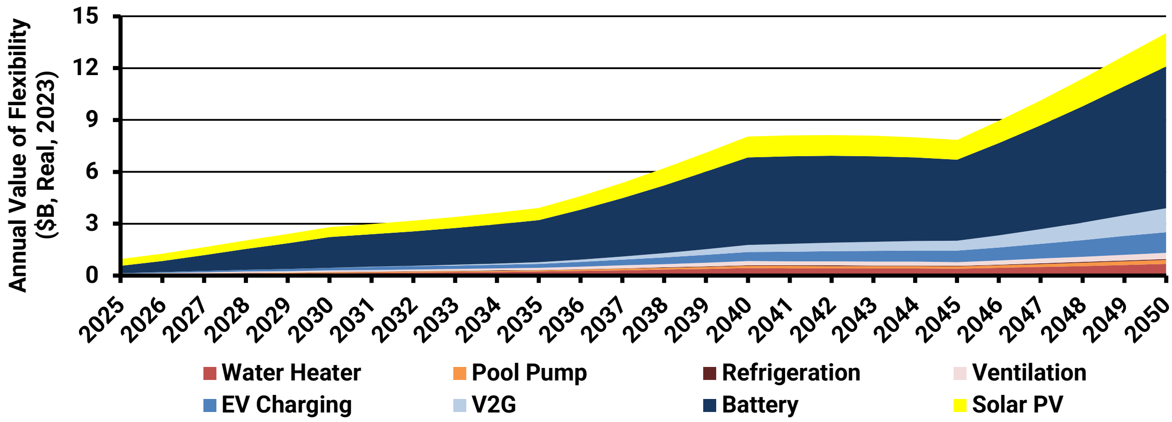
Step Change load flexibility forecast, which forms a key part of the consensus view, presumes that all policy and regulatory barriers have been removed.

The resulting estimate of total potential market benefits from completely unlocking CER flexibility to 2050 (assuming no transaction costs) is reported in Figures ES1 to ES3 by device type, consumer segment, and benefit stream, respectively.

Overall, this analysis found that $14B of annual system benefits could be achieved by unlocking all CER flexibility by 2050, assuming CER acts to minimise total system costs by participating in wholesale and frequency control ancillary service (FCAS) markets and network demand response. These benefits total $45B in net present value (NPV) terms, assuming a 7% real discount rate. The magnitude of benefits is relative to the case in which all CER acts to maximise the owner's self-consumption or convenience, with no consideration for the wider system or their retail tariff.

Figure ES1 shows the annual system benefits broken down by different CER technologies. Analysis showed that batteries are the expected key driver of potential benefits, accounting for 60% of all accessible value.[3] Electric vehicles (EVs) also are expected to be key drivers of system benefits, through both charging and vehicle-to-grid (V2G) capabilities.

Figure ES1 – Total Annual Potential Flexible CER by Resource Type

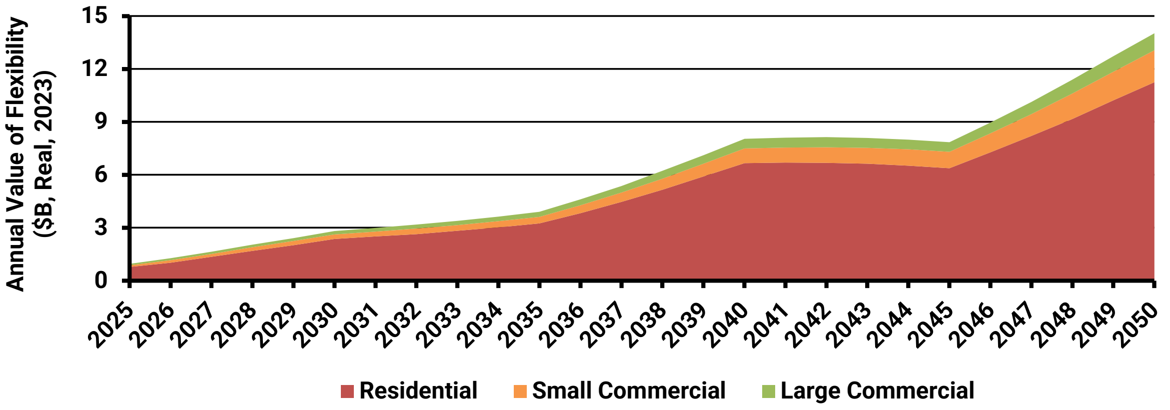


Source: Energeia

The analysis also found that over 80% of the potential benefits are expected to come from the residential sector, with the rest split between small and large commercial consumers. This is mainly due to the assumed, relatively high level of CER adopted by residential consumers compared to non-residential consumers.

[3] Batteries assumed to be 2-hrs, with capacity of 10 kWh for small customers and 150 kWh for large customers

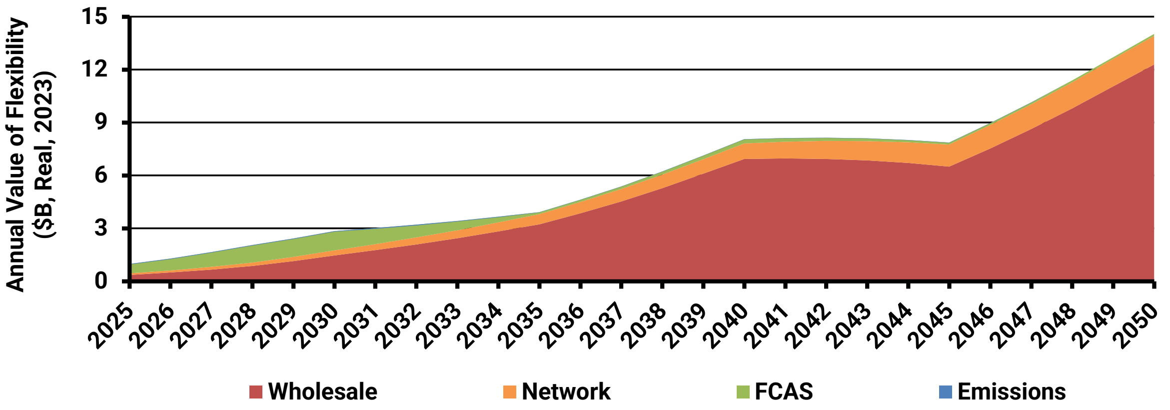
Figure ES2 – Total Annual Potential Flexible CER by Consumer Segment



Source: Energeia

The analysis, using 2021 actual wholesale market pricing data, found that most system benefits likely will result from the avoidance of wholesale costs. Captured FCAS revenues are forecast to be high in initial years; however, they are expected to significantly taper in later years due to an oversupply resulting in the value of FCAS dropping. Modelled network benefits are estimated based on avoided network costs, utilising Australian Energy Regulator (AER) approved estimates of long-run-marginal-cost, and this represents 12% of the total benefits in NPV terms to 2050.

Figure ES3 – Total Annual Potential Flexible CER by Benefit Stream



Source: Energeia

The results of Energeia's analysis of the impact on consumer bills of the above orchestration are outlined below.

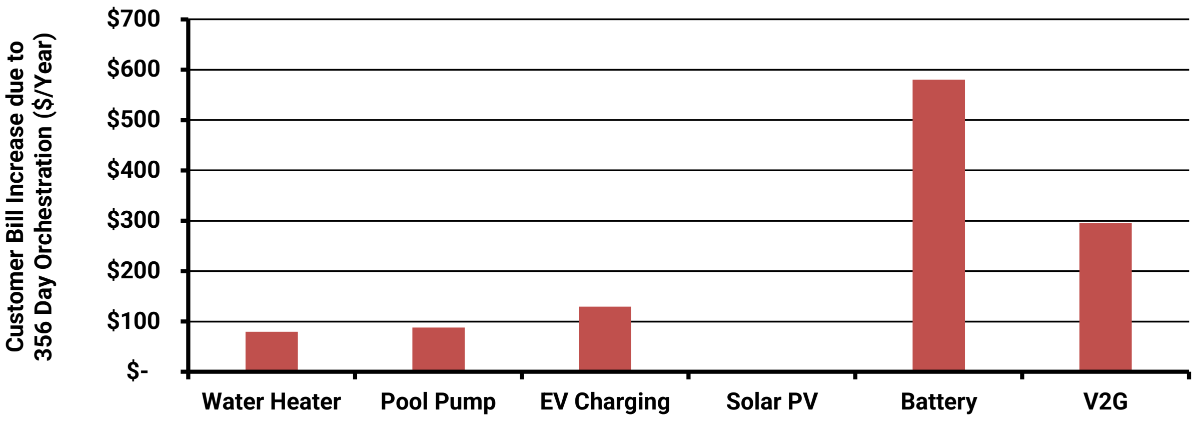
Consumer Impact Analysis

Energeia also modelled the non-economic wealth transfer impacts on participating consumers with CER from changes in the use of their devices for system benefits. This analysis is typically done to determine if any policy or regulatory changes could help mitigate these financial impacts, especially for vulnerable consumers.

For active consumers, the main wealth transfer Energeia identified and quantified was an increase in retail bills resulting from the use of a customer's CER for grid services relative to minimising their retail bill. In the absence of any other incentives, customers will use their CER flexibility to minimise their retail bill costs. However, if retail tariffs were cost-reflective, the best retail bill outcome for a customer would align to a customer using their CER flexibility to minimise their impact on the grid, for example, to reduce demand in the face of high wholesale prices or network peak demand.

The results of this wealth transfer analysis by CER type are shown for a small consumer in Figure ES4 assuming the same utilisation rate of 100% of days optimised to meet system needs. The results show this effect would have a significant impact on a CER consumer's retail bill. Flexible CER program offers will need to overcome these costs to attract participants.

Figure ES4 – Small Consumer Example Impact: Maximise System Benefits vs. Minimise Retail Bill



Source: Energeia

In practice, current VPP operation occurs at a far lower number of days due to consumer impact, pricing inefficiencies, and low margins on less optimal days. This is done to reduce the costs that flexible CER program operators will have to offer participants to get them to enrol.

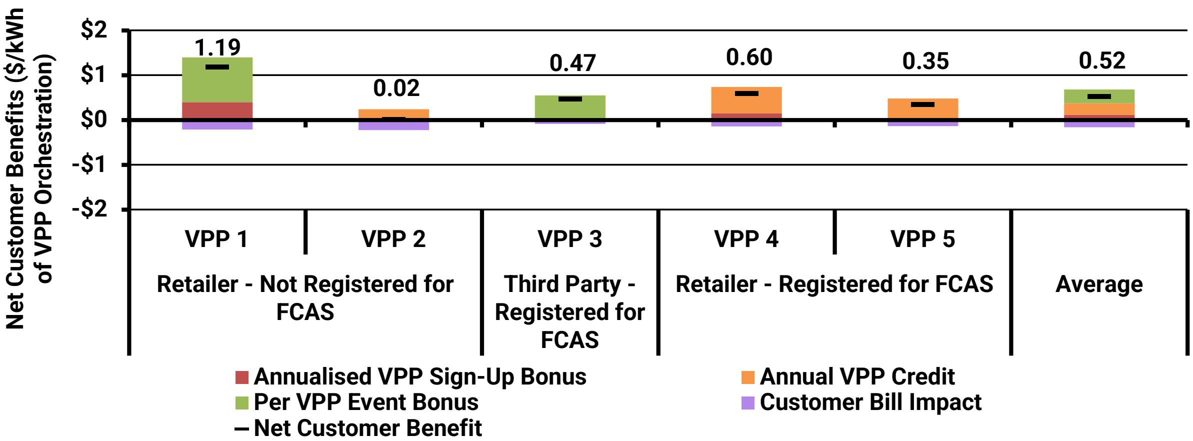
Current VPP Offers Passthrough Analysis

Energeia developed an analysis of existing VPP offers by retailers and third-party aggregators to determine the current pass-through value of existing VPP offers to demonstrate the net economic benefit to the consumer vs. the VPP operator due to CER flexibility.

Energeia modelled a case study of these VPPs by orchestrating a consumer's battery to the terms of the VPP and modelling the financial outcomes resulting from revenue generated, agreed pass-through of the value to consumers in sign-up bonuses, and ongoing participation credits.

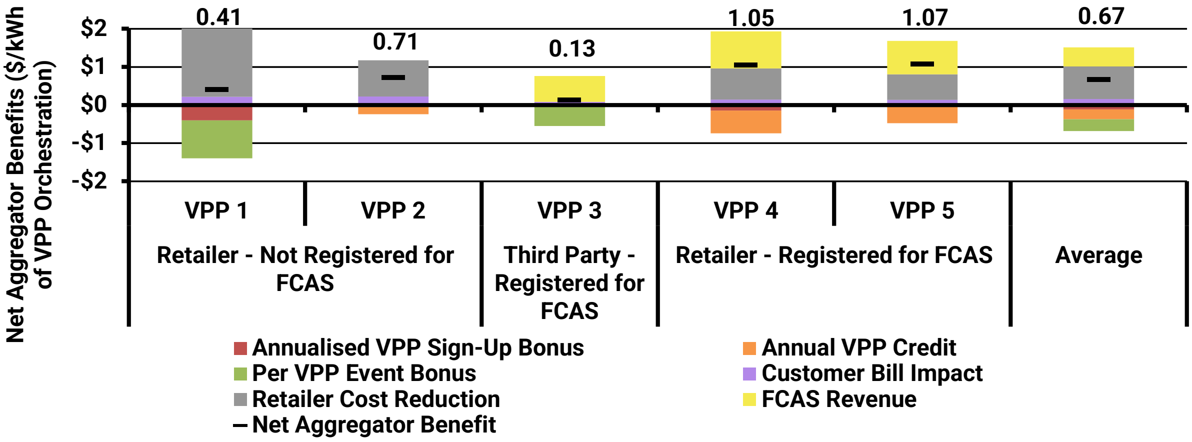
The results of the passthrough analysis are captured in Figure E5 and Figure E6, which show the VPP consumer and provider net benefits. The benefits were normalised on an energy basis (per kWh of battery charged/discharged by the VPP provider).

Figure ES5 – VPP Consumer Net Benefits by Offer



Source: Energeia

Figure ES6 – VPP Provider Net Benefits by Offer



Source: Energeia

Energeia found that, on average, 50% of the earnings associated with VPP operation would be passed through to the consumer, and the remaining 50% would be retained by the VPP provider, eventually flowing through to lower retail prices through competitive effects. Note the 50% passthrough estimate excludes any retail bill interactions, which are ultimately the result of inefficient pricing.

This estimate comes from the results showing that of the $1.36/kWh in total direct benefits that the average VPP provider generated from retailer cost reductions ($0.85/kWh) and FCAS markets ($0.51/kWh), $0.68/kWh was passed to the consumer through sign-up bonuses ($0.12), annual credits ($0.25), and per-event bonuses ($0.31).

Findings, Conclusions, and Recommendations

Based on our analysis, Energeia found that the total value of flexible CER modelled in this analysis resulted in $45B in NPV terms to 2050. Most of this value is expected to be generated by residential consumers, delivering over 80% of the total value in NPV terms. However, Energeia's modelling found that consumers who provide this value would currently be significantly negatively impacted on their retail bills on a net basis due to misalignment between actual system costs and retail tariffs. Energeia additionally notes that not all value streams are currently accessible by consumers, with market ancillary service specification (MASS)-compliant metering required for consumers to access FCAS value streams.

Energeia has developed the following recommendations based on the key findings of this analysis:

- **Ensure cost-reflective network and retail incentives:** Establishing cost-reflective network and retail prices allows for more efficient CER utilisation. Current retail tariffs lead to conflict between customer retail bills and system savings when enacting CER flexibility. This disincentivises optimal behaviour with respect to minimising total system costs without establishing wealth transfers such as VPPs to bridge the gap in pricing signals. Cost-reflective pricing would enable 100% flexible CER utilisation and maximise system benefits.
- **Level the playing field for third parties:** Currently, retailers have the upper hand in accessing the value of CER flexibility through existing access to the wholesale value. Allowing third-party aggregators equal access to these benefits will increase competition amongst flexibility service providers, generating additional value to consumers. Additionally, reform to encourage network service providers to better utilise CER to resolve growth-related constraints on the network would enhance the value of CER flexibility.
- **Remove barriers to using devices for MASS-compliant metering**: FCAS was found to be a key value driver for flexible CER in the early years of modelling but currently faces significant barriers to accessing this value within this timeframe, mainly due to metering requirements. Enabling the use of devices for MASS compliance, provided they meet operational requirements, would unlock access to the significant FCAS value stream.

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1. Background

This report aims to quantify how key consumer energy resource (CER) technologies can be utilised to provide system benefits. It also investigates the current impact optimised CER would have on consumer retail bills. Using CER flexibly to provide system benefits aims to provide lower-cost solutions for grid and market requirements, such as reducing network peak demand and providing energy into the wholesale market, to lower overall energy costs to all consumers.

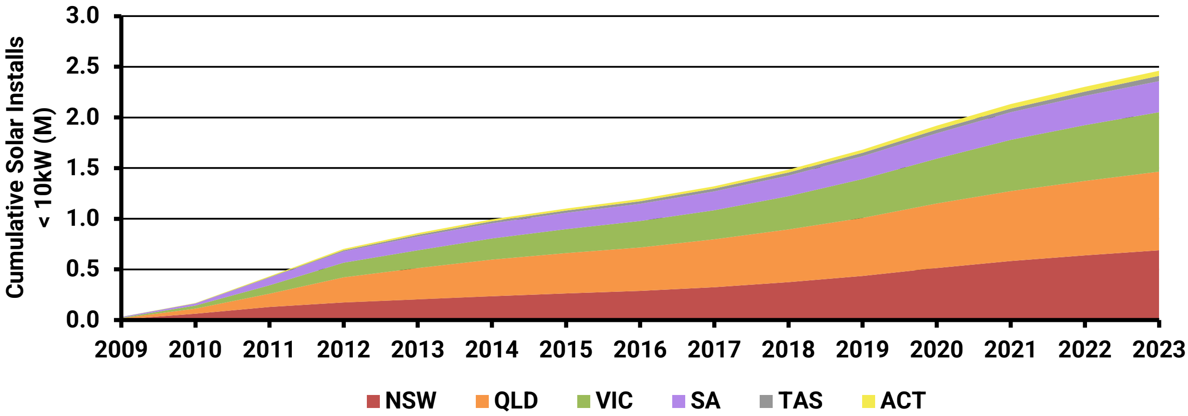
1.1. The Rise of Consumer Energy Resources and the Benefits of Flexibility

CER is a broad term that refers to flexible load and generation at consumers' premises (residential, small business, commercial, and industrial). The Australian Energy Market Commission (AEMC) defines CER assets to include rooftop solar panels, batteries, home and business energy management systems, pool pumps, electric vehicles EVs, and EV charging, as well as 'newer smart devices' such as hot water systems and traditional controlled hot water. For large customers, these can include heating and air conditioning (HVAC), on-site refrigeration, and on-site backup generation.[4]

The most impactful of these CER that is currently adopted on-masse in Australia is rooftop solar PV, with almost 2.5M households in the NEM having it installed on their dwelling as of December 2023, as shown in Figure 1 below. Rooftop solar is a technology that aims to reduce household energy usage and bills by using solar energy to power household appliances during the day and exporting excess energy to the grid.

Historically, falling rooftop solar prices have been paired with rising retail prices. These economic drivers have contributed to the strong uptake of rooftop solar amongst consumers, as shown in Figure 1 below. This demonstrates the appetite of consumers to actively control their electricity costs.

Figure 1 – Cumulative Uptake of Rooftop Solar PV by State



Source: Australian Photovoltaic Institute (APVI), Energeia Analysis

Over the last few years, advancements in other technologies have allowed consumers to join the ranks of rooftop solar to provide additional CER, such as batteries, electric vehicle charging (EVs) and smart appliances. Similar to rooftop solar, these technologies are becoming increasingly commonplace in the average, modern Australian household and thus can be utilised to support the grid and market.

The potential benefits of these resources can be seen outside of the impacts on the CER owner when they are effectively integrated into the system. Previous examples of modelling the benefits of CER

[4] AEMC, National Electricity Amendment (Unlocking CER benefits through flexible trading) Rule 2024 (2024), https://www.aemc.gov.au/sites/default/files/2024-08/Final%20determination%20-%20Unlocking%20CER%20benefits%20through%20flexible%20trading%20-%2015%20Aug%202024.pdf

have estimated the value of integrating these resources to be between $1B and $6.3B by 2030-2040.[5,6] Energy Networks Australia's (ENA's) Electricity Transformation Roadmap also highlighted that $16B in network infrastructure investment would be avoided by CER and distributed energy resource (DER) orchestration.[7] The 2024 Integrated System Plan (ISP) estimates that well-coordinated consumer batteries could avoid spending up to $4.1B on additional utility-scale storage in the National Energy Market (NEM) by 2050.[8]

Successful integration of CER means that:

1. Consumers can use their CER for their convenience (lifestyle) and optimisation (economics)
2. CER assets respond to price signals from the wholesale market or the distribution networks ("active CER"), thus securing additional revenue streams for their owner/user and operating in coordination with the power system's needs

To date, CER has largely operated independently of what is happening in the wholesale energy market or in relation to levels of congestion on networks. Currently, most CER is not signalled by the grid or market and/or is incapable of reacting to these market or network signals. In other words, CER assets are not always operated in coordination with the power system's needs.

1.2. Australia's Power System Reforms to Enable CER Integration

To support and enable CER integration, market bodies are driving a series of interrelated reforms. A CER Taskforce convened by energy ministers has developed a National CER Roadmap that defines and will help to drive the integration actions needed.

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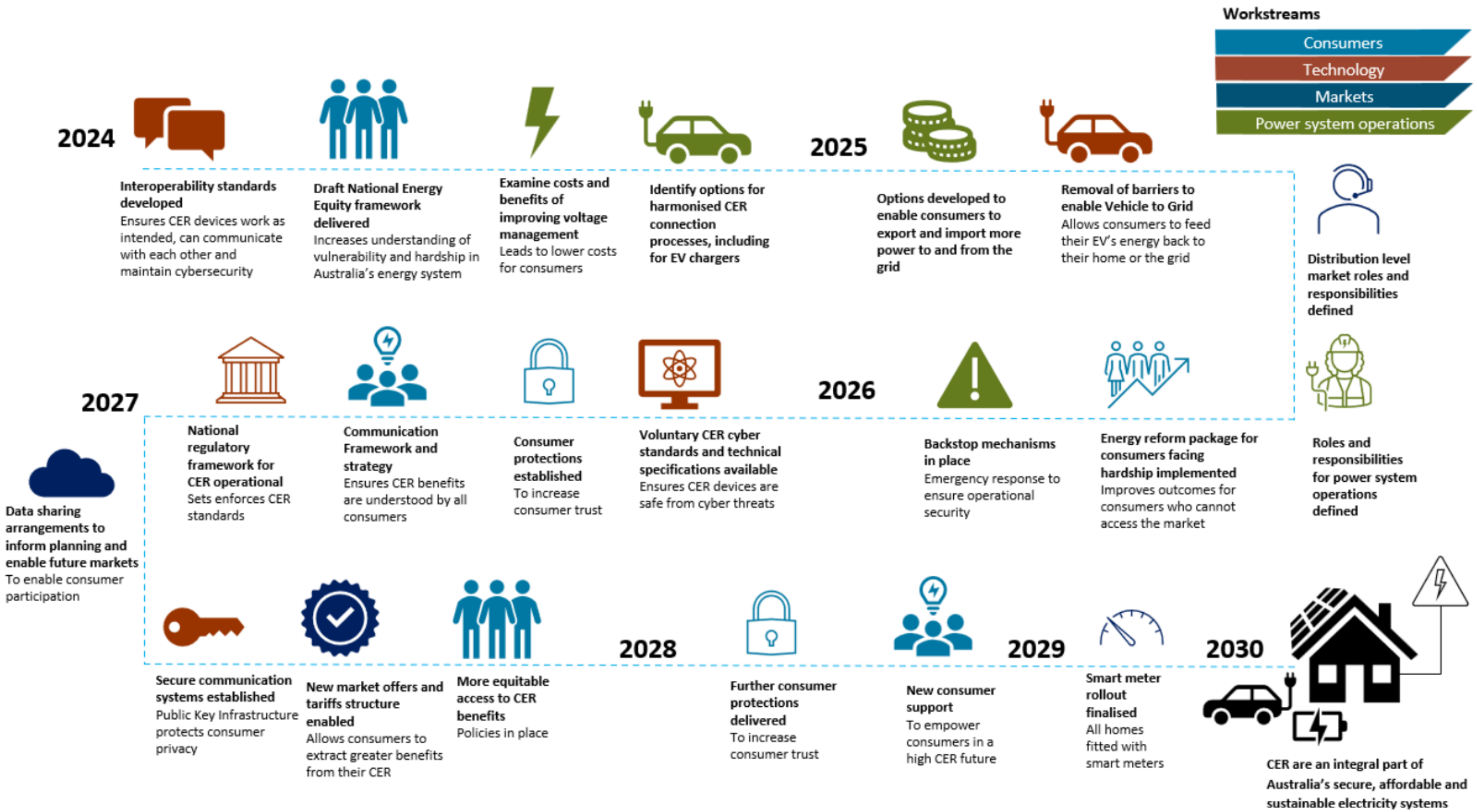
[5] Graham, P.W., Brinsmead, T., Spak, B. and Havas, L. 2019, Review of cost-benefit analysis frameworks and results for DER integration. CSIRO, Australia

[6] ARENA Load Flexibility Study Technically Summary (2022). https://arena.gov.au/assets/2022/02/load-flexibility-study-technical-summary.pdf

[7] ENA, Electricity Transformation Roadmap: Final Report (2017) https://www.energynetworks.com.au/resources/reports/electricity-network-transformation-roadmap-final-report/

[8] AEMO, 2024 Integrated System Plan (2024). https://aemo.com.au/-/media/files/major-publications/isp/2024/2024-integrated-system-plan-isp.pdf?la=en

Figure 2 – National Consumer Energy Resources Roadmap



Source: Department of Climate Change, Energy, the Environment and Water

At the time of publication, the AEMC and other market bodies are conducting rule changes and reviews that work towards to goal of enabling CER integration. This includes four AEMC rule changes and reviews:

- **Accelerating smart meter deployment** – This rule change[9] which focuses on providing consumers with the tools to manage their CER to save money and allowing CER to be used by the energy system.
- **Electricity pricing for a consumer-driven future** – This is a broad forward-looking review[10] aiming to address the important role that electricity pricing, products, and services will play in supporting the diverse needs of customers, including delivering the consumer energy resources (CER) necessary for the energy transition.
- **Integrating price-responsive resources into the NEM** – This rule change[11] which aims to enable greater integration of unscheduled price-responsive resources, such as community batteries and VPPs, in the wholesale market.
- **Real-time data for consumers** – This rule change[12] that aims to improve access to real-time data for consumers and their authorised representatives.

It is therefore in the interest of all key stakeholders in the energy industry to better understand the benefits that load flexibility can provide to the energy system.

[9] AEMC, Accelerating smart meter deployment (2024) https://www.aemc.gov.au/rule-changes/accelerating-smart-meter-deployment

[10] AEMC, Electricity pricing for a consumer-driven future (2024) https://www.aemc.gov.au/market-reviews-advice/electricity-pricing-consumer-driven-future

[11] AEMC, Integrating price-responsive resources into the NEM (2024) https://www.aemc.gov.au/rule-changes/integrating-price-responsive-resources-nem

[12] AEMC, Real-time data for consumers (2024) https://www.aemc.gov.au/rule-changes/real-time-data-consumers

2. Scope and Approach

This study explores how key CER technologies can be optimised to provide system benefits. It also investigates the current impact optimised CER would have on consumer retail bills. Using CER flexibly to provide system benefits aims to provide lower-cost solutions for market and grid requirements, such as reducing network peak demand and providing energy into the wholesale market, with the aim of lowering the overall costs of energy to all consumers.

2.1. Scope

The AEMC engaged Energeia to determine the incremental value of the most promising CER load flexibility options in terms of benefits to the electricity system and to consumers, considering an expected sharing of benefits across supply chain participants. The analysis aimed to estimate the total system benefits from the incremental flexibility of CER to 2050, as well as the associated retail bill impacts for consumers responding to the needs of the system.

The above analysis was conducted using a fit-for-purpose Microsoft Excel-based modelling tool that estimated the material costs and benefits of flexible CER for the system and consumers. The modelling included the most significant types of flexible loads and consumer segments which were outlined in the Methodology Report[13] across the NEM to 2050.

The sections below describe the approach in more detail.

2.2. Approach

Energeia worked closely with the AEMC to deliver the following scope and approach.

The key project steps included:

- Develop and Agree Upon Key Inputs, Assumptions, and Methodology
- Develop CER Flexibility Optimisation Tool
- Determine Allocation of Benefits
- Validate Reporting with Key Stakeholders

The following sections summarise each step.

Develop and Agree Upon Key Inputs, Assumptions, and Methodology

Energeia developed key CER flexibility modelling inputs and assumptions, including technical parameters, operational profiles, and adoption to 2050. Preliminary inputs and proposed methodology were documented in Energeia's Methodology Report and further developed and refined based on feedback as the project progressed.

The final inputs and modelling methodology are contained in Section 3.

Develop CER Flexibility Optimisation Tool

Energeia developed a CER flexibility model to estimate the impacts of retail bills and system costs, including wholesale, ancillary services, transmission, distribution, and carbon emissions. These outcomes were then extrapolated to a NEM-wide level using CER uptake and flexibility paths consistent with the consensus view of CER flexibility uptake.[14]

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[13] Energeia, Benefit Analysis of Load-Flexibility from Consumer Energy Resources: Methodology Report (2023), https://www.aemc.gov.au/sites/default/files/2023-08/CER%20Flexibility%20Modelling%20Methodology%20Paper%20-%20FINAL.pdf

[14] The consensus view referred to throughout this report considers Energeia's consolidation of respected industry publications, primarily the AEMO ISP Step Change Inputs and Assumptions (2023), the E3 Residential and Commercial Baseline Studies (2022), and the E3 'Smart' Demand Response Capabilities report (2022)

Determine Allocation of Benefits

Energeia researched and analysed current virtual power plant (VPP) offers to estimate the average level of CER utilisation and the impact on the consumer's bill of orchestration of CER to provide system benefits.

Validate Reporting with Key Stakeholders

Energeia presented the delivered research, analysis, and results to key AEMC stakeholders and revised them based on feedback received, before being documented in this report.

3. Value of Flexible Consumer Energy Resources

This analysis aimed to determine the incremental value of the most promising CER load flexibility options in terms of benefits to the electricity system and consumers, considering an expected sharing of benefits across supply chain participants. This analysis included three main workstreams that aimed to demonstrate the impact of CER flexibility within the NEM. The workstreams were:

- **Total System Benefits of CER Flexibility Analysis** – modelled the total system benefits accessible through entirely unlocking the CER flexibility under consensus forecast uptake, including the Australian Energy Market Operator's (AEMO's) 2023 Inputs and Assumptions Report (IASR)
- **Consumer Impact Analysis** –modelled the impact on a CER consumer's retail bill of operating their CER flexibly in response to NEM market drivers, including real-time wholesale pricing, FCAS value, and transmission and distribution
- **VPP Passthrough Analysis** – aimed to determine the current pass-through value of existing VPP offers to demonstrate the economic benefit to the consumer and the VPP operator of CER flexibility

The detailed methodology, inputs, and results of the above workstreams are outlined below.

3.1. <u>Total System Benefits of CER Flexibility Analysis</u>

The aim of modelling total flexibility potential in the NEM was to illustrate the potential benefits accessible from forecast uptake of CER flexibility in the NEM under an optimal state in which all regulatory barriers to flexibility have been removed.

3.1.1. Methodology

Methodology Report

The AEMC published Energeia's Methodology Report[15] which outlined the proposed methodology and subload selection criteria. The modelling in this report reflects the feedback Energeia received from the public consultation. A summary of feedback received, along with how it was addressed, is provided in Appendix A.

Methodology

The methodology of this stage included:

1. **Processing inputs** – data was collected and processed into inputs for the tool, including physical device characteristics, forecast device uptake, and price signals. All inputs were sourced from existing industry standard analysis (the consensus view of uptake). Section 3.1.2 shows and sources the key underlying inputs within the modelling.
2. **Determining "No Orchestration" State** – the "no orchestration" state was configured to represent the expected usage of CER to 2050 in which consumers operate with convenience behaviour patterns. Utilising the inputs collected, Energeia developed a consumption model that isolates subloads.[16] Consumer subloads under the no orchestration state were unoptimised (i.e., follow a convenience-based usage), except for bi-directional subloads (batteries and vehicle-to-grid [V2G]), which were simply operated to self-consume excess solar to immediately cover grid consumption following solar hours.

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[15] Energeia, Benefit Analysis of Load-Flexibility from Consumer Energy Resources: Methodology Report (2023), https://www.aemc.gov.au/sites/default/files/2023-08/CER%20Flexibility%20Modelling%20Methodology%20Paper%20-%20FINAL.pdf

[16] In this analysis, subloads refer to the energy consumption and demand of CER devices

3. **Determining the "Full Orchestration" State** – the "full orchestration" state was configured to capture the fully optimised use of the same volume of CER as the "no orchestration" state with the complete unlocking of all policies that enable CER flexibility, including:
    a. Pricing for a consumer-driven future
    b. Integrating price-responsive resources

    Using the existing subloads, the developed model fully orchestrated the participation of the flexible subloads to maximise value to the system, through:
    a. Wholesale market arbitrage
    b. Providing FCAS value
    c. Minimising consumption during transmission and distribution peak periods
    d. Maximising consumption during transmission and distribution minimum periods

    The loads were orchestrated within operational limits, including the rated power of the subload under orchestration. Electric vehicles (EVs), including V2G, have a further limitation of typical hours connected to a charger because smart charging cannot occur when an EV is not on the premises.

    Calculating System Benefits – total system benefits represent the total system value available by fully unlocking CER flexibility. System benefits were determined by determining the difference between the no orchestration and full orchestration states calculated at a daily level,[17] as shown in the equation below:

$$System\ Benefits_{Net} = \sum System\ Benefits_{Full\ Orchestration} - \sum System\ Benefits_{No\ Orchestration}$$

Calculation of system benefits included:

- Avoided wholesale energy purchase costs
- Captured FCAS value
- Avoided transmission and distribution network capital and operational expenditure
- Avoided emissions cost[18]

3.1.2. Inputs

This section outlines the scope of inputs utilised in this modelling, separated into CER flexibility modelling mechanisms and cost-benefit inputs.

CER Flexibility Modelling Mechanisms

The selection criteria for subloads included is outlined in Energeia's Methodology Report. The chosen segments for this analysis include:

- Residential
- Small Commercial
    - Offices
    - Retail
    - Accommodation

[17] Daily switching between optimisation algorithms was utilised due to processing abilities of Microsoft Excel

[18] Emissions are reported; however, they are not modelled as a driver of consumer behaviour

- Warehouses
- Health

- Large Commercial
  - As above for Small Commercial

It's important to note that upon discussion with the AEMC, industrial consumers were deemed out of scope and were not included in the large commercial segment, as they are already strongly involved in the market with regard to their flexibility (registered loads, etc.). Segments were iterated across all five NEM states to account for jurisdictional differences between energy usage by subloads.

The modelling mechanisms through which CER flexibility was considered for each load type are summarised in Table 1 and Table 2, for small and large consumers, respectively. They were intended to approximate what CER flexibility would look like in reality, rather than a complete strategy.

Table 1 – CER Flexibility Modelling Mechanisms: Small Consumers

<table>
<tr><th>Tech Type</th><th>No Orchestration</th><th>Time-of-Use Tariff Orchestration</th><th>Wholesale Price Orchestration</th><th>Tx Orchestration</th><th>Dx Orchestration</th><th>FCAS Orchestration</th></tr>
<tr><td>Storage Water Heater (100% power flexible)</td><td rowspan="4">Operates per base subload</td><td rowspan="3">Shifts all[2] retail tariff peak and shoulder period flexible consumption to retail tariff off peak period, daily</td><td rowspan="3">Shifts all flexible consumption from highest price to lowest price, daily</td><td rowspan="3">Shifts all flexible consumption out of the peak network period and into the minimum network period, defined as the top 0.3% peak/minimum demand hours on the network</td><td rowspan="3">Shifts all flexible consumption out of the peak network period and into the minimum network period, defined as the top 0.3% peak/minimum demand hours on the network</td><td rowspan="5">Flexible loads and generation bid into the highest value contingency market between 6 sec – 5 min for raise and lower, but does not change load behaviour from the optimal state</td></tr>
<tr><td>Pool Pump[1] (100% power flexible)</td></tr>
<tr><td>Level 2 EV Charger (availability varies by hour)</td></tr>
<tr><td>Solar (100% power flexible)</td><td>No orchestration</td><td>Curtailed when RRP < 0 $/MWh</td><td>No solar exports during the minimum period</td><td>No solar exports during the minimum period</td></tr>
<tr><td>Battery (100% power flexible)</td><td>Charges during excess solar and immediately discharges as soon as grid consumption is recorded. Does not export to the grid</td><td>Dispatches to cover grid consumption during the highest retail tariff period(s) of the day or until the battery is empty. Does not export to the grid</td><td>Charges during lowest RRP price intervals to fully charge the battery. Discharges during the highest RRP prices of the day to fully discharge the battery. Can export to the grid</td><td>Charges during network minimum period, discharges during network peak period to flatten demand. If neither occurs in a day, the battery performs bill minimisation behaviour. Can export to the grid</td><td>Charges during network minimum period, discharges during network peak period to flatten demand. If neither occurs in a day, the battery performs BaU behaviour. Can export to the grid</td></tr>
<tr><td>Vehicle to Grid (V2G) (100% power flexible,)</td><td colspan="6">Same logic as the battery, availability varies by hour.</td></tr>
</table>

Source: Energeia. [1]Pool pumps modelled only for residential premises, [2]Off-peak period assumed to have sufficient hours within which to recharge, Note: Tx = Transmission, Dx = Distribution, RRP = Regional Reference Price, BaU = Business as Usual

Table 2 – CER Flexibility Modelling Mechanisms: Large Consumers

<table>
<tr><th>Tech Type</th><th>No Orchestration</th><th>Time-of-Use Tariff Orchestration</th><th>Wholesale Price Orchestration</th><th>Tx Orchestration</th><th>Dx Orchestration</th><th>FCAS Orchestration</th></tr>
<tr><td>Storage Water Heater (100% power flexible)</td><td rowspan="4">Operates per base subload</td><td rowspan="3">Shifts all[3] peak and shoulder flexible consumption to off-peak periods, daily</td><td rowspan="3">Shifts all flexible consumption from highest price to lowest price, daily</td><td rowspan="3">Shifts all flexible consumption out of the peak network period and into the minimum network period, defined as the top 0.3% peak/minimum demand hours on the network</td><td rowspan="3">Shifts all flexible consumption out of peak network period and into minimum network period, defined as top as top 0.3% peak/minimum demand hours on network</td><td rowspan="5">Flexible loads and generation bid into the highest value contingency market between 6 sec – 5 min for raise and lower, but does not change load behaviour from the optimal state</td></tr>
<tr><td>Refrigeration[1] (100% power flexible)</td></tr>
<tr><td>Ventilation[2] (100% power flexible)</td></tr>
<tr><td>Solar (100% power flexible)</td><td>No orchestration</td><td>Curtailed when RRP < 0 $/MWh</td><td>No solar exports during the minimum period</td><td>No solar exports during the minimum period</td></tr>
<tr><td>Battery (100% power flexible)</td><td>Charges during excess solar and immediately discharges as soon as grid consumption is recorded Does not export to the grid</td><td>Dispatches to cover grid consumption during the highest period(s) of the day, or until the battery is empty Does not export to the grid</td><td>Charges during lowest RRP price intervals to fully charge the battery. Discharges during the highest RRP prices of the day to fully discharge the battery. Can export to the grid</td><td>Charges during network minimum period, discharges during network peak period to flatten demand. If neither occurs in a day, the battery performs bill minimisation behaviour. Can export to the grid</td><td>Charges during network minimum period, discharges during network peak period to flatten demand. If neither occurs in a day, the battery performs BaU behaviour. Can export to the grid</td></tr>
</table>

Source: Energeia. [1]Includes refrigeration units and freezers for cold storage, [2]Includes ventilation units and fans for maintaining air quality, [3]Off-peak period assumed to have sufficient hours within which to recharge

An explanation of the reasoning behind the technologies selected for inclusion in this study is available in Appendix A: Inclusion of Flexible Subloads.

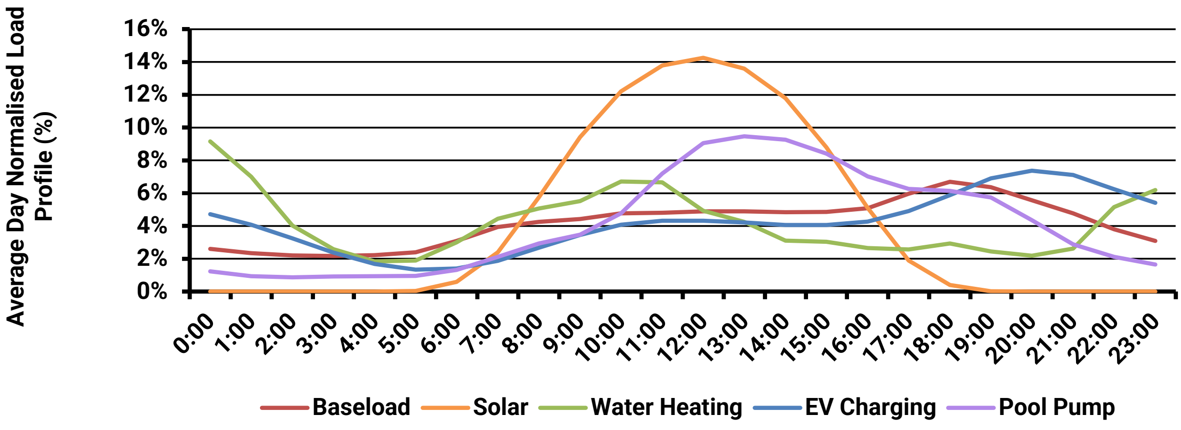
Subload Profiles

Appliance load shapes provided the timing of energy consumption of each CER before any load flexibility. The load shapes provided the foundation with which load shifting and shedding were modelled in this analysis.

The residential load profiles are sourced from the Residential Baseline Study,[19] and are shown in Figure 3 below.

[19] Energy Rating, Residential Baseline Study (2022), https://www.energyrating.gov.au/industry-information/publications/report-2021-residential-baseline-study-australia-and-new-zealand-2000-2040

Figure 3 – Average Day Residential Normalised Load Shape



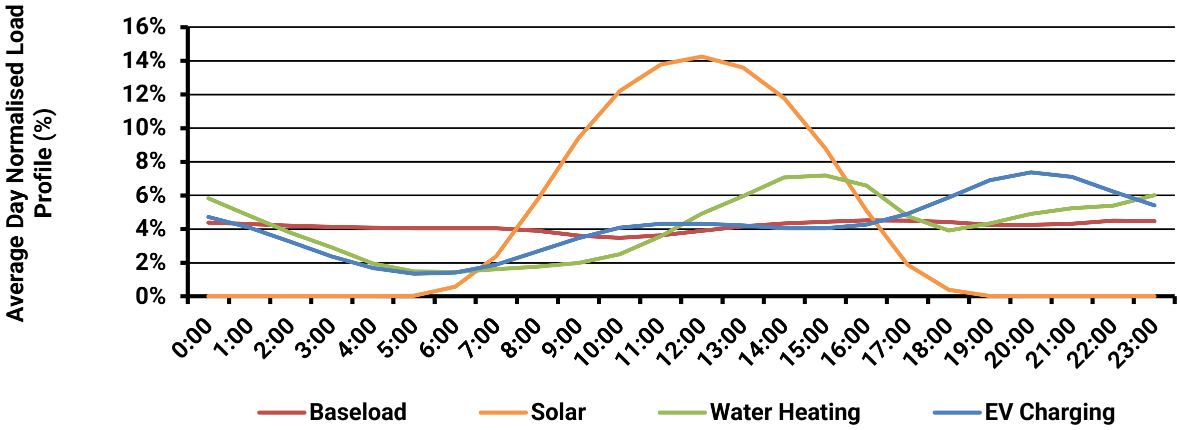
Source: Residential Baseline Study (2022)

The load shapes for small and large commercial water heating, refrigeration, and ventilation were adapted from end-use load profiles from the United States (U.S.) Building Stock data set developed by the National Renewable Energy Laboratory (NREL), mapped to 2022 capital city weather and seasonality for each NEM state considered and are shown in Figure 4 and Figure 5.

The process of climate matching Australian cities with a US city involved comparing several different climatic and economic factors, such as average temperature differential, average humidity differential, average daylight differential, average wind differential, average rainfall differential, average income, and average energy prices. These factors were compared across major US cities, and the city that matched most closely (i.e., that had the most factors with low amounts of difference) was taken forward.

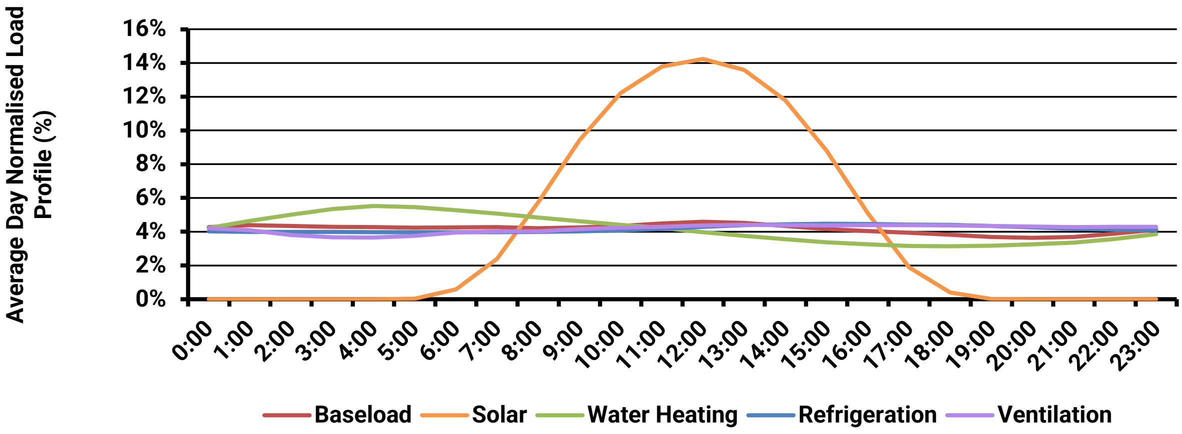
U.S. data was used because, to the best of Energeia's knowledge, no publicly available data exists on Australian subload consumption load shapes for commercial premises.

Figure 4 – Average Day Small Commercial Normalised Load Shape



Source: Commercial Baseline Study (2022), NREL

Figure 5 – Average Day Large Commercial Normalised Load Shape



Source: Commercial Baseline Study (2022), NREL

The solar photovoltaic (PV) load shapes were adapted from NREL's PV Watts tool for each capital city in each NEM state. The EV charging load shapes were sourced from the AEMO 2023 IASR. The convenience charging load shapes were taken forward for this analysis.

Annual Consumption and Capacity

The annual consumption inputs for each subload are shown in Table 3, Table 4, and Table 5, for the residential, small commercial, and large commercial segments. These consumption values are per premises and were used to scale the normalised consumer load profiles to a per premises level. In turn, the per premises profiles could then be scaled based on forecast CER and flexibility uptake by segment and state.

Table 3 – Residential Annual Consumption by Subload

Baseload (kWh)	Water Heating (kWh)	EV Charging (kWh)	Pool Pump (kWh)
4,011	996	2,240	1,099

Source: Energeia

Table 4 – Small Commercial Annual Consumption by Subload

Sub Segment	Baseload (kWh)	Water Heating (kWh)	EV Charging (kWh)
Offices	16,253	255	2,240
Retail	16,461	46	2,240
Accommodation	16,196	311	2,240
Entertainment	16,199	309	2,240
Warehouses	16,414	93	2,240
Health	16,225	322	2,240

Source: Energeia

Table 5 – Large Commercial Annual Consumption by Subload

Sub Segment	Baseload (kWh)	Water Heating (kWh)	Refrigeration (kWh)	Ventilation (kWh)
Offices	417,861	27,300	-	70,098
Retail	397,161	15,958	-	102,139
Accommodation	342,595	106,076	2,920	63,667
Entertainment	414,406	26,408	4,836	69,609
Warehouses	348,750	2,114	-	164,395
Health	375,987	64,490	1,039	73,743

Source: Energeia

For generation and storage devices, the capacities of each subload are shown by segment in Table 6. These were used to determine the generation and load-shifting capabilities of these CER devices.

Table 6 – Subload Capacities by Segment

Segment	Solar PV (kW)	Battery (kW/kWh)	V2G (kW/kWh)
Residential	7.5	5/10	5/5.83
Small Commercial	30	5/10	5/5.83
Large Commercial	100	75/150	-

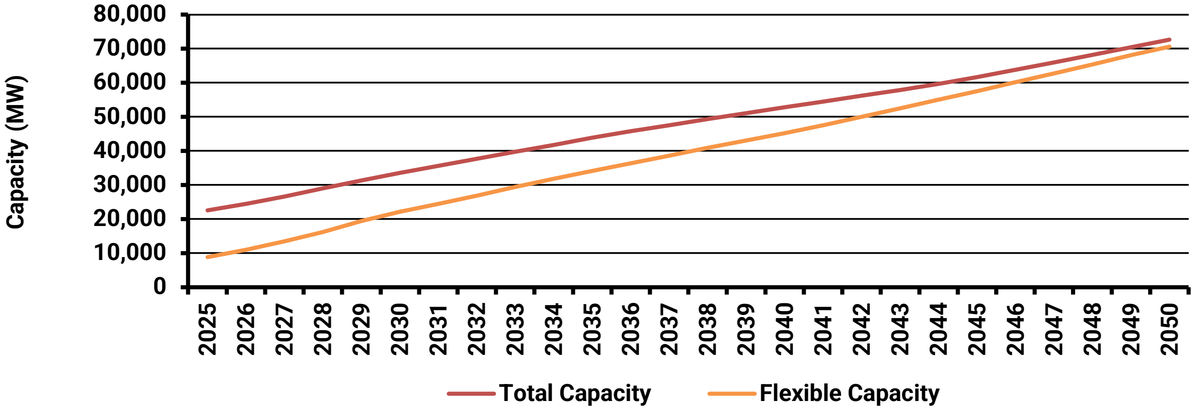
Source: Energeia
Note: Stationary battery and V2G capacities are dictated by export limits

CER and Flexibility Uptake Consensus View

The consensus view[20] uptake of flexible CER devices was used in the analysis to scale the consumer-level benefits calculated to the NEM-wide level and forecast these first order impacts out to 2050. Energeia developed flexible CER uptake profiles for all consumer segments considered in the analysis. However, for simplicity, the following section summarises these to the device level.

The total consumption and flexibility uptake curves for solar and battery technology, shown in Figure 6 and Figure 7, respectively, were collected from AEMO's 2023 IASR Step Change scenario to model flexible capacity uptake to 2050 as a percentage of total capacity. Flexible battery capacity is expected to grow to above 95% of total battery capacity by 2050 due to its inherently flexible load capability, allowing it to be quickly dispatched when called upon. Due to a lack of data on flexible solar capacity, flexible solar uptake was set to follow the flexible battery uptake rate. New solar PV inverters will have greater smart control, due to regulatory changes and the technology cost falling, making it effectively standard for new and replacement inverters.

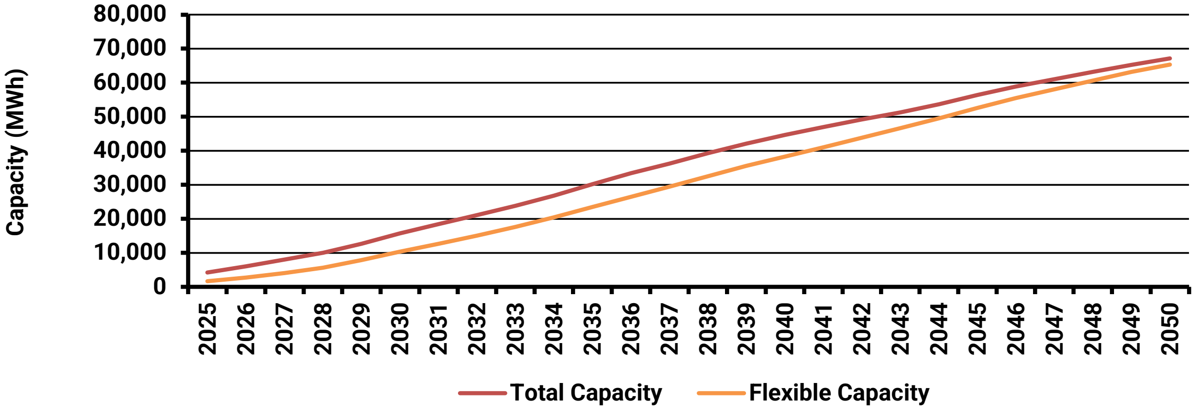
Figure 6 – Total Solar Capacity vs Flexible Capacity



Source: AEMO IASR (2023), Energeia

20 The consensus view referred to throughout this report considers Energeia's consolidation of respected industry publications, primarily the E3 Residential and Commercial Baseline Studies (2022), the AEMO ISP Step Change Inputs and Assumptions (2023), and the E3 'Smart' Demand Response Capabilities report (2022)

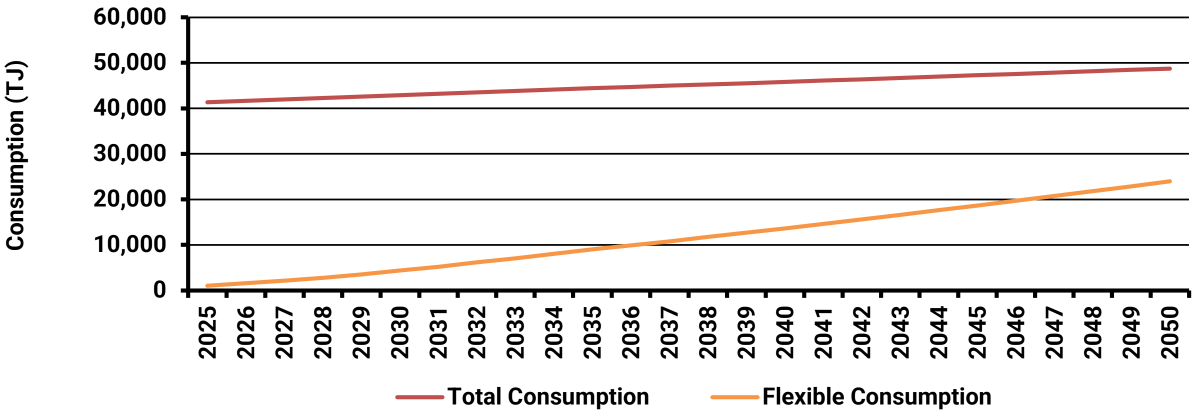
Figure 7 – Total Battery Capacity vs Flexible Capacity



Source: AEMO IASR (2023), Energeia

The total water heating consumption, shown in Figure 8, was collected for both residential and commercial premises from the Energy Rating Residential Baseline Study[21] and DCCEEW Commercial Baseline Study,[22] respectively, and modelled out to 2041, with the remaining years trended to 2050. The flexible water heating uptake rate came from the E3 Demand Response Capabilities report[23] and was modelled to 2036, with the remaining years trended to 2050.

Figure 8 – Total Water Heating Consumption vs Flexible Consumption



Source: Energy Rating Residential Baseline Study (2022), E3 Report (Gov Energy rating) (2019), Energeia

Total pool pump consumption, shown in Figure 9, was collected from the Residential Baseline Study and modelled out to 2041, with the remaining years trended to 2050. The flexible pool pump uptake rate also came from the E3 Demand Response Capabilities report and was modelled to 2036, with the remaining years being trended to 2050. Pool pump consumption had the highest uptake percentage of flexible load compared to all other technologies. It is one of the easiest to integrate with demand

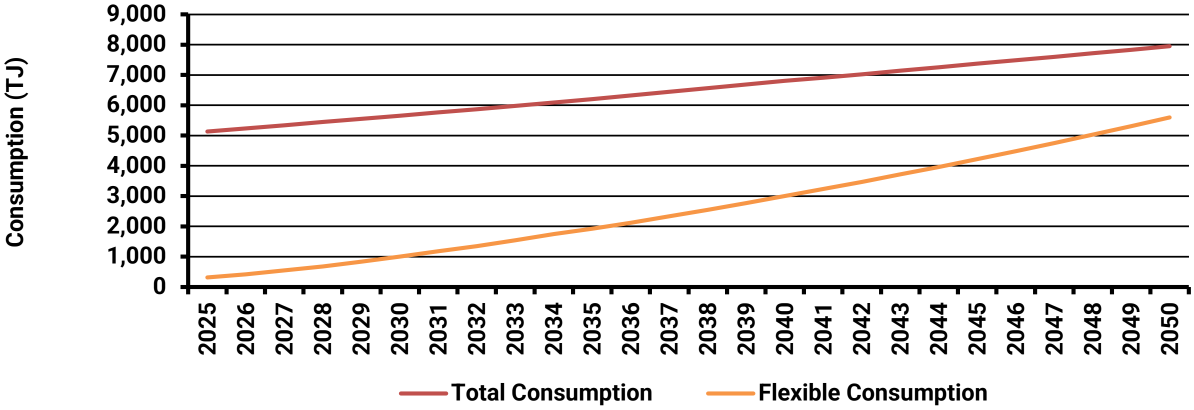
[21] Energy Rating, Residential Baseline Study (2022), https://www.energyrating.gov.au/industry-information/publications/report-2021-residential-baseline-study-australia-and-new-zealand-2000-2040

[22] DCCEEW, Commercial Baseline Study (2022), https://www.dcceew.gov.au/energy/publications/commercial-building-baseline-study-2022

[23] Equipment Energy Efficiency, Regulation Impact Statement for Decision: 'Smart' Demand Response Capabilities for Selected Appliances (2019), https://www.energyrating.gov.au/sites/default/files/2022-12/smart_appliance_decision_ris.pdf

response programs due to its ability to be scheduled to run during off-peak hours. Pool pump consumption was collected only for residential premises.

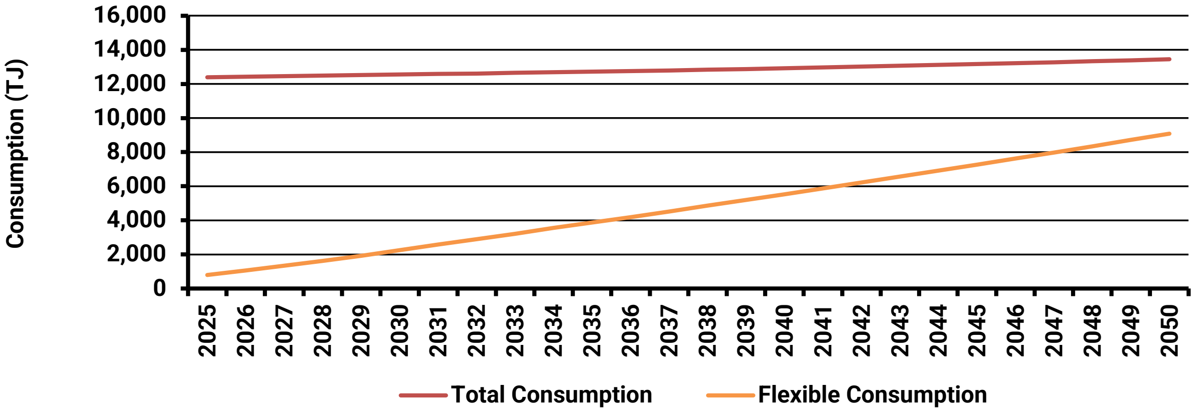
Figure 9 – Total Pool Pump Consumption vs Flexible Consumption



Source: Energy Rating Residential Baseline Study (2022), E3 Report (Gov Energy rating) (2019), Energeia

The CER flexibility uptake curves for refrigeration and ventilation consumption, shown in Figure 10 and Figure 11, respectively, were also collected from the E3 Demand Response Capabilities report and modelled out to 2036, with the remaining years trended to 2050. Total commercial consumption for ventilation and refrigeration was collected from the Commercial Baseline Study[24] to 2041, with the remaining years being trended to 2050. Flexible ventilation consumption is shown to reach around 73% in 2050. Refrigeration was assumed to follow the same uptake curve as ventilation, due to its similar constraints and consumption profile, as well as a lack of publicly available data. These loads were considered only for large commercial premises.

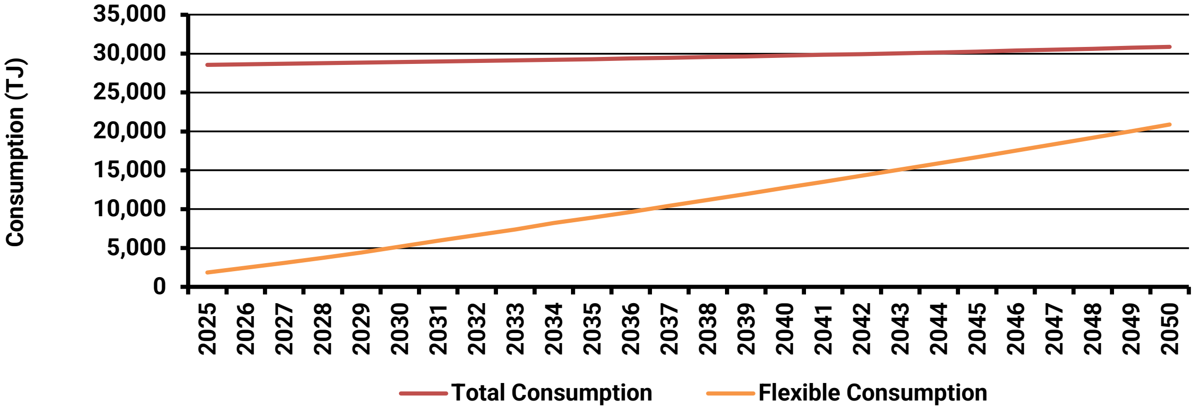
Figure 10 – Total Refrigeration Consumption vs Flexible Consumption



Source: DCCEEW Commercial Baseline Study (2022), E3 Report (Gov Energy rating) (2019), Energeia

[24] DCCEEW, Commercial Baseline Study (2022), https://www.dcceew.gov.au/energy/publications/commercial-building-baseline-study-2022

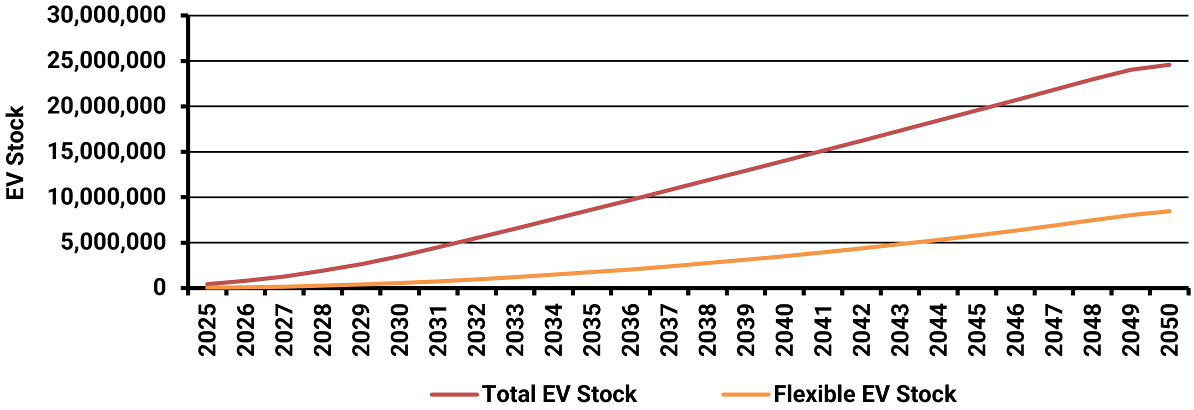
Figure 11 – Total Ventilation Consumption vs Flexible Consumption



Source: DCCEEW Commercial Baseline Study (2022), E3 Report (Gov Energy rating) (2019), Energeia

The vehicle stock uptake for EVs, shown in Figure 12, was gathered from AEMO's 2023 IASR Step Change scenario to model total and flexible EV stock uptake to 2050. Flexible EV stock reaches only 36% of total stock, with the assumed flexibility uptake derived from the E3 Demand Response Capabilities report. Despite this low percentage uptake in flexible EV stock, a load flexibility study published by the Australian Renewable Energy Agency (ARENA)[25] determined that flexible charging of EVs, whether through deferred charging or V2G services, remained the most utilised source of load flexibility. Energeia notes that the IASR/ISP has a 'coordinated charging' cohort of EVs in its forecasts. However, it does not include a typical usage profile for coordinated charging as it is flexible.

Figure 12 – Total EV Stock vs EV Charging Flexible Stock

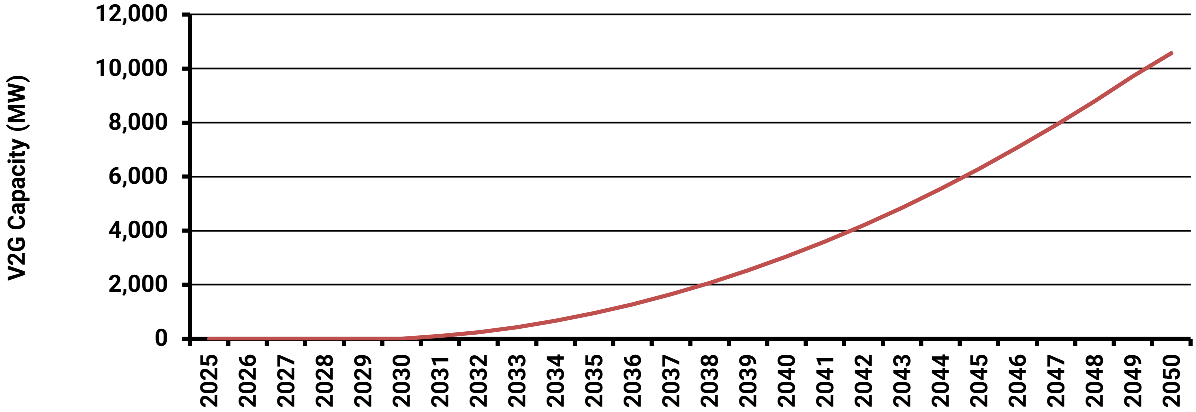


Source: AEMO IASR (2023), Energeia

Data on V2G capacity, illustrated in Figure 13, was similarly collected from AEMO's 2023 IASR Step Change scenario, and shows V2G growing sharply from post-2030 to beyond 10GW by 2050. All V2G capacity was assumed to be flexible.

[25] ARENA, Load Flexibility Study Technical Summary (2022), https://arena.gov.au/assets/2022/02/load-flexibility-study-technical-summary.pdf

Figure 13 – V2G Total Capacity



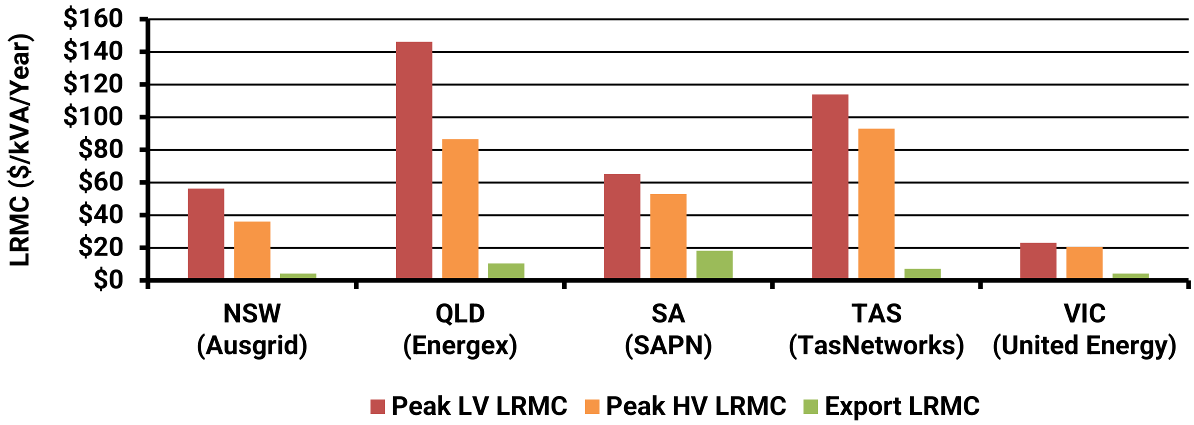
Source: AEMO IASR (2023), Note, that all V2G capacity is assumed to be flexible

Network Long-Run Marginal Cost

Network long-run-marginal cost (LRMC) denotes the annualised cost for a network to host an incremental unit of demand. Network LRMC inputs were used to determine the cost impacts of flexible operation on distribution and transmission networks. For each NEM state, Energeia selected a relevant distribution network service provider (DNSP) and transmission network service provider (TNSP) to represent that state in the modelling.

Energeia sourced peak demand distribution network LRMCs directly from DNSP Tariff Structure Statements (TSS) published on the AER's website. Export LRMCs were taken forward from a previous Energeia analysis for AEMO, which forecast a bottom-up cost estimation of the least-cost pathway to resolve voltage insufficiency caused by hosting solar PV on the distribution low-voltage (LV) network for each DNSP in the NEM. These values are shown in Figure 14.

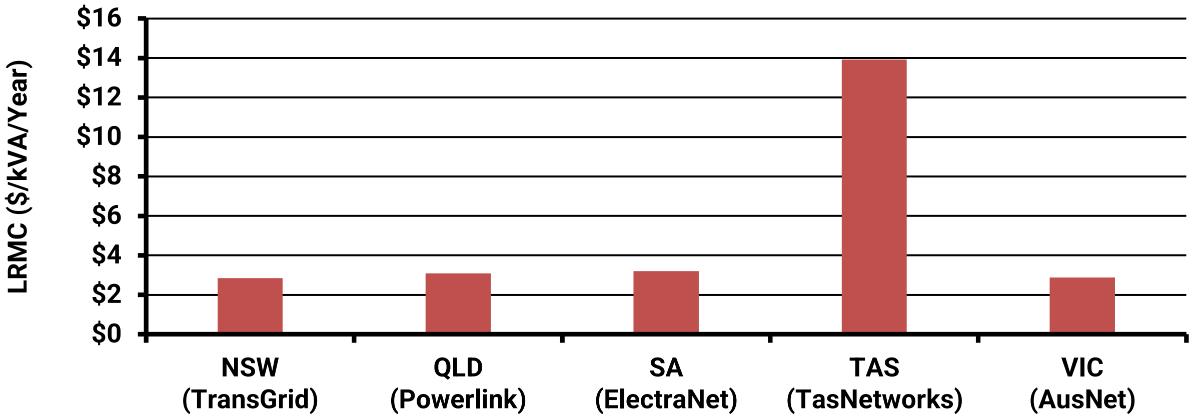
Figure 14 – Distribution Network LRMC Inputs



Source: AER (2023), Ausgrid (2019), Energex (2022), SAPN (2021), TasNetworks (2022), United Energy (2021), Energeia

As TNSP LRMCs are not published, they were estimated for this analysis. To cost the load hosting capacity-driven expenditure, Energeia observed the relationship between each TNSP's stated replacement and augmentation expenditure requirements and their stated annual peak demand to develop an LRMC estimate in $/kVA/year. These values are shown in Figure 15.

Figure 15 – Transmission Network LRMC Inputs



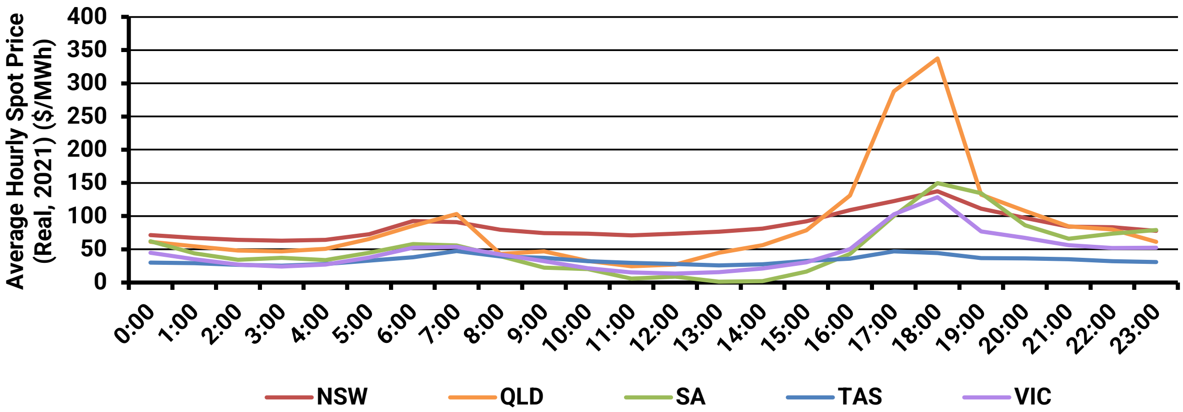
Source: AER (2023), TransGrid (2019), Powerlink (2022), ElectraNet (2021), TasNetworks (2022), AusNet (2021), Energeia

Wholesale Costs and Forecast

The electricity wholesale RRPs at hourly intervals were used in the model to value the impact of load flexibility on the wholesale market by moving a load from higher-priced time intervals throughout a given day to lower-priced time intervals.

Energeia applied wholesale cost input data from 2021. This allows for the typical variation of prices to be incorporated, while avoiding non-typical market occurrences, such as the 2022 spot market suspension. The average annual hourly spot market price can be seen in Figure 16.

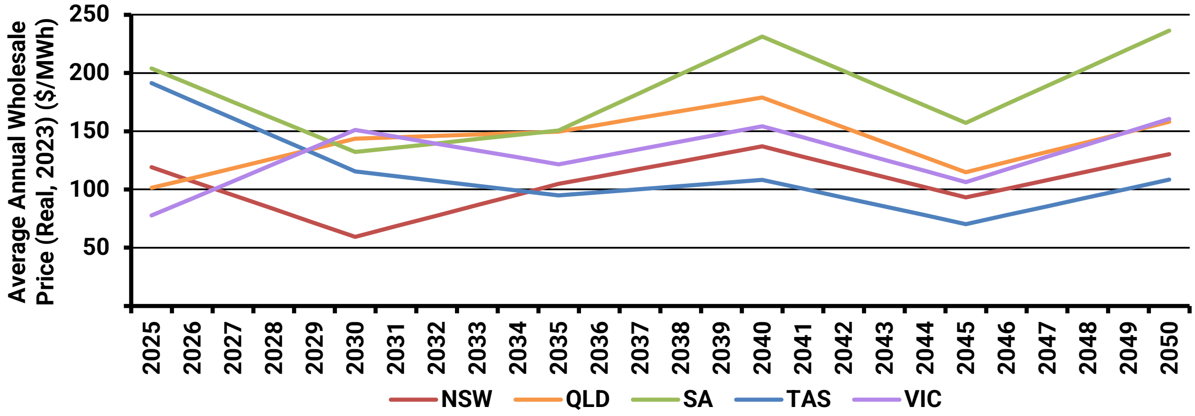
Figure 16 – Average 2021 Hourly Spot Price ($/MWh)



Source: AEMO (2021), Gorman et al. (2018)

Energeia scaled the 2021 hourly prices over the year across the forecast period to 2050 using a forecast provided by the AEMC. The projected change in wholesale price can be seen below in Figure 17.

Figure 17 – Forecast Annual Average Spot Price ($/MWh)



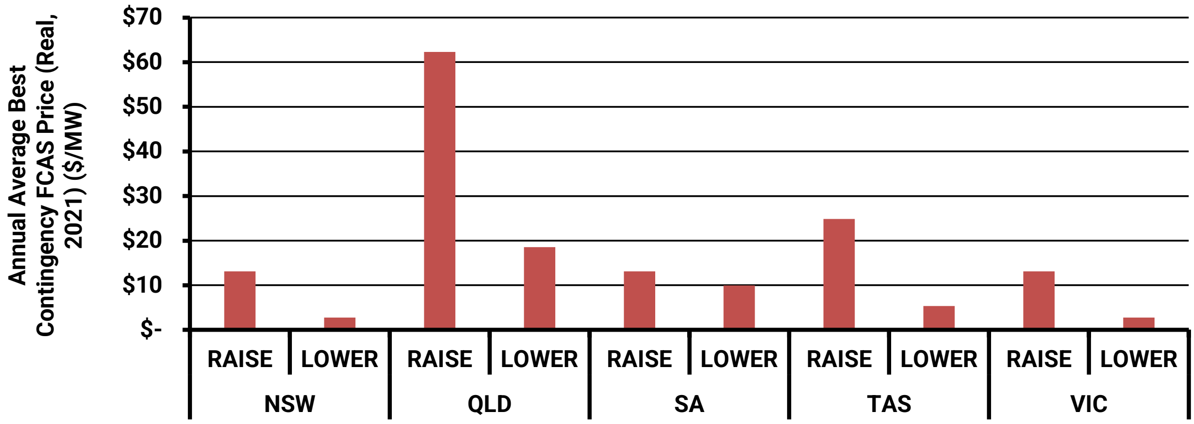
Source: AEMC

FCAS Costs

Contingency FCAS pricing at 30-minute intervals was used in the model to value the impact of load flexibility by using the spare capacity of a CER at a given interval to make it available to the highest-valued market.

As with wholesale costs, Energeia based its FCAS analysis on 2021 prices to minimise the impact of the market shutdown. Prices were collected for each state for the 6-second, 60-second, and 5-minute contingency raise and lower markets. The highest raise and lower prices across these markets were calculated for each 30-minute interval by state, as the best use-case option for FCAS capacity. Figure 18 shows the annual average of these best prices by state.

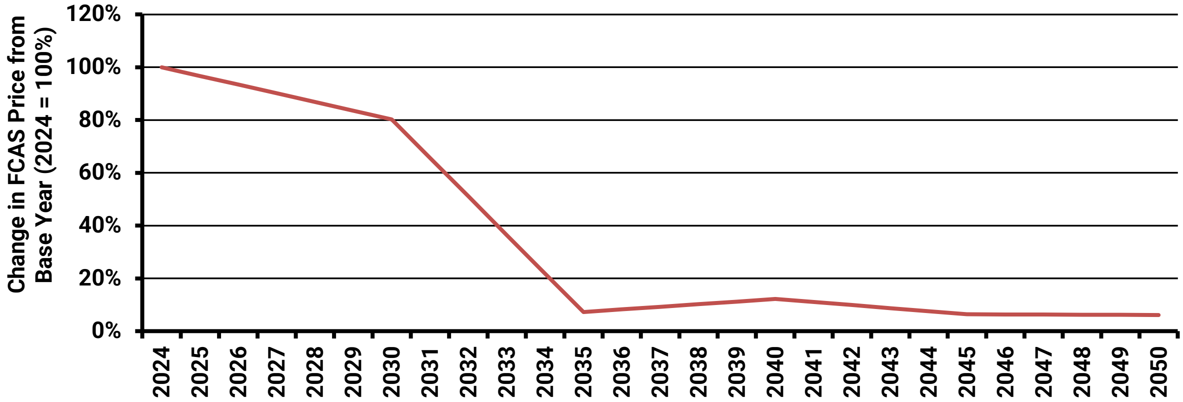
Figure 18 – Annual Average Best Contingency FCAS Price by State (2021)



Source: AEMO (2021), Gorman et al. (2018)

Forecast FCAS prices are scaled, similarly to wholesale prices, using a forecast provided by the AEMC developed for the Integrating Price Responsive Resources rule change (IPRR). The projected change in FCAS price can be seen below in Figure 19 below.

Figure 19 – Forecast FCAS Price Trajectory



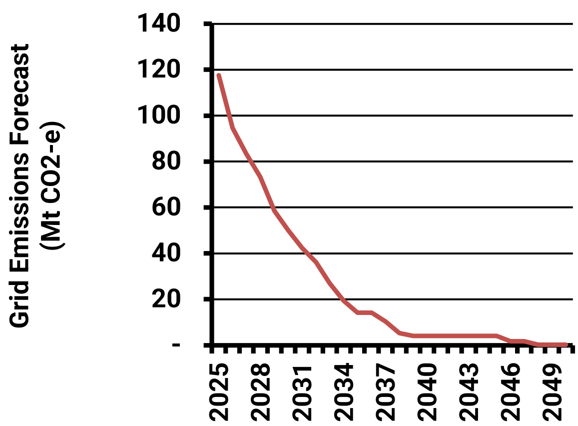
Source: AEMC

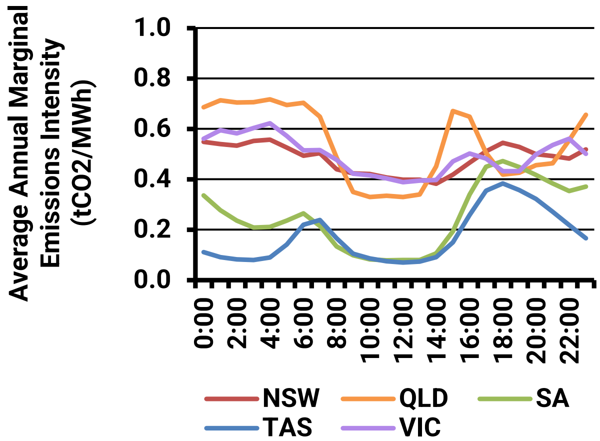
Value of Emissions Reductions and Forecast Grid Emissions

The calculated volume of emissions in the NEM within the modelling was determined by the change in the import or export[26] from the premises in a given state, multiplied by the grid emissions factor by hour and year. The value of emissions reduction increases over time at a moderate rate, as opposed to the overall decarbonisation of the grid.

Figure 20 below demonstrates the change in emissions intensity by hour[27] and by year utilised in the modelling. This accounts for the change in emissions intensity by hour and overtime to 2050.

Figure 20 – Grid Emissions Forecast (Left) and Marginal Hourly Emissions Factor (Right)





Source: AEMO IASR 2023 (Left), Energeia (Right)
Note: CO2e = Carbon Dioxide equivalent

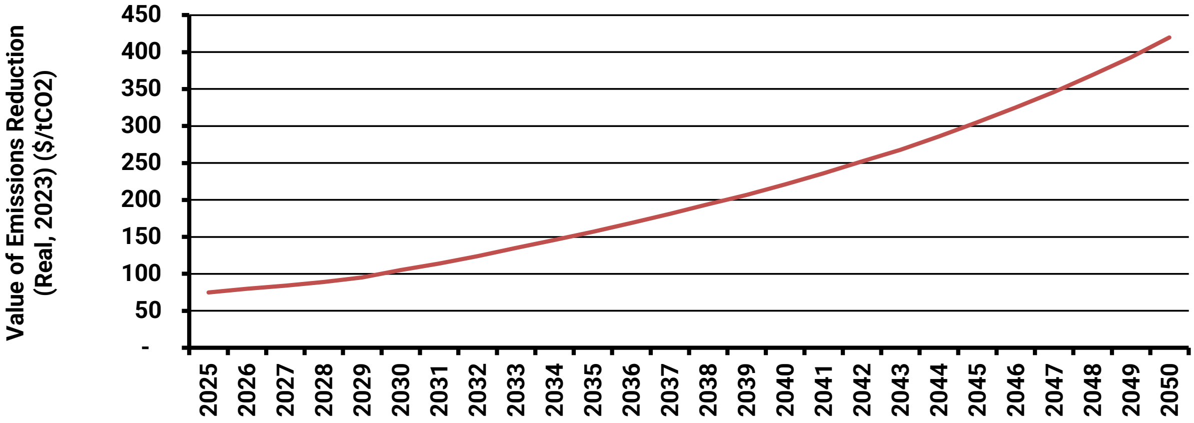
The value of emissions reductions, shown in Figure 21, increases over time and is based on an interim methodology established by the Ministerial Council on Energy (MCE).[28] This input was used to price the system benefits of reducing emissions.

[26] Export from a premises can include solar generation, or exports from batteries or V2G

[27] A yearly emissions profile is used to account for seasonality of emissions.

[28] AEMC, MCE statement about the interim value of greenhouse gas emissions reduction (2024), https://www.aemc.gov.au/sites/default/files/2024-04/MCE%20statement%20on%20interim%20VER.pdf

Figure 21 – Carbon Emissions Reduction Value ($/tCO2e)



Source: MCE (2024)

3.1.3. Results

This section outlines the modelling results, with two key focus areas: the total accessible value of completely unlocked CER flexibility to consumers and the impact of the operation of these resources to consumers under current retail tariff offerings.

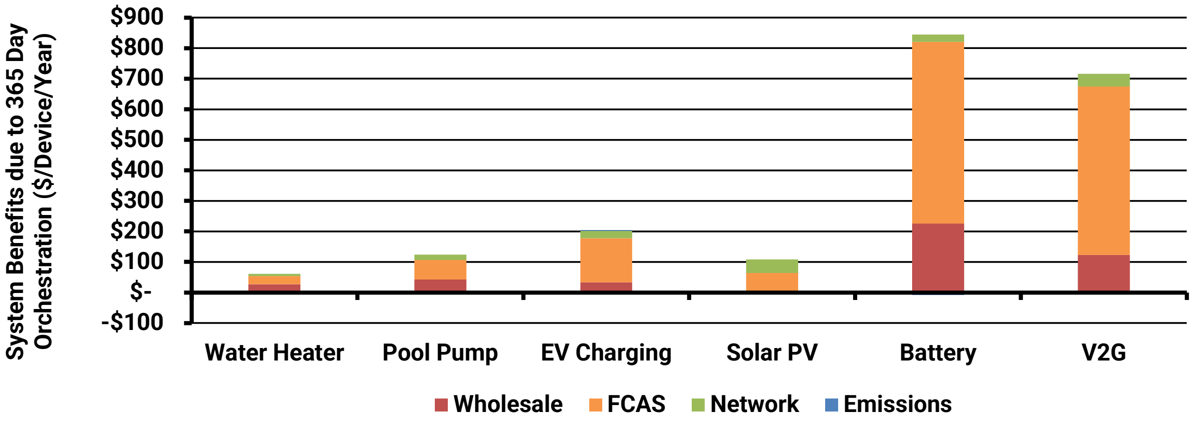
System Benefits per Device

Energeia's initial analysis determined the maximum potential system benefits accessible in the first year modelled through the complete unlocking of CER flexibility for each representative consumer considered, compared to no load orchestration. For simplicity, the result from this analysis is shown in Figure 22 and Figure 23 for a representative small and large consumer in the base year modelled, respectively.

The findings demonstrate that the size of the load strongly correlates to the amount of value it can provide. Batteries provide large system benefits across small and large consumers consistently.

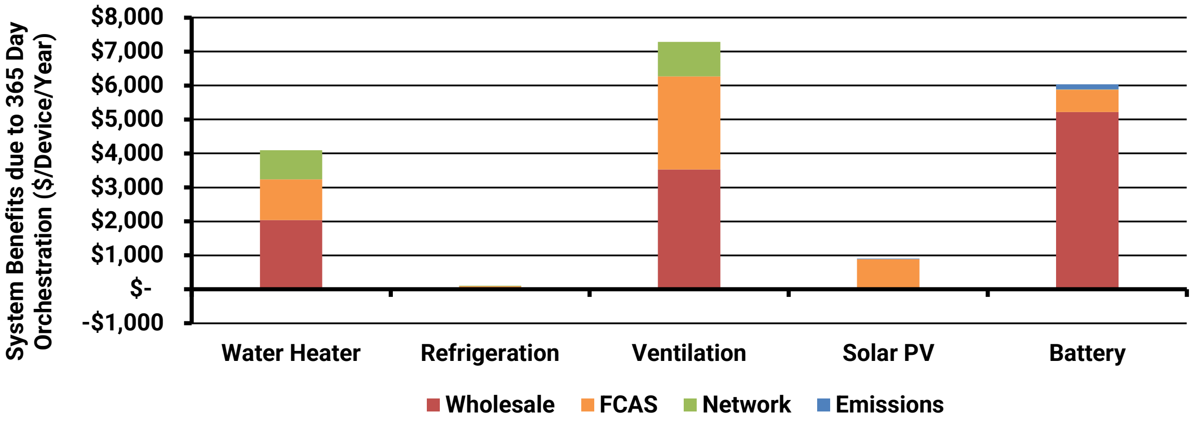
The customer case study results show a large value stream from FCAS revenue in the base year; however, this is a result of the current volatility of FCAS prices. The change in value stream outcomes is discussed further in the following sections.

Figure 22 – Annual System Benefits per Device (NSW Residential Consumer Example)



Source: Energeia, Small customer battery assumed to be 10kWh

Figure 23 – Annual System Benefits per Device (NSW Large Health Consumer Example)



Source: Energeia.
Note: Large commercial battery assumed to be 150kWh

Energeia applied these consumer benefits to the system and scaled them out to 2050 according to the level of expected CER and flexibility uptake.

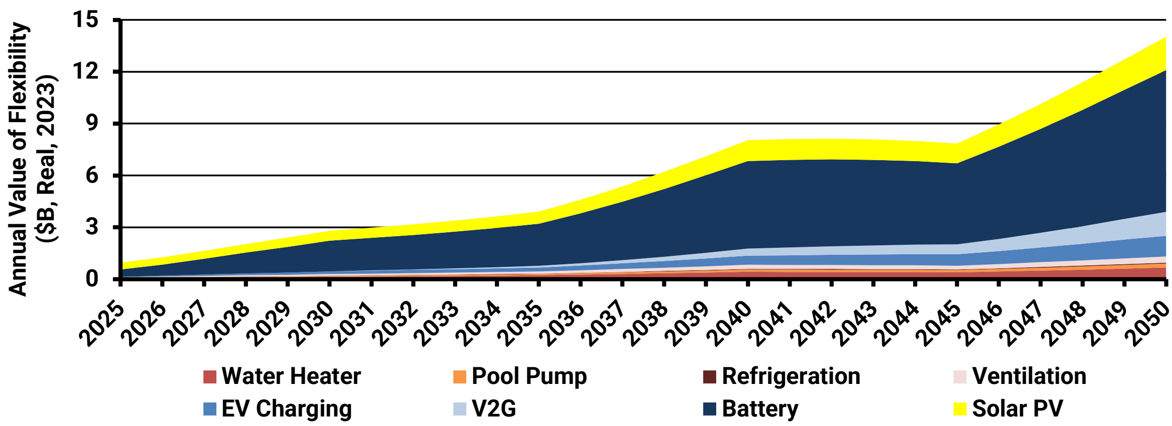
Annual System Benefits by Subload

Energeia then extrapolated this initial analysis to the NEM to determine the total system benefits accessible through the complete unlocking of CER flexibility. This analysis provides a macro perspective on the total potential value of CER, assuming all barriers to optimal system behaviour were unlocked.

This analysis found that $14B of system benefits could be achieved annually by unlocking all CER flexibility by 2050, assuming CER acts to minimise total system costs by participating in wholesale and frequency control ancillary service (FCAS) markets, and network demand response. These benefits total $45B in net present value terms, assuming a 7% discount rate. The magnitude of benefits was calculated relative to the case in which all CER acts to maximise the owner's self-consumption or convenience, with no consideration for the wider system or their retail tariff.

Figure 24 displays the annual system benefits broken down by CER type. Analysis showed that batteries are the expected key driver of potential benefits, accounting for 60% of all accessible value. EVs also are expected to be key drivers, through both charging and V2G capabilities.

Figure 24 – Annual System Benefits by Subload



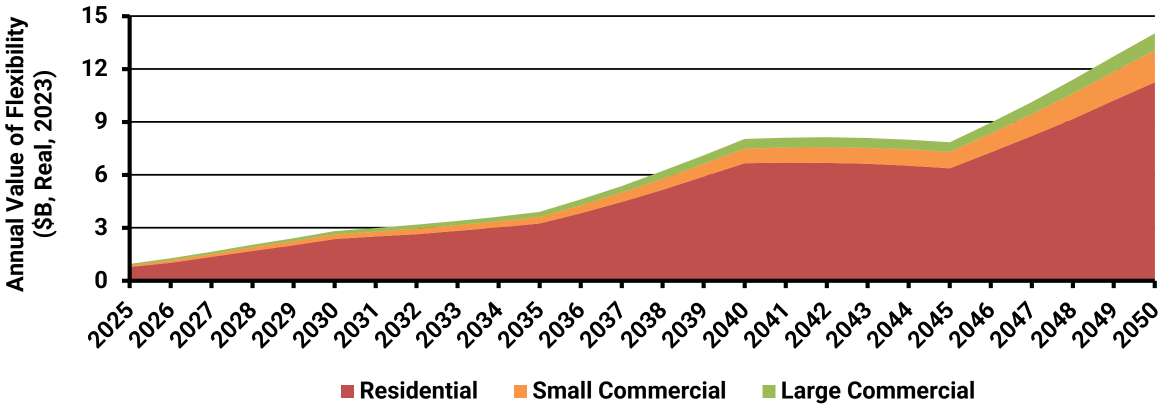
Source: Energeia

It is important to note that while the uptake of flexible CER was assumed to be increasing throughout the forecasting period, the flattening of the total system benefits forecast observed in the early 2040s is driven by falling wholesale prices, while FCAS market prices and network LRMC remain steady.

Annual System Benefits by Consumer Class

Our analysis of benefits by consumer class showed that residential consumers gain the most significant share of potential benefits, as shown in Figure 25. Residential consumers are forecast to have higher levels of flexible CER uptake given the number of consumers in the segment, compared to other consumer classes, despite devices having lower capacities.

Figure 25 – Annual System Benefits by Consumer Class



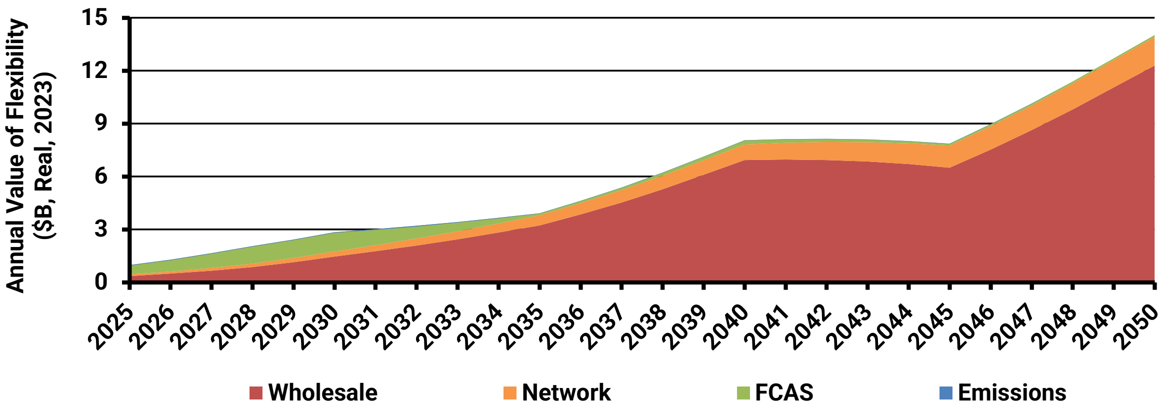
Source: Energeia

Annual System Benefits by Value Stream

Figure 26 highlights the different system value streams that contribute to the total accessible benefits. The wholesale market accounts for most of the value over the long term, which is a byproduct of increasing market volatility.

Network value contributed the second largest value stream, predominantly composed of distribution peak demand benefits. FCAS benefits are the highest value stream in the base year modelled and maintain their majority share over the early years; however, these benefits are expected to taper significantly by 2035 due to an oversupply of FCAS supply resulting in a drop in overall market value. The value of emissions reductions is included; however, it constitutes a small portion of the total cost to the system.

Figure 26 – Annual System Benefits by Value Stream



Source: Energeia

Emissions Outcomes of Full CER Flexibility

The following analysis shows the estimation of emissions impacts of operating CER flexibly to provide value to the wholesale market and transmission and distribution networks. The outcome of this modelling can be seen in Figure 27. The results show that, overall, flexibility in the NEM is modelled to cause an increase in emissions compared to un-orchestrated CER when considering the same installed capacity, due to the curtailment of solar in an electricity network that is not fully decarbonised.

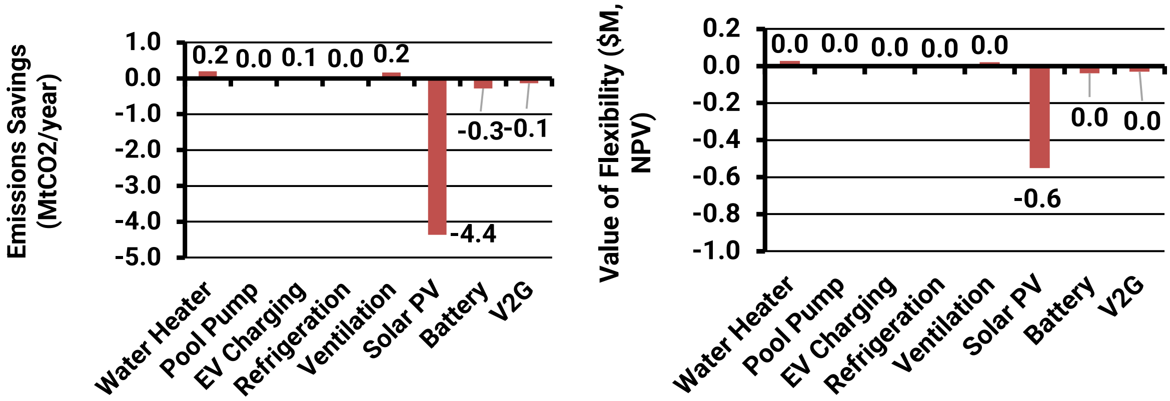
This result predominantly stems from the curtailment of solar PV when wholesale prices fall below $0/MWh, during which a portion of the current fleet of fossil fuel generators still run at minimum levels to avoid shutdown and restart costs. Hence, curtailing available solar generation and requiring a consumer's baseload demand to be served by grid energy has a net negative emissions outcome against the No Orchestration scenario. This increase in emissions is also, in part, due to a limitation of the first-order modelling that does not account for the impact of no curtailment of solar to the wider grid, as seen in the no orchestration state. As solar generation exceeds the capabilities of the network, management of solar exports must be undertaken to ensure that the grid is not depleted.

Small negative emissions impacts are also shown for battery and V2G subloads due to the assumption of customer behaviour before grid flexibility is implemented.

Battery behaviour before the system orchestration charges during solar hours and discharges during evening peak hours to solar soak and minimise grid consumption by discharging as soon as possible to maximise the ability to soak up additional PV generation.

System orchestration shifts these subloads away from higher to lower emissions reduction behaviours due to high spot prices and/or distribution and transmission network peak periods, which do not necessarily align with minimising grid emissions.

Figure 27 – Emissions Outcomes of Total Flexibility



Source: Energeia Modelling

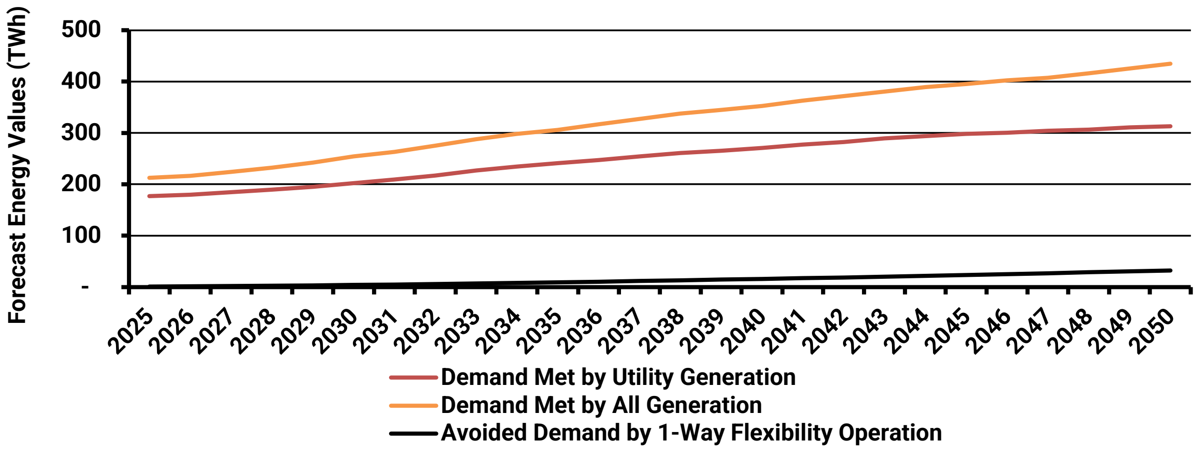
Load flexibility of CER that only consumes energy has a net positive grid emission benefit. Generally speaking, load flexibility for these devices shifts energy into lower-cost wholesale periods in which the price of energy is lowered by an abundance of low-cost renewables, which are also low emissions.

3.1.4. Validation

Energeia validated the results against reasonable upper limits to ensure the technical feasibility of the outcomes with respect to the value of flexibility being provided.

Figure 28 compares the total energy consumed in NEM against the magnitude of loads modelled to 2050 within the scaling model. It shows that one-way CER flexibility uptake totals around 10% of the sent-out demand in 2050. This proportion of total energy was considered reasonable for this modelling, and Energeia consequently did not implement any feedback loop to cap wholesale behaviour for flexibility benefits below this level.

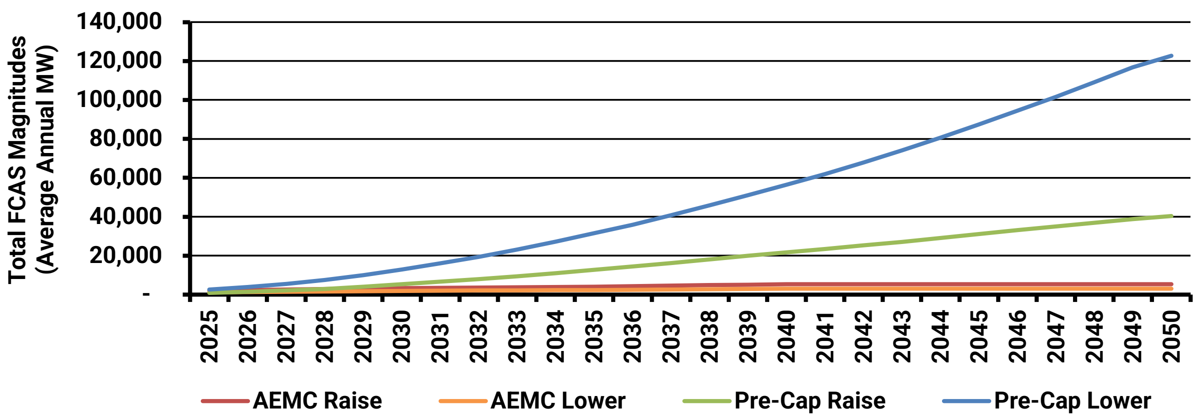
Figure 28 – Modelled Flexibility vs. Annual Demand Forecast



Source: AEMO ISP (2024), Energeia

Figure 29 shows the forecast of average FCAS volumes demanded in the NEM, derived from AEMC modelling for the integrated price responsive resources (IPRR) workstream, which was used as a cap for the modelled FCAS volumes. This ensured that the CER flexibility forecasts would not be potentially providing value that did not exist. The forecast was constrained down to the AEMC's cap to ensure that the outcomes in this modelling were not unrealistic. With the cap implemented, Energeia's forecast volume aligns with the AEMC's volume cap across all forecast years.

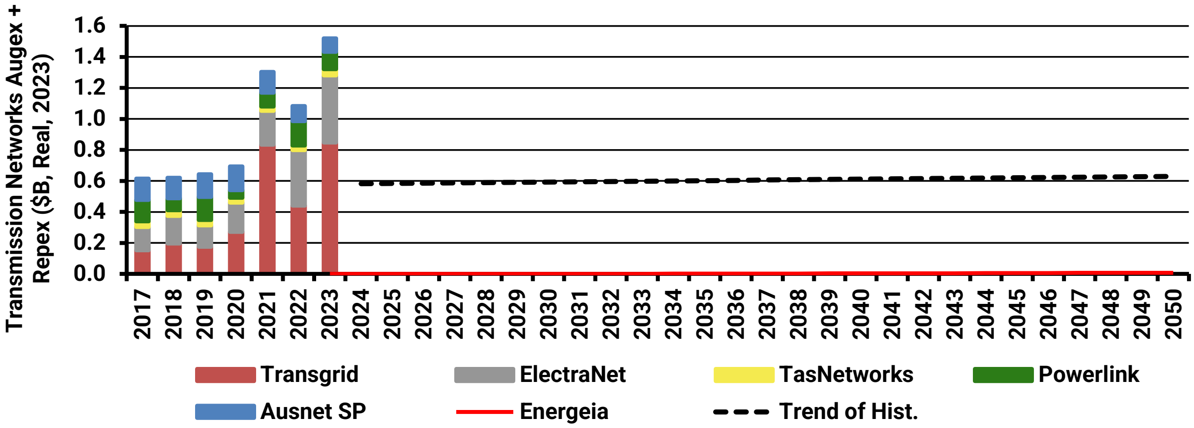
Figure 29 – Projected FCAS Volumes vs. AEMC FCAS Forecast Used in Model



Source: AEMC, Energeia, Note: AEMC Raise/Lower taken forward as FCAS capacity for this analysis

Transmission and distribution network value outcomes were validated against historical data due to the typically short-term planning of networks. TNSP and DNSP regulatory information notice (RIN) datasets were used to benchmark results. Figure 30 shows that Energeia's transmission benefits modelling contributes a very small portion of the average of the historical (2017-2023) TNSP rates when trended to 2050.

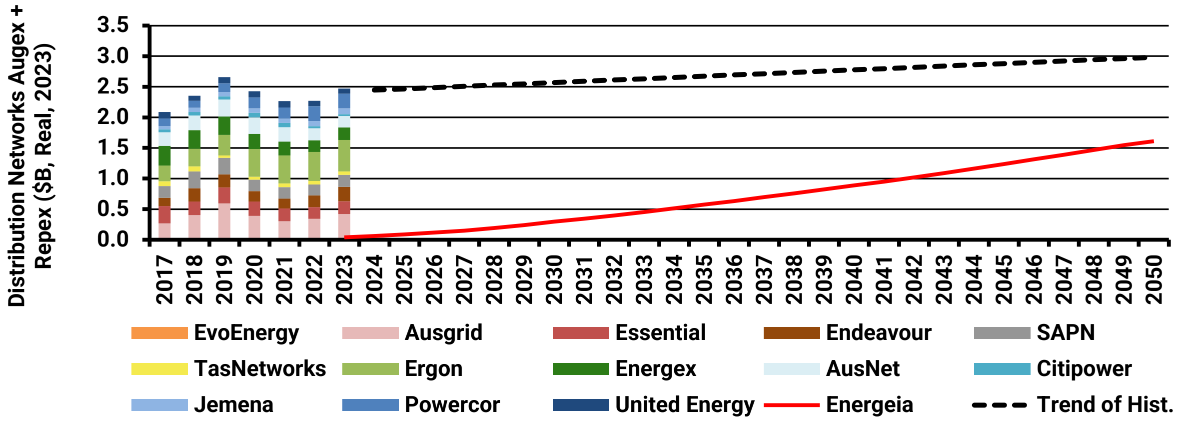
Figure 30 – System Benefits vs. TNSP Augex + Repex



Source: TNSP RINs, Energeia. Note: Trend of Hist. excludes Transgrid and ElectraNet augex which are significant outliers.

Figure 31 shows Energeia's distribution augmentation expenditure (augex) and replacement expenditure (repex) forecast reaches marginally higher than 50% of the trended historical repex and augex. It is likely a simple trend is an understatement of future network costs as future costs of CER integration are expected to have an impact on network costs. Notably, the network integration costs of EVs are currently discussed as a risk by networks, with Evoenergy proposing a project contingent on EV uptake within the current period's regulatory proposal.[29]

Figure 31 – System Benefits vs. DNSP Augex + Repex



Source: DNSP RINs, Energeia

3.2. Consumer Impact Analysis

The following section demonstrates an analysis of the impact of flexible CER operation on consumers under currently offered time-of-use (ToU) tariffs.

3.2.1. Methodology

The consumer impact analysis compares the system benefits provided by the consumer's flexible CER against the calculated impact of providing flexibility to a consumer's retail bill. This was carried out through the following stages:

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[29] Evoenergy, *Regulatory Proposal* (2023) https://www.aer.gov.au/system/files/Evoenergy-Regulatory%20proposal-January%202023_Public.pdf

1. **Develop Inputs** – inputs of consumer retail tariffs by state and segment were required in addition to the modelling tool developed within the analysis in Section 3.1.
2. **Characterise Bill Impacts** – the modelling tool described in Section 3.1 was configured to report the impact of flexibility on the consumer's bill under two scenarios:
    a. *Minimise Retail Consumer Bill* – which aimed to orchestrate a consumer's CER to minimise a consumer's bill depending on the tariff they were assigned
    b. *Full Orchestration* – as defined within the total system benefits of CER flexibility analysis, used to analyse maximum system benefits

3.2.2. Inputs

The consumer impact analysis utilised the model and inputs developed within the total system benefits of CER flexibility analysis, outlined in Section 3.1. 2023/24 Retail tariffs were gathered as described below. These were the rates at the time of modelling and may not be indicative of future rates.

Retail Tariffs

Retail tariff inputs were included to gauge the bill impacts of the change from a no orchestration to a full orchestration state. A unique tariff was used for each consumer type in each NEM state. Residential and small commercial retail tariffs were sourced from available ToU offers (from the Energy Made Easy and Victorian Energy Compare websites) provided by Origin Energy, or Aurora Energy for Tasmania. These inputs are detailed in Table 7.

Table 7 – Residential and Small Commercial Retail Tariff Rates

	NSW Ausgrid		QLD Energex		SA SAPN		TAS TasNetworks		VIC United Energy	
	Res.	Small Com.	Res.	Small Com.	Res.	Small Com.	Res.	Small Com.	Res.	Small Com.
Peak Energy (c/kWh)	69.2	58.3	42.0	36.1	52.5	55.0	36.2	30.3	31.4	36.9
Shoulder Energy (c/kWh)	36.5	31.2	29.5	-	25.8	-	-	21.9	-	-
Off-peak Energy (c/kWh)	21.1	18.8	23.8	31.2	31.1	35.7	16.9	12.8	16.8	23.1
FiT Rate (c/kWh)	7.0	7.0	5.0	5.0	6.0	6.0	10.9	10.9	4.9	4.9

Source: Energy Made Easy (2023), Victorian Energy Compare (2023), Origin (2023), Aurora Energy (2023). Note: SA off-peak tariff period is during solar hours, and shoulder period is overnight, as defined by the retail tariff.

For large commercial consumers, input rates were a combination of network ToU and demand tariffs, sourced from pricing proposals published on the AER's website by relevant DNSPs in each NEM state. Table 8 shows retail tariff rates developed by Energeia through the addition of wholesale energy costs during ToU periods, as well as the addition of retail margins, and the normalisation of demand charges on a daily basis.

Table 8 – Large Commercial Retail Tariff Rates

	NSW Ausgrid Large Commercial	QLD Energex Large Commercial	SA SAPN Large Commercial	TAS TasNetworks Large Commercial	VIC United Energy Large Commercial
Peak Energy (c/kWh)	16.0	21.6	13.4	4.3	8.4
Shoulder Energy (c/kWh)	9.8	-	-	-	-
Off-peak Energy (c/kWh)	9.3	9.3	10.6	3.1	6.7
FiT Rate (c/kWh)	-	-	-	-	-
Peak Daily Demand (c/kW)	-	42.5	25.7	41.2	31.0
Off-peak Daily Demand (c/kW)	-	6.6	0.0	13.7	-
Flat Daily Demand (c/kW)	36.9	-	9.5	-	27.3

Source: AER (2023), Ausgrid (2023), Energex (2023), SAPN (2023), TasNetworks (2023), United Energy (2023),

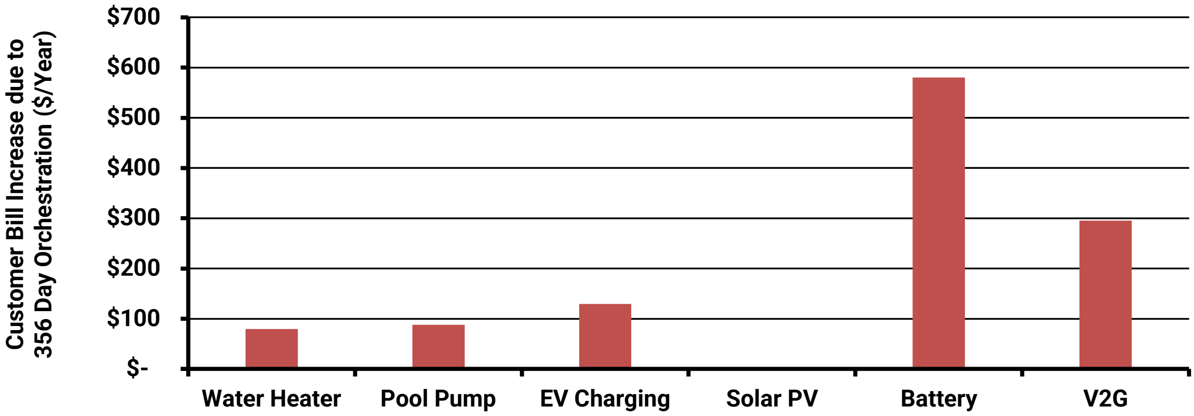
These tariffs were utilised in the analysis to quantify the consumer bill impacts.

3.2.3. Results

Consumer Bill Impacts

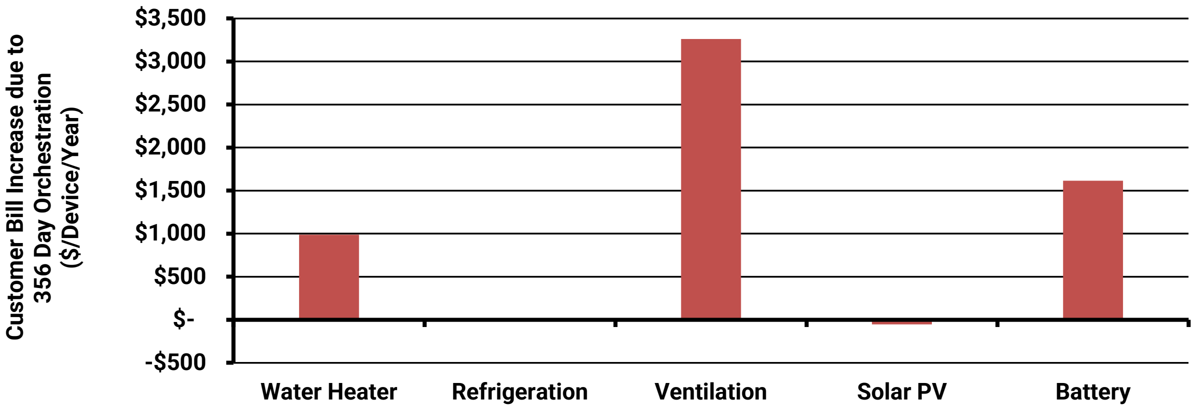
Figure 32 and Figure 33 display the impact analysis results for example small and large consumers. These results highlight the additional increase in consumer retail bills from using CER flexibility to maximise system benefits instead of using it to minimise retail bills.

Figure 32 – Small Consumer Example Impact: Maximise System Benefits vs. Minimise Retail Bill



Source: Energeia. Note: The chart captures a case study of an NSW residential consumer

Figure 33 – Large Consumer Example Impact: Maximise System Benefits vs. Minimise Retail Bill



Source: Energeia. Note: The chart captures a case study of an NSW large consumer health segment consumer

The key finding of this analysis is that even with current ToU tariff structures, an existing opportunity cost disincentivises consumers from providing flexible resources to NEM retailers. VPP participants may be financially exposed to costs associated with typical subload behaviour. This implies that consumers would require additional compensation for having their load managed to maximise system benefits, consistent with existing VPP business models (see Section 3.3). Results also show that the size of the opportunity cost generally increases with the size of the load being flexed.

Under existing ToU structures, minimising customer bills produces results in different CER activity than minimising system costs. Therefore, without changes to prices, customers and VPPs will need additional incentives to maximise system benefits of their CER.

3.3. VPP Passthrough Analysis

This section outlines the methodology, inputs, and results of the VPP pass-through analysis. This analysis aimed to develop a view of existing VPP benefits pass-through to the active consumer and the remaining margin retained by the provider.

3.3.1. Methodology

An estimate of existing battery VPP passthrough was developed through the following steps:

1. **Capture Inputs –** Available battery VPP offers in Australia were researched and narrowed to a feasible subset, capturing relevant consumer incentives and operational limits.
2. **Model VPP Offers –** VPP offers were elucidated with the model described in Section 3.1, using the following modelling rules:
    a. The VPP provider picks the top days of retailer cost reduction or FCAS value to orchestrate the VPP within their designated limits (e.g., max kWh, max days, retailer or third party, registered for FCAS or not)
    b. Retailer cost reduction operations conducted by the provider optimise the battery to charge and discharge to minimise wholesale energy and network tariff costs
    c. FCAS value orchestration holds the battery state of charge constant to maximise FCAS raise and lower bid capacity
    d. No orchestration was assumed to occur outside of the VPP orchestration days; instead, batteries maximised self-consumption of PV
3. **Generate Passthrough Results** – The net benefits of each offer were modelled and averaged, considering both the consumer and provider perspectives, to reveal an estimated passthrough of benefits.

3.3.2. Inputs

Energeia researched all available residential battery VPP offers in Australia, totalling 17 active offers, and narrowed them down to a selection of offers that included explicit annual operation limits or estimates, allowing them to be modelled. These limits are defined in units of energy (kWh) or days of the year, depending on the provider. The analysis assumed that the battery would cycle once per day of operation, allowing for a conversion between the units of limit. Table 9 shows a final selection of VPP offers, with a breakdown of all the relevant benefits and conditions provided to the consumer.

Table 9 – Available Battery VPP Offers

VPP Number	VPP Type	Sign-Up Bonus ($)	Annual Benefits ($/yr)	Per Event Bonus ($/kWh)	FiT Rate ($/kWh)	Usage Rate ($/kWh)	Max Annual Operation Limit
VPP 1	Retailer - Not Registered for FCAS	$1,500 (New Battery) or $400 (BYOB)	×	$1/kWh	Standard	Standard	200 kWh
VPP 2		×	$120	×	Standard	Standard	500 kWh
VPP 3	Third-Party - Registered for FCAS	×	×	$0.55/kWh Drawn From Battery	Standard	Standard	104 Events*
VPP 4	Retailer - Registered for FCAS	$800 (New Battery) or $300 (BYOB)	$240	×	Standard	Standard	405 kWh
VPP 5		$1,000 (New Battery) or $100 (BYOB)	$220	×	Standard	Standard	50 Cycles (675 kWh)

Source: VPP Provider Websites, Energeia research
Note: "Standard" refers to the standard retail rates offered by the VPP provider or the consumer's existing retailer; BYOB = Bring Your Own Battery

The availability of offers varied by provider, but all offers were available to South Australian residential consumers, so this was the modelled consumer segment. Solar PV systems were also required as part of most VPP offers, so modelled consumers were assumed to have PV systems.

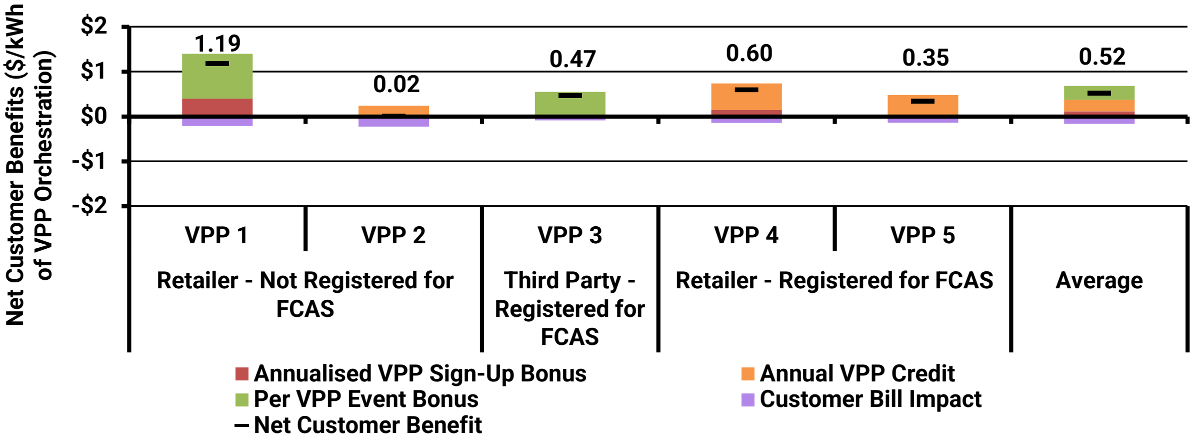
Other assumptions made for modelling were:

- Consumer battery size assumed to be 5 kW, 10 kWh under a bring your own battery (BYOB) offer (meaning the relevant BYOB sign-up bonuses were assumed)
- The battery and PV system purchases were considered sunk costs and were not factored into the benefits analysis
- Sign-up bonuses were annualised assuming a five-year contract length
- Per VPP event bonuses were assumed to apply to the defined maximum kWh of orchestration
- Consistent tariff rates were assumed across all VPP offers

3.3.3. Results

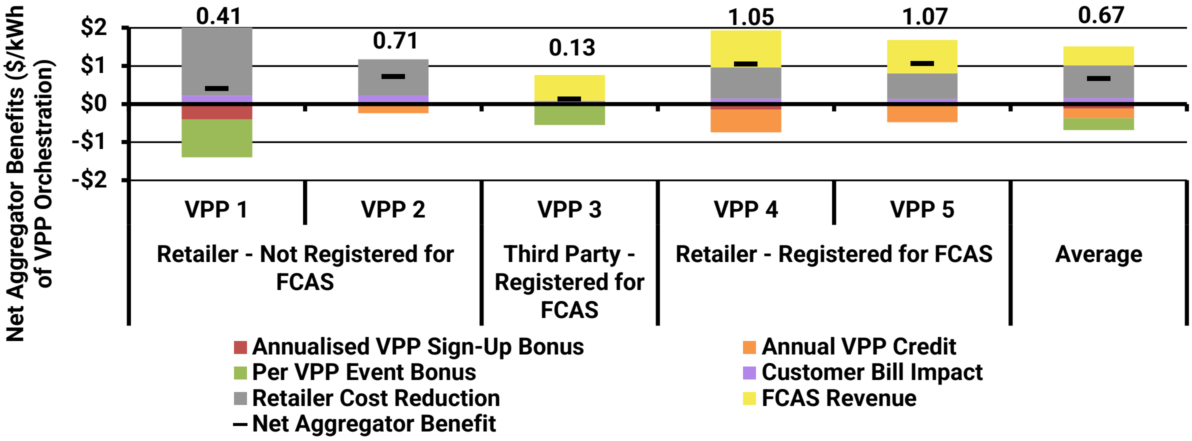
The results of the passthrough analysis are captured in Figure 34 and Figure 35, which shows the VPP consumer and provider net benefits. The benefits were normalised on an energy basis (per kWh of battery charged/discharged by the VPP provider).

Figure 34 – VPP Consumer Net Benefits by Offer



Source: Energeia

Figure 35 – VPP Provider Net Benefits by Offer



Source: Energeia

The results show that all modelled VPP offers produced net benefits to the consumer, albeit this was very low for VPP number 2 modelled ($0.02/kWh). The modelled consumer's retail bill always increased in the analysis relative to operation with no orchestration (maximising self-consumption of PV). The average net benefit to the consumer was $0.52/kWh.

The modelled VPP offers always produced net benefits to the provider. The lowest amount made by the provider in net benefits totalled $0.13/kWh. The average net benefit to the provider was $0.67/kWh.

Energeia found that, on average, 50% of the earnings associated with VPP operation would be passed through to the consumer, and the remaining 50% would be retained by the VPP provider, eventually flowing through to lower retail prices through competitive effects.

This estimate comes from the results showing that of the $1.36/kWh in total direct benefits that the average VPP provider generated from retailer cost reductions ($0.85/kWh) and FCAS markets ($0.51/kWh), $0.68/kWh was passed to the consumer through sign-up bonuses ($0.12), annual credits ($0.25), and per-event bonuses ($0.31). Note the 50% passthrough estimate excludes any retail bill interactions, which are ultimately the result of inefficient pricing.

4. Modelling Limitations

In the applied methodology, simplifications were made such that the resulting model would be parsimonious and tractable. As a result, six key limitations were identified and are detailed below.

It is Energeia's view that the modelling is fit for purpose given the project scope and objective to inform the AEMC regarding the indicative size of the load flexibility market. More detailed and complex modelling is recommended in the future to gain a clearer understanding of the potential benefits on a more granular basis.

Reliance on First Order Impacts

The modelling method implemented contained interactions between consumer behaviour and the wholesale and frequency control ancillary services (FCAS) markets as well as transmission and distribution networks to determine the value of load flexibility. However, no feedback loop was modelled between electricity wholesale market outcomes and load flexibility. In reality, increased flexibility uptake likely would directly alter market outcomes (e.g., change wholesale prices) which would diminish flexibility incentives. The modelling utilised a wholesale forecast that was produced independently of this work as a part of the AEMC IPRR modelling.

Use of Key Case Studies

The selected consumer case studies were limited in that they did not include an exhaustive list of consumer segments and consumer energy resources (CER) technologies for modelling. Instead, Energeia carried out an analysis of end-use load magnitudes by consumer segment and a review of third-party load flexibility assessments to inform the proposed scoping of flexible loads to be included, which Energeia then validated with the AEMC team. This analysis included considerations of the probability of each technology becoming a significant source of flexibility, and the quality of information available. Energeia and the AEMC believe the resulting scope defined through this analysis captures the segments that are the most significant and representative. Further discussion on the technologies selected is provided in Appendix A: Inclusion of Flexible Subloads.

Alignment to AEMO's 2023 Step Change Scenario for Adoption and Participation Rates

Another key limitation is the alignment of assumptions to the Australian Energy Market Operator's (AEMO's) 2023 Inputs, Assumptions and Scenarios Report (IASR)[30] in developing a consensus view of load flexibility uptake upon which to base the breakeven analysis. The IASR is not descriptive about its assumed load flexibility uptake, particularly around the uptake of load flexibility in water heating, pool pumps, ventilation, and refrigeration. Energeia has made assumptions about the level of flexibility assumed in the modelling by utilising forecasted activation rates from a 2019 E3 paper.[31] The level of solar photovoltaic (PV) flexibility assumed in the modelling was aligned with the level of behind-the-meter battery aggregation assumed in the IASR. Energeia believes these assumptions align the consensus view of flexibility uptake defined in this analysis to the Step Change scenario in a reasonable way.

Use of Hourly Model Resolution

Hourly profiles were used in modelling despite 5-minute market settlements. Five-minute resolution is important for several reasons including greater accuracy of faster response resources, but in the view of Energeia and the AEMC, it is unlikely to be justified given the indicative nature of this work.

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[30] AEMO, 2023 Inputs and Assumptions Workbook (2023), https://aemo.com.au/-/media/files/major-publications/isp/2023/2023-iasr-assumptions-workbook.xlsx?la=en

[31] Equipment Energy Efficiency, Regulation Impact Statement for Decision: 'Smart' Demand Response Capabilities for Selected Appliances (2019), https://www.energyrating.gov.au/sites/default/files/2022-12/smart_appliance_decision_ris.pdf

Additionally, the resolution was limited by the data and computational limits of the platform (Microsoft Excel).

Susceptibility to Load Homogeneity

Whilst the modelled representative consumer impacts were scaled to represent the population accurately, there is a possibility that the use of representative consumers could have exaggerated peak and minimum demand impacts, potentially overstating the value of load flexibility due to load homogeneity. However, the impact of this was likely mitigated by the fact that consumers face the same incentives for load flexibility, and also that aggregated load flexibility seeks to homogenise consumer loads in any case.

Broad Network Impact Scope

Energeia undertook modelling of grid impacts on a network-wide basis and assumed a continuous benefit from reducing peak and increasing minimum demand, based on the associated long-run marginal cost (LRMC) for thermal and voltage upgrades. While the impacts may vary within networks, the chosen approach gives a relatively unbiased view of network-wide benefits. The expected impact on the cost-benefit analysis (CBA) accuracy is the potential understatement of low-voltage (LV) and high-voltage (HV) thermal and voltage impacts.

5. Key Findings, Conclusions and Recommendations

Based on our analysis, Energeia found that the total value of flexible CER modelled in this analysis resulted in $45B in NPV terms to 2050. Most of this value is expected to be earned by residential consumers, delivering over 80% of the total value in NPV terms. However, Energeia's modelling found that consumers who provide this value would currently be significantly negatively impacted on their retail bills due to misalignment between actual system costs and retail tariffs. Energeia additionally notes that not all value streams are currently accessible by consumers, with market ancillary service specification (MASS)-compliant metering required for consumers to access FCAS value streams.

Energeia has developed the following recommendations based on the key findings of this analysis:

- **Ensure cost-reflective network and retail incentives:** Establishing cost-reflective network and retail prices allows for more efficient CER utilisation. Current arrangements lead to conflict between retail bills and system savings and result in sub-optimal CER utilisation. Cost-reflective pricing would enable 100% flexible CER utilisation and maximise system benefits.
- **Level the playing field for third parties:** Currently, retailers have an upper hand in accessing the value of CER flexibility through existing access to the wholesale value. Allowing third-party aggregators equal access to these benefits will increase competition amongst flexibility service providers, generating additional value to consumers. Additionally, reform to encourage network service providers to better utilise CER to resolve growth-related constraints on the network would enhance the value of CER flexibility.
- **Remove barriers to using devices for MASS compliant metering**: FCAS was found to be a key value driver for flexible CER in the early years of modelling but currently faces significant barriers to accessing this value within this timeframe, mainly metering requirements. Enabling the use of devices for MASS compliance, provided they meet operational requirements, would unlock access to the significant FCAS value stream.

Appendix A: Inclusion of Flexible Subloads

The following sections contain an excerpt from Energeia's Methodology Report,[32] published alongside the Australian Energy Market Commission's (AEMC's) Directions Paper. This Appendix summarises the justification of the subloads utilised within the analysis.

Scope of Flexible Loads Considered

Energeia carried out an analysis of end-use load magnitudes by consumer segment and a review of third-party load flexibility assessments to inform the proposed scoping of flexible loads to be included in the modelling, which was then validated with the AEMC team.

Table A1 outlines the range of flexible loads and consumer segmentations initially incorporated as part of the analysis and the resulting scope, designed to capture the most significant flexible loads.[33]

Table A1 – Initial Scope of Flexible Loads

Consumer Type	Appliances	Flexibility Options
Residential and Small Business	Water Heating	Shift Shed
	Heating, Ventilation and Air Conditioning (HVAC)	Shift Shed
	Pools / Spas	Shift Shed
	Lighting	✗
	Cooking	✗
	Solar Photovoltaics (PV)	Shed
	Battery	Shift
	Electric Vehicle (EV) Charging and Discharging	Shift Shed
	Refrigeration	✗
Large Business**	Water Heating	Shift Shed
	HVAC*	Shift Shed
	Pools / Spas	✗
	Lighting	✗
	Cooking	✗
	Solar PV	Shed
	Battery	Shift
	EV Charging and Discharging	Shift Shed
	Refrigeration*	Shift Shed

Source: Energeia
* Will vary by type of consumer
** Does not include industrial consumers

[32] Benefit Analysis of Load-Flexibility from Consumer Energy Resources: Methodology Report https://www.aemc.gov.au/sites/default/files/2023-08/CER%20Flexibility%20Modelling%20Methodology%20Paper%20-%20FINAL.pdf

[33] Load shifting refers to moving electricity consumption from one time period to another. Load shedding refers to reducing/removing electricity consumption.

Upon discussion with the AEMC, industrial consumers were deemed out-of-scope because they are already strongly involved in the market for their flexible consumption (e.g., registered loads).

Load Magnitude by End Use

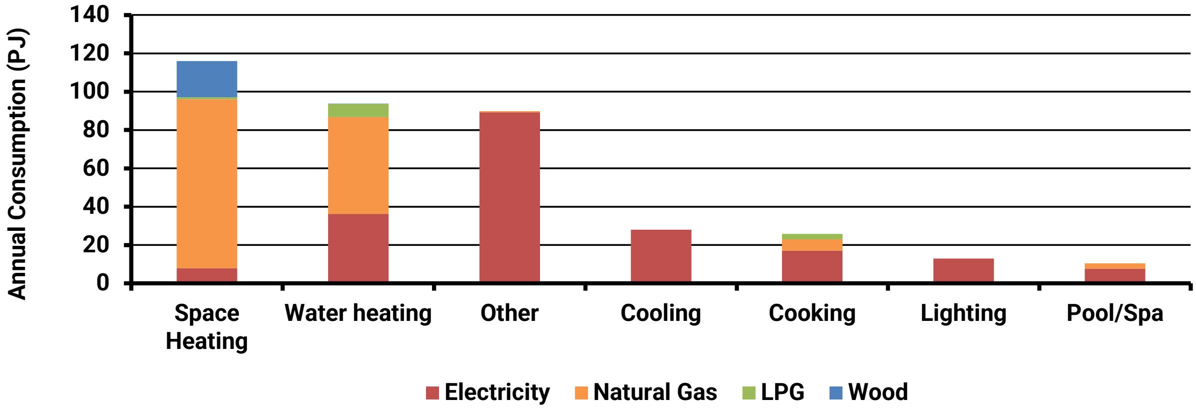
Energeia conducted a quantitative analysis of estimated building end uses by consumer segment to identify the highest consumption end uses in the National Electricity Market (NEM) states. This analysis provides insight into the existing resource potential.

Residential Buildings

Energeia sourced data from the 2021 Residential Baseline Study[34] to identify the most significant residential end uses by consumption.

As shown in Figure A1, space heating and water heating are responsible for the most significant end-use consumption in the NEM states, with most of this energy being provided by natural gas. “Other” end uses also constitute a significant source of load but are not further considered due to the lack of information regarding the nature of the load.

Figure A1 – NEM Residential End Use Consumption by Fuel Type

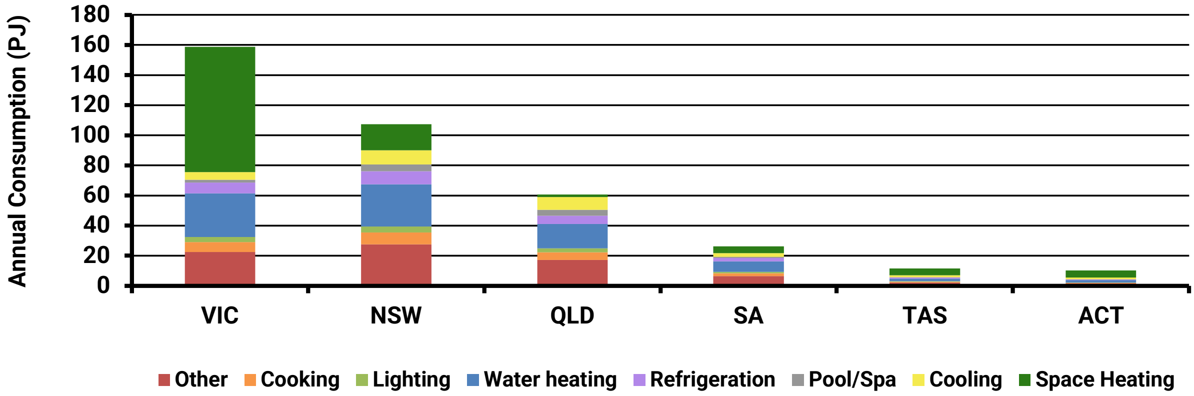


Source: EnergyConsult (2022), Energeia, Note: LPG = liquefied petroleum gas

Figure A2 shows consumption by NEM state and end-use. Victoria leads with an extreme, predominantly gas-fuelled space heating load. The other states show expected breakdowns based on their differing climates and populations.

[34] https://www.energyrating.gov.au/industry-information/publications/report-2021-residential-baseline-study-australia-and-new-zealand-2000-2040

Figure A2 – Residential End-Use Consumption by NEM State



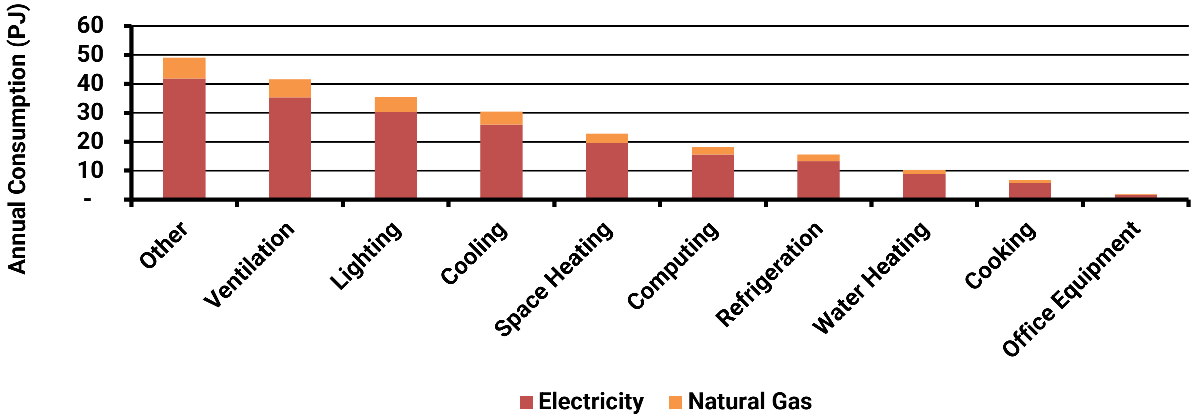
Source: EnergyConsult (2022), Energeia

Commercial Buildings

To the best of Energeia's knowledge, no publicly available dataset estimates subload consumption by commercial building type in Australia. As such, Energeia estimated commercial subload energy consumption by fuel type and end-use in NEM states by gathering commercial end-use energy intensities, sourced from United States (US) data,[35] and applying them to Australian energy consumption by building type from the 2022 Commercial Buildings Energy Consumption Baseline Study.[36]

Figure A3 displays the total annual electricity and natural gas consumption by end-use. "Other" end uses provide the greatest source of consumption but these are out of scope, as are the more minor loads of computing and office equipment. Of the remaining loads, HVAC loads (space heating, cooling, and ventilation) are the most significant, alongside lighting, which Energeia deemed as inflexible.

Figure A3 – NEM Commercial End Use Consumption by Fuel Type



Source: Energy Information Administration (2018), DCCEEW (2022), Energeia

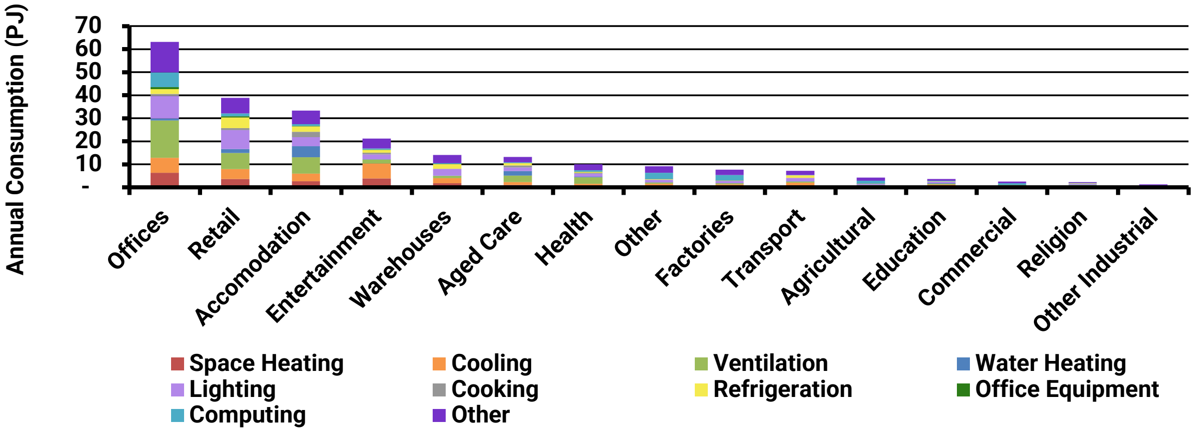
Figure A4 displays the end-use consumption by building type, showing that office buildings are the dominant consumption source in the NEM states, followed by retail and accommodation. Although

[35] https://www.eia.gov/consumption/commercial/data/2018/index.php?view=consumption

[36] https://www.energy.gov.au/publications/commercial-buildings-energy-consumption-baseline-study-2022

there is some variation between building types, HVAC loads and lighting are frequently the highest sources of consumption, consistent with the results in Figure A3.

Figure A4 – NEM Commercial End-Use Consumption by Building Type



Source: Energy Information Administration (2018), DCCEEW (2022), Energeia

End Use Load Flexibility Potential

Energeia analysed the latest research regarding load flexibility and found two key reports relevant to this study. The first is from the Reliable Affordable Clean Energy (RACE) for 2030 initiative and the second is from the Australian Renewable Energy Agency (ARENA) assessing the flexibility potential of different loads in the Australian context to supplement discussions with the AEMC on which loads to include in the modelling scope. Energeia used this research to inform the final scoping of which end uses and technologies were likely to be the most significant for inclusion in the study.

RACE for 2030 – Opportunity Assessment, Flexible Demand and Demand Control

RACE for 2030[37] commissioned an assessment of the prospective potential for commercial load flexibility by end-use, to identify priority research areas to assist in advancing flexible demand growth.

Assessments were completed using a semi-qualitative HUFF Matrix, which evaluates potential load flexibility using the following criteria:

- **Homogeneity:** How replicable is the solution?
- **Ubiquity:** How scalable is the solution?
- **Feasibility (techno-economic):** How cost-effective is the solution?
- **Feasibility (realistic):** How well does the solution fit with the industry?

RACE for 2030 gave each type of load score of 1 to 3 for each of the HUFF criteria, for which a higher score is more prospective based on a qualitative assessment. Scores were summed to produce a total ranging from 4 to 12. Each building type also was given a score of 1 to 3 for each criterion and summed. The summed load and building scores were multiplied to produce the final score in the matrix for each opportunity (hence the scores could range from 16 to 144).

The HUFF Matrix in Figure A5 shows that RACE for 2030 rated HVAC and electrical storage as the most prospective forms of load flexibility in the commercial sector. Embedded generation, water heating, thermal storage, and refrigeration were also highly rated. Commercial EV flexibility was given the lowest rating.

[37] https://www.racefor2030.com.au/wp-content/uploads/2021/10/RACE-B4-OA-Final-report.pdf

Figure A5 – Commercial End Use HUFF Matrix

	HVAC	Heat pumps	Hot water	Thermal storage	Electric vehicles	Pool pumps	Embedded generation	Electrical storage	Refrigeration
Retail	70	56	63	63	35		63	70	
Offices	80	64	72	72	40		72	80	
Warehouses	80	64		72	40		72	80	72
Apartments	90	72	81	81	45	72	81	90	81
Public buildings	90	72	81	81	45		81	90	81
Data centres				63			63	70	
Supermarkets	90	72	81	81	45		81	90	81
Aquatic centres		72	81	81	45	72	81	90	

Source: RACE for 2030 (2021)

ARENA – Load Flexibility Study

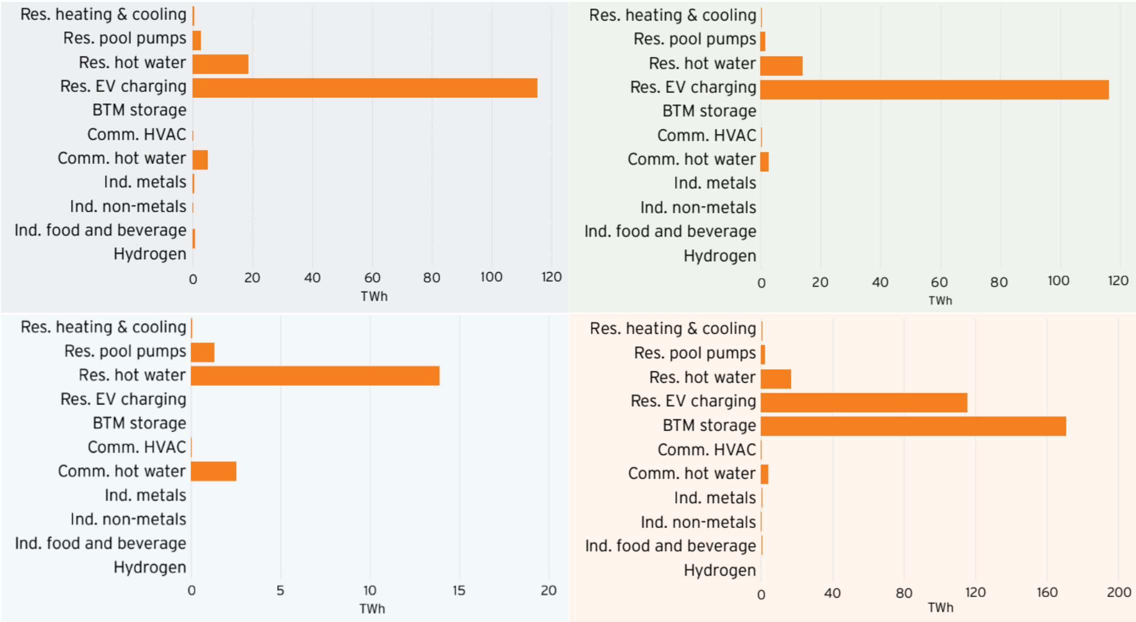
ARENA[38] identified load flexibility as a focus area in their 2021 Investment Plan, leading them to produce their Load Flexibility Study. ARENA used PLEXOS[39] to model a range of scenarios through to 2040 and have reported the magnitude of load flexibility by resource.

Figure A6 shows results by scenario, each indicating the total modelled load flexibility contributions by resource. Across all the scenarios, residential EV charging, and hot water heating were significant contributors to flexible load, with minor contributions from residential pool pumps. The High distributed energy resources (DER) Uptake scenario showed batteries as the largest flexible load. On the commercial side, water heating provided the most flexible load. Other resources were modelled to be relatively negligible.

38 https://arena.gov.au/assets/2022/02/load-flexibility-study-technical-summary.pdf

39 PLEXOS is a specialised market simulation software, https://www.energyexemplar.com/plexos

Figure A6 – Modelled Flexible Load by Scenario (2021-2040)



Scenarios: Baseline (top left), High EV Uptake (top right), Electrification (bottom left), High DER Uptake (bottom right)
Source: ARENA (2022)

Subload Inclusions

Table A2 outlines the resulting scope of flexible loads to be included in the modelling, which has been refined from the original scope in Table A1.

The objective of this project was not to model every flexible load option, but rather to estimate the quantum of system benefits that added load flexibility could potentially provide.

Table A2 – Proposed Scope of Flexible Loads

Category	Subload	Estimated Total Energy Consumption/Generation (PJ, 2023)	Load Flexibility Ranking	Include/Exclude?	Flexibility Options
Residential and Small Business	Space Heating	121.2	Medium	×	Shift Shed
	Water Heating	96.1	High	✓	Shift Shed
	Solar PV	82.6	High	✓	Shed
	Space Cooling	34.9	Medium	×	Shift Shed
	Cooking	25.7	Low	×	×
	Refrigeration	15.5	Low	×	×
	Lighting	12.9	Low	×	×
	Pools / Spas	10.3	High	✓	Shift Shed
	Ventilation	9.5	Medium	×	Shift Shed
	Battery	8.0	High	✓	Shift
	EV Charging EV Discharging	1.0	High	✓	Shift Shed
Large Business*	Solar PV	82.6	High	✓	Shed
	Ventilation	32.0	Medium	✓	Shift Shed
	Lighting	27.3	Low	×	×
	Space Cooling	23.5	Medium	×	Shift Shed
	Space Heating	17.6	Medium	×	Shift Shed
	Refrigeration	12.0	High	✓	×
	Water Heating	7.9	High	✓	Shift Shed
	Battery	8.0	High	✓	Shift
	Cooking	5.2	Low	×	×
	EV Charging EV Discharging	1.0	Low	×	Shift Shed
	Pools / Spas	0.0	High	×	Shift Shed

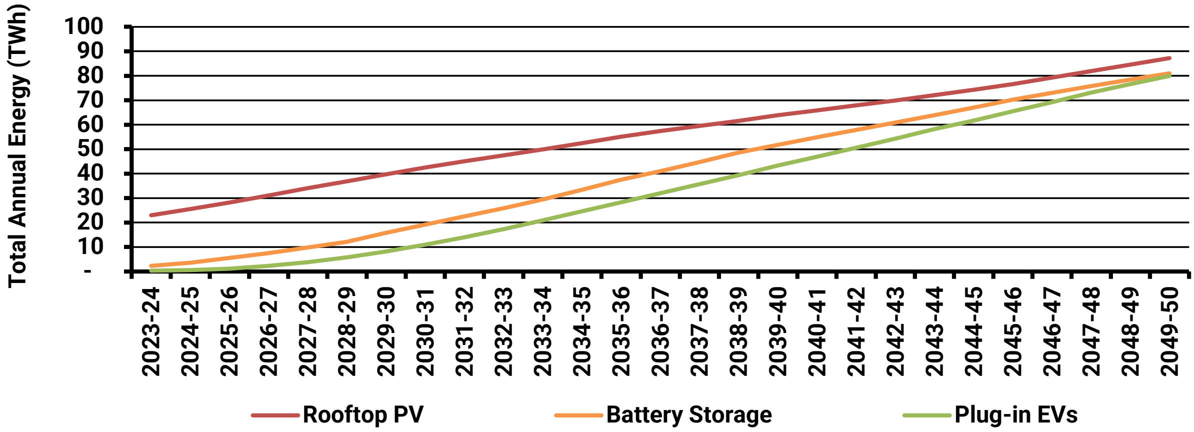
Source: Energy Information Administration (2018), DCCEEW (2022), AEMO (2023), Energegia
* Does not include industrial consumers

More detailed explanations for the notable inclusions and exclusions are as below:

- Space heating, cooling, and ventilation were excluded because they are not expected to be a practical source of flexibility due to the lack of centralised control and smart home thermostats in Australia. Electrification of heating may increase the ability to control in the future, and thus in future iterations, this assumption should be revisited. Additionally, ARENA did not find these loads to be significant flexibility resources in their modelling (See Figure A6).
- Refrigeration was also excluded from the residential and small business segment for similar reasons regarding lack of opportunity and materiality of flexibility. Refrigeration is included in the large business segment because they are not expected to have the same degree of conflict and have been identified as potentially flexible loads by RACE for 2030 (See Figure A5).
- Battery and EV flexibility was included despite current uptake levels being low, as they are expected to grow in uptake in the future and are highly flexible resources. Figure A7 shows

the forecast uptake from the Australian Energy Market Operator's (AEMO's) Draft Inputs, Assumptions and Scenarios Report (IASR) 2023.[40]

Figure A7 – Total Energy by CER, 1.8°C Orchestrated Step Change



Source: AEMO Draft IASR (2023)

Another key finding of the analysis and validation with the AEMC was that the modelling of large and small businesses would be represented by the following key building types:

- Offices
- Retail
- Accommodation
- Entertainment
- Warehouses
- Health

These categories were selected due to these commercial building types having the highest total consumption across the NEM (see Figure A4), therefore representing most of the system.

[40] https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/2023-inputs-assumptions-and-scenarios-consultation/draft-2023-inputs-and-assumptions-workbook.xlsx?la=en

Appendix B: Feedback Received on Draft Methodology

Table B1 summarises key feedback provided to Energeia's draft Methodology Report, anonymised by provider and grouped by topic.

Table B1 – Summary of Feedback by Topic

Issue #	Topic	Issue	Energeia's Response
1	End-to-End Modelling Process	Concerned Energeia's method is an overestimation of value as it does not account for diminishing returns	The AEMC has considered a more complex modelling approach and has determined that a simplified, first-order-based approach is appropriate
2	End-to-End Modelling Process	Energeia's methodology doesn't consider opportunities and costs from a customer's perspective	Method accounts for the alternative case where consumers minimise their own bill, and also the impact of system optimisation on their bill
3	End-to-End Modelling Process	Concerned that the method is double counting/overestimating benefits	Energeia has accounted for the fact that addressing one system benefit has implications for other value streams, so should lower the risk of double-counting
4	Population Inputs	Note the lack of consideration for jurisdictional differences	We are considering unique jurisdictional subloads and costs to the extent the information is in the public domain
5	Selection of Subloads	Suggest that Residential HVAC should be re-included as it has a large opportunity (up to 25% during system peak intervals)	The resource was excluded due to the technology's availability and ultimate level of flexibility
6	Selection of Subloads	Flexible load should only consider electric load (referring to Table 3 of the methodology report)	Modelling will only consider electric load. However, all load was used to determine the scope of analysis since it could be electrified in the future
7	Selection of Subloads	Concerned V2G isn't likely due to car warranties	In the long run, if the benefits are great enough we expect warranty issues will be resolved; we note no warranty issues currently exist
8	System and Consumer Inputs	Caution using 2022 prices, suggest taking an average or other historical year or AEMO forecast	We agree to use 2021 prices noting they are lower on average vs. today. We disagree with averaging as it would smooth hourly price spikes, which are a key driver of the value of flexible resources

Source: AEMC, Various Stakeholders

Energeia's mission is to empower our clients by providing evidence-based advice using the best analytical tools and information available

Heritage

Energeia was founded in 2009 to pursue a gap foreseen in the professional services market for specialist information, skills and expertise that would be required for the industry's transformation over the coming years.

Since then, the market has responded strongly to our unique philosophy and value proposition, geared towards those at the forefront and cutting edge of the energy sector.

Energeia has been working on landmark projects focused on emerging opportunities and solving complex issues transforming the industry to manage the overall impact.

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