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Opportunity Assessment Report: Rewarding residential electricity flexibility: User-friendly cost-reflective tariffs and incentives

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Executive Summary

1. Introduction

The *H4 Rewarding residential electricity flexibility: User-friendly cost-reflective tariffs and incentives* opportunity assessment aims to describe a pathway of research projects and industry development activities to increase flexibility of household electricity use and generation through cost-reflective incentives.

Increasing household electricity flexibility is not an end in itself, but is a means of supporting the transition to a low-carbon electricity system by increasing capacity for (distributed and utility) renewable generation, reducing reliance on fossil fuels, while minimising costs for all households. While cost-reflectivity is an important consideration in incentive design, 100% cost-reflectivity is neither an attainable goal nor a desirable outcome, given, for example, widespread public support for locational cross-subsidies to maintain affordability in remote areas.

The report uses the term “households” rather than “customers” throughout. While customers are singular and defined by their relationship with the retailer or whoever else is selling them a product, households are dynamic and multifaceted and subject to multiple influences. Understanding these influences is essential as provision of cost-reflective tariffs and other incentives is not, on its own, sufficient to create household flexibility.

Uptake of, and response to, flexibility incentives varies between households, according to their abilities, opportunities and values (Figure E-1). Provision of incentives should therefore be targeted appropriately. Significant to a household’s ‘flexibility capital’ are their access to loads or generation that can be shifted or curtailed and to enabling technologies to monitor and control them. While some households will shift some loads manually in response to incentives, widespread and effective deployment of flexibility incentives is dependent on - and drives - large-scale deployment of distributed energy resources including solar PV, batteries, controllable loads, home energy management systems, electric vehicles and smart appliances.

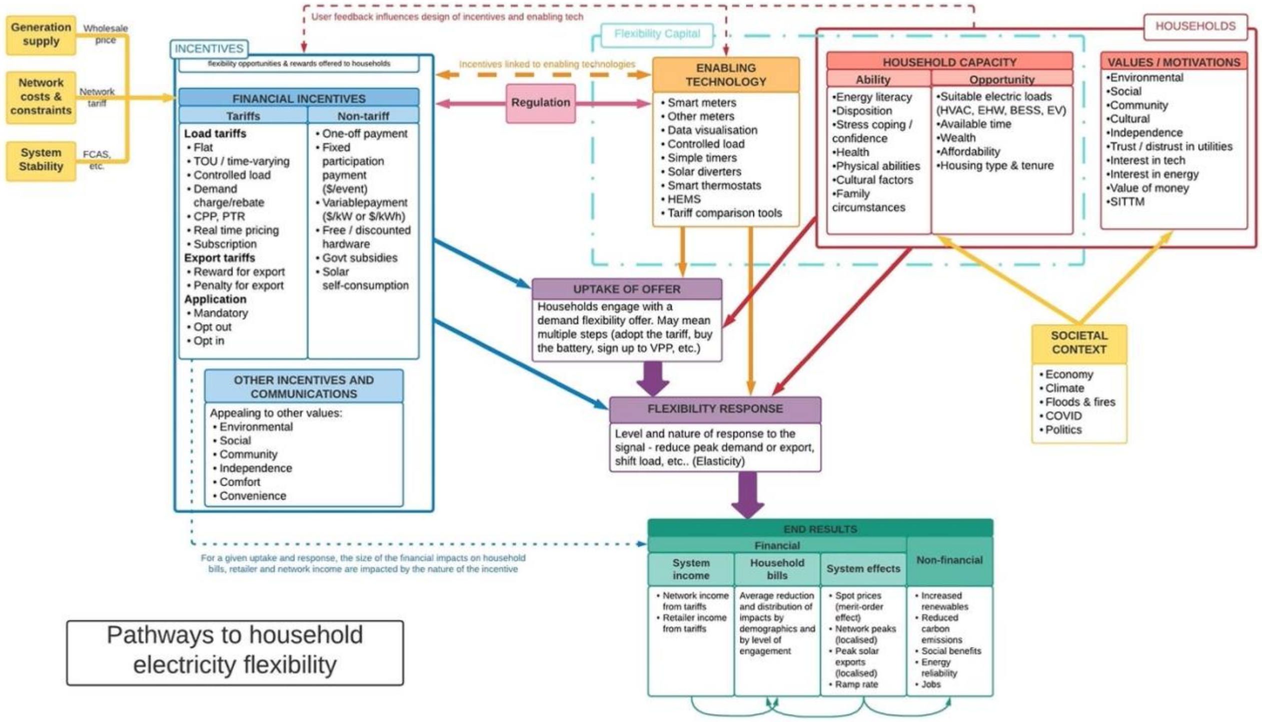

Figure E-1 Conceptual framework showing pathways to household electricity flexibility and the multiple factors that influence take-up of offers and flexibility response to signals

Because automation is not suitable for, nor wanted by, all households, universal household flexibility is neither a realistic outcome, nor a necessary one. The aim of the research theme should be to drive adoption of incentives and deployment of DER by sufficient households to deliver system-wide benefits that flow to non-participants. While incentivising flexibility and supporting households to increase their capacity to provide it, it is important to avoid penalising inflexible households in ways that might increase their vulnerability.

2. Markets for residential electricity flexibility

There are currently three markets that households can potentially participate in using electricity flexibility: the wholesale spot market, network markets and ancillary services markets. Local energy trading (LET) is a fourth type of market that operates within these other markets. The most common way to access the first two markets is through tariffs in the retail electricity market, however access through an aggregator, including to ancillary services markets, is currently under development. The Energy Security Board is also developing a two-sided market, with consultation ongoing. There may be future limitations on participation in such markets due to requirements imposed through technical standards and by DNSPs as well as due to direct control by DNSPs and AEMO. Additionally, electricity flexibility successfully incentivised through one market may undermine the business case through other markets. For example, a high uptake of and response to cost-reflective tariffs might reduce the need for VPPs that target high spot prices and network demand peaks.

3. Tariffs and other incentives

Flexibility incentives reward households for managing their energy consumption and generation to reduce system-wide costs (by lowering spot prices, reducing network peaks in demand and solar export, and by providing ancillary services). Incentives for household flexibility include cost-reflective tariffs (CRTs), other financial rewards and non-financial benefits such as reduced emissions or positive social outcomes. Section 3.1 discusses electricity tariffs, broken down into network tariffs and retail tariffs.

It firstly reviews the different types of **network tariffs** available throughout the NEM, with a focus on their cost-reflectivity, variability and complexity. There is a significant amount of variation between the different tariffs, reflecting both their degree of cost-reflectivity and the network's location. The default approach for allocation of more cost-reflective network tariffs also varies between DNSPs, with some being more forceful than others. Potential novel network tariffs are also discussed, including 'solar export' tariffs (which include payments for exports when they provide benefit), local use of system charges and aggregated NUOS.

Retail tariffs are then discussed in detail, focussing in particular on those offered in Ausgrid's, SAPN's, Horizon Energy's and Ergon Energy's network areas. Most tariffs currently follow the standard structure of flat, TOU, demand charge and controlled load tariffs, with some new entrant tariffs linked to the wholesale spot price. Again, the tariffs in each of these areas are assessed in detail based on their cost-reflectivity, variability and complexity. The key findings are that:

i) There is a significant variability between different retailers in the same network region, including differences in the degree of cost-reflectivity and the extent that network price signals are passed through.

ii) The price signals from the network tariffs are muffled in the retail tariffs because some of the retailers' other costs are not being allocated in the same ratio as the network costs, but instead are more averaged across the different time periods and pricing components. In some cases, retailers may pass through the charges but in a different component: for example, passing through demand charges as TOU peak usage charges.

iii) Retailers appear to base their peak/off-peak ratios in their TOU tariffs on the NSW spot price, with little attention paid to the network tariff, meaning that in some cases the peak price is lower than the combined spot and network prices, which in turn means that to avoid losing money they would need to have higher rates in one or more of the other tariff components.

iv) The degree to which retail tariffs follow the same structure as the underlying network component varies between DNSPs (a different structure means the time periods of the different components of the DNSP and retail tariffs are different). For Ausgrid and Ergon, 70% and 75% respectively of tariffs did not have the same structure, whereas for SAPN 70% did. Horizon Power does not have separate network tariffs.

The **uptake of smart meters** and cost-reflective tariffs is then discussed. Although around 42% of NEM customers have smart meters, outside Victoria (where smart meters are mandatory) penetration drops to 17.4%. Only 22.8% of households in the NEM (excluding Victoria) were on any kind of cost-reflective tariff by June 2020, with significant variation between states, ranging from 39% in NSW to 1% in Qld. There are more than 40 retailers for small customers in the NEM. However, although the dominance of the “big three” (AGL Energy, Origin Energy, Energy Australia) is declining, they still hold 63% of market share.

Embedded network tariff design is an emerging area of interest, with over half a million households on such tariffs. This section briefly discusses their characteristics and the difficulty that embedded network operators (ENOs) face in applying cost-reflective tariffs – that households may choose to move on market, leaving the ENO with less revenue to pay its fixed costs.

There is a range of other **financial incentives** that can be used to encourage electricity flexibility. These include one-off payments, payments for each demand response event, payments dependent on demand reductions, survey and event participation payments, technology subsidies and low-cost finance. **Non-financial incentives** also have a critical role to play in driving electricity flexibility, and there is evidence that alignment of financial and non-financial incentives can have a synergistic effect. The range of non-financial incentives are discussed in some detail, and include environmental benefits, network benefits and broader community motivations. Of course, there are also many motivations that may work against flexibility, such as the desire for autonomy / independence from energy companies or the desire for convenience or control, which could both work against third parties controlling or orchestrating household devices.

4. Mechanisms for electricity flexibility response

This section outlines the mechanisms, both manual and automated, available to households to enable them to respond to flexibility incentives. These are summarised in Table E-1.

Some households are able to provide flexibility by manually shifting household appliance use or adjusting air-conditioning settings, whether in response to time varying tariffs or critical peak reduction incentives (behavioural demand response), or to increase solar self-consumption. This is contingent on having shiftable loads available, as well as on lifestyle, social and other constraints, and requires a high level of user engagement and understanding. Manual load shifting is common in solar households, driven by the difference between evening tariff rates and the feed-in-tariffs, as well as by environmental and independence motivations.

Behavioural demand response (BDR) trials, using financial payments and non-financial incentives to reduce peak demand report positive, but variable, outcomes. There are challenges in recruiting participants as well as in measuring achieved flexibility against an estimated baseline and rewarding participants appropriately.

Automation of loads can overcome some of the barriers households face in manually shifting their electricity use. Loads can be controlled locally, using timers, smart Home Energy Management Systems (HEMS) responding to tariffs or to increase solar self-consumption, or remotely through Direct Load Control (including Controlled Load) of air-conditioning, electric hot water or pool pumps by a DNSP or third party. Smart HEMS may also involve automation to increase household comfort or convenience, which may conflict with beneficial energy flexibility outcomes based on price or system benefits. If automation is ‘set and forget’, it only requires a single decision to participate (compared to multiple decisions for manual flexibility) but the ability to opt-out of or override automated control is popular with households.

Energy Queensland use direct load control (DLC) of DRED-enabled air-conditioning in 120,000 households to reduce critical network peaks, incentivised with point-of-sale discounts on A/C equipment. Other DLC trials have been hampered by technical and installation issues and high cost of participant recruitment. Large numbers of households (e.g., 500,000 in the Ausgrid network) have Controlled Load (CL) tariffs for their electric hot water or pool pumps. These are generally operated overnight but could be shifted to absorb excess daytime solar generation, although there are technical challenges. The use of smart meters with switching capability to control these loads is promising but hampered by low smart meter penetration and challenges of co-ordination between multiple parties under the metering contestability framework.

A battery energy storage system (BESS) greatly enhances a household's flexibility capital. The most basic battery management system (BMS), designed to maximise solar self-consumption, will decrease peak demand and reduce daytime export. Decreasing FiTs and network export charges provide an incentive for BESS deployment. More sophisticated BMS can provide energy arbitrage in response to time-varying tariffs or wholesale prices or participate in a virtual power plant (VPP) selling network services into FCAS markets.

Table E-1 Types of electricity flexibility response

Mechanism	**Load / DER**	**Behaviour change**	**Automation**	**Orchestration**	**Signal**	**Market**	**Enabling technology**
Energy management behaviour	Household appliances	✓	×	×	Time-varying tariffs or solar self-consumption	Indirectly in network and wholesale markets	None necessary, but visualisation of smart meter or load monitoring data can assist
Battery **M**anagement **S**ystem	BESS	×	✓	×	Time-varying tariffs or solar self-consumption or export payment	Indirectly in network and wholesale markets	Monitoring of PV, load and BESS; BESS control
Home **E**nergy **M**anagement **S**ystem	PV, EHW, A/C, EV, Household appliances	[✓]	✓	×	Time-varying tariffs or solar self-consumption	Indirectly in network and wholesale markets	Various: load and PV monitoring, timers, smart switches, smart thermostats, smart chargers, IR A/C control, diverters…
Direct **L**oad **C**ontrol	A/C, EHW, EV, Pool pump	[✓]	✓	✓	External signal controlling DRED or circuit switch or (for A/C) thermostat or IR	Network services and indirectly in wholesale markets	DREDs, IR A/C controllers, smart thermostats & switches, controlled via 3G/4G, wi-fi or ripple control
Controlled **L**oad	EHW, Pool pump	[✓]	✓	✓	Responding to tariff period	Network services and indirectly in wholesale markets	Local timer, ripple control or smart meter relay
Behavioural **D**emand **R**esponse	A/C or household appliances	✓	×	✓	SMS/Email notification	Network services	Smart meter or other load monitoring to measure response
Virtual **P**ower **P**lant	PV, BESS, EHW, EV, Pool pump	[✓]	✓	✓	3G or wi-fi responding to market prices	Wholesale, network and FCAS	3G/4G or wi-fi control of BMS, relays or charger

5. Tools to support household decision making

This section describes the various tools used to support household decision-making with respect to taking up a tariff (retailer comparison and technology assessment tools) and/or responding to tariffs or other market signals (monitoring and control technologies). These tools were reviewed to assess their functionality and effectiveness, and they were categorised by design type, social support framework and Passive-Interactive-Proactive (PIP) typology.

Retailer comparison sites are relatively straightforward to use, but issues include complexity due to the number of available tariffs, exclusion of non-tariff factors, omission of some retailers (for commercial tools) and the challenge of identifying the optimum tariff for households without smart meter data. There is a lack of data on the take-up and effectiveness of these tools.

Technology assessment tools enable households to assess the costs and benefits of solar and/or batteries, with variable accuracy of results depending on availability of smart meter data. None of these tools include assessment of the impacts of flexibility on electricity bills.

Monitoring tools provide visualisation of energy use (and/or solar generation) which can support households in understanding the energy use and costs of their appliances and in assessing the impact of load-shifting. Some also enable comparison of different tariffs. Costs vary according to whether the monitoring is self-installed (or leverages smart meter data) or requires an electrician. For households to respond to the data presented by these tools requires varying levels of understanding, depending on the nature and design of the user interface.

Smart meters (or ‘dumb’ interval meters) are a prerequisite for households to adopt a time-varying tariff and are also necessary for estimating baseline consumption and measuring demand response. Outside Victoria, where smart meters are mandatory, less than one in five households in the NEM has a smart meter. Although annual smart meter deployment is increasing, driven by rooftop solar installation, end-of-life meter replacement, new connections and retailer-led roll outs, penetration lags behind other jurisdictions.

Enabling control technology goes beyond presenting households with data to giving them a mechanism to control their energy consumption. They include timers, smart plugs and relays, smart air-conditioning control, hot water diverters and Demand response enabled devices (DRED). The control can be manual but remote (e.g., a smart plug operated through a phone app), but more often includes a degree of automation, triggered by a time signal (aligned with a tariff period), by a threshold level of excess solar generation, or by a third party.

6. State of research and barrier analysis

Through a review of the academic literature and industry reports, this section describes the various factors that influence the three stages of household flexibility provision:

- utilities and others making tariff and incentive products available to households;
- households taking up those products (e.g., switching to the tariff, participating in the scheme); and
- households responding to the incentives (e.g., shifting loads to off-peak periods, reducing peak demand).

The review identified a range of barriers or considerations at each stage of the process.

Regulatory considerations

Although there are many regulatory influences on making tariff and incentive products available to households, most are not necessarily barriers. For example, **DNSPs** are not allowed to operate in competitive markets and so cannot provide flexibility services, however third parties can do this, as can ring fenced arms of DNSPs. Although the Tariff Structure Statements and Pricing Proposals through which DNSPs introduce tariffs have limitations on changes that can be made after they are submitted, ‘sub-threshold tariffs’ can be used as long as they contribute less than 1% of the DNSP’s annual revenue, and when combined with the revenue from all other relevant tariffs, make up less than 5% of their revenue. Until recently there were limitations on applying distribution use of system charges (DUOS) charges/rewards to exports, and on applying different tariffs to different customers with a similar connection and usage profile, however the AEMC Rule Determination on ‘Access, Pricing and Incentive Arrangements for DER’ has removed these limitations. This Rule Determination also removes what many considered to be another barrier, which was that the structure of each tariff must be reasonably capable of being understood by retail customers. This has been amended to being understood by retail customers or retailers or Market Small Generation Aggregators, so that DNSPs can provide more complex tariffs to the latter two, who can then package them up for small customers as they see fit.

For **electricity retailers**, although the requirement for the Default Market Offer (DMO) and the Victorian Default Offer (VDO) have placed downward pressure on prices, there are opposing views on their impact on innovation: they may encourage innovation because retailers must be more innovative to find different ways to compete, or they may discourage innovation by discouraging bundled offers, and the VDO requires customers be notified and moved to the flat VDO if their TOU tariff results in a bill more than a specified amount above the VDO. The requirement for Multiple Trading Relationships (MTRs) to have a separate connection point for each retailer/aggregator may also inhibit innovation, although the P2025 process has flagged this as an area for reform. Finally, the more innovative offers may span both the National Energy Retail Law (NERL) and the Australian Consumer Law (ACL), which may discourage retailers offering such products.

Market considerations

The number of households on cost-reflective retail tariffs is low. DNSPs are moving towards **assigning cost-reflective network tariffs** by default for new customers, who can choose to opt out, while CRTs are opt-in for existing customers. Households with peaky loads are unlikely to opt-in to CRTs, and may choose to opt-out, reducing their effectiveness in both allocating costs efficiently and incentivising flexibility. However, mandating CRTs can act as a barrier to smart meter adoption and can decrease trust.

Academic studies of household **price-responsiveness** to CRTs and other incentives report diverse findings. Price-responsiveness, or elasticity, varies between the short and long-term and depends on multiple factors, including having suitable loads, and their availability; socio-demographic and other household characteristics; tariff design and assignment; content and timing of messaging; time of day, week and year; season and weather; external economic and social factors; interaction with everyday routines and practices; and access to data feedback and enabling technologies. This complexity can be a barrier to effective implementation of flexibility incentives and needs to be addressed in research and industry trials.

Some studies and trials have found that the **value of household flexibility** is inadequate to enable sufficient incentivisation of households. This is exacerbated by the cost of recruiting and retaining participant households, particularly for behavioural demand response and direct load control addressing peak demand. The value of flexibility is also highly variable between households (with different loads and ability to shift them), between network locations, seasons and weather conditions. Its future value has additional uncertainty and may diminish as more flexibility enters the various markets. This creates a barrier to the design of incentives and to household decision-making.

There is evidence that the **complexity of the existing retail market**, with 40 retailers offering thousands of tariffs, is overwhelming for many households and there is a risk that the increase in available options – including a greater variety of tariffs and diverse flexibility incentives, technologies and business models – will increase barriers to household decision making.

Enabling technologies

Engagement in electricity flexibility in response to an incentive requires the ability to measure the flexibility (such as a smart meter) and is facilitated by enabling technologies that provide data feedback and/or control of loads, or by DER including solar and batteries. **Access** to these technologies is inequitable, with barriers faced by low-income households, non-homeowners, apartment residents, older or disabled people, or those with low levels of technology literacy. This is, in part, due to the capital and installation costs of these technologies, which can also be a barrier to utilities linking technology deployment to roll-out of incentives.

Smart meters are essential to deployment of time-varying tariffs and to measurement of demand response. Their low penetration in the NEM (17.4% of households outside Victoria) is therefore a significant barrier to household flexibility, due to lower than expected incidence of meter failure, technical installation barriers, challenges of co-ordination between multiple parties, and household antipathy due to perceived lack of value. There is a question whether the current metering governance framework and data management arrangement are properly designed to support innovation in the smart meter rollout.

Control technologies need to be **compatible and interoperable** to enable control of multiple devices, whether remotely by a DNSP or aggregator, or locally, either manually or by a Home Energy Management System (HEMS). Trials suggest that compatibility of appliances with the AS4755 Demand response Enabled Device (DRED) standard is inconsistent and in some cases the implementation of the standard is non-compliant. Moreover, DRED functionality is limited to a few response states and its one-way communication protocol does not enable verification of responses or allow households to opt-out of demand response events. AS47555 is unique to Australia, and adoption of an international standard for HEMS device control, such as IEEE 2030.5 or OpenADR, may be preferable. There are also interoperability issues with smart meters, PV and battery inverters using different communication protocols.

The successful introduction in South Australia of mandated remote export control without requirements for any specific control or communications protocol may suggest there is no need for standardisation. Conversely, compliance with international rather than local standards could serve to reduce costs of compliant appliances.

Challenges associated with **installation** of DER and enabling technologies include communication and co-ordination issues, technical incompatibilities and complexity, and unexpected underlying faults or safety deficiencies. This highlights the value of simpler self-install technologies. For many households engaging in a flexibility scheme or deploying DER, the installer is the main or only point of contact and a key source of information and education. This points to the importance of education and training for installers and electricians.

In order to apply appropriate incentives, household flexibility is commonly measured against a counterfactual baseline load profile. There are challenges in estimating this baseline at the household level, due to the interaction of multiple factors (including weather, social and lifestyle constraints, etc.) affecting the load profile. **Baseline estimation** is particularly challenging for solar households as the relationship between net load and temperature is not straightforward.

Information and communication

Issues relating to **data access** create barriers to the provision of incentives, and to household take-up of, and response to, incentives. The benefit of smart meter data to households, retailers, DNSPs and aggregators is broadly discussed, but the value of the data to each stakeholder is unclear. Under the current metering contestability framework, access to smart meter data is inequitable and it is hard for households to access their data in a usable form. The Community Data Right could play an important role in enabling households to control access to their data, but its progress is slow.

Household understanding of the energy system, and of the relationship between their behaviour and energy use, is variable but generally low. While this can be seen as a barrier to uptake of and response to flexibility incentives, there is a danger that focusing on household understanding puts the onus of responsibility for the energy system on them, rather than on the utilities and institutions that run it. An emphasis on education and energy literacy in isolation is unlikely to significantly increase flexibility. However, there is evidence that DER ownership increases understanding of, and engagement with, household energy use and it is likely that participation in flexibility schemes will similarly increase understanding.

A number of industry trials have reported the difficulty and expense of **communicating** the value proposition of demand response and recruiting participants. Use of ‘customer-friendly’ language, social media, community presentations and recruitment at point of sale have had some success. Real time **digital feedback** of energy consumption and costs can help reduce household consumption, the reported impact varies with different platforms, messaging, and communications approaches and there is less evidence of the impact on flexibility.

Social, cultural and behavioural issues

The report uses the concept of **‘flexibility capital’** to frame the ability of households to respond to flexibility incentives. The sources of flexibility capital are diverse and include available electrical loads, household occupancy, working patterns, building structure, wealth, social and cultural factors, etc. While some households with limited resources are highly incentivised to reduce electricity bills and able to trade comfort and convenience to provide flexibility, others with greater resources are more able to provide flexibility through investment in DER and enabling technologies.

While discretionary loads such as dishwashing, clothes washing and drying are more easily shifted, significant flexibility relies on the **availability of appropriate loads** (electric hot water, air-conditioning, batteries and electric vehicles). As well as requiring the appropriate appliances to be in the household, these loads also need to be in use when demand reduction is needed or ready to turn on when solar soaking is needed. Someone also needs to be home and able to turn loads on or off, or suitable control technologies that can respond to a timer or remote signal are required.

Households may be **unwilling** to take up cost-reflective tariffs or other flexibility products, or to respond to price signals, for diverse reasons, including time constraints, loss and risk aversion, status quo bias, low perceived benefit, information or choice overload, or simply because they have more pressing priorities. Additionally, they may have **concerns** about decreased comfort or convenience, about safety risks, lack of control or autonomy, data security or loss of privacy. Many of these concerns are influenced by a general **distrust** in energy suppliers, particularly retailers, and in the energy market more generally.

A further limitation on the capacity to provide demand flexibility is associated with **household routines and social dynamics**. Household ability and willingness to respond to incentives changes throughout the day and the year and varies between different types of households and on whether the signal disrupts everyday routines, such as those associated with children’s eating and sleeping. The ‘work’ of providing flexibility also puts uneven demands on different household members, at least in part along gender lines. Social and **external factors**, including weather, climate, economics and health also influence household flexibility.

Automation of household loads can enable households to participate in flexibility, while minimising inconvenience. However, legitimate concerns about loss of control, data security, privacy and disruption to daily routines need to be addressed if external parties such as utilities or aggregators are to be granted a ‘social licence’ to automate. This social licence also depends on trust in the program provider, which relies on households having a sense of agency around the terms of their engagement.

Households experiencing vulnerability

Rather than vulnerable households being a distinct identifiable group, **vulnerability** can affect anyone, and does affect a large proportion of Australians at some point in their lives because of illness, loss, natural disaster, bereavement or other life events. However, low-income households, renters, apartment residents, older people, single parents, Indigenous Australians, non-English speakers and people with poor health face particular barriers to taking up and responding to flexibility incentives. These include poorly insulated houses and inefficient appliances, reduced access to DER, smart meters and enabling technologies, health constraints reducing air-conditioning flexibility, high daytime occupancy, and social and cultural factors.

These households have diverse load profiles, but some use very little energy, and so have few options for providing flexibility, while others have large but non-negotiable loads. Applying mandatory or opt-out cost-reflective tariffs to these households can result in increased bills and/or energy saving behaviours that risk health impacts. The complexity of electricity market structures and pricing, and information asymmetries can also disproportionately affect households experiencing vulnerability, and can even trigger or exacerbate that vulnerability.

It is important that research projects assessing the impact of flexibility incentives on household bills include the impact on bills of households that do not respond with flexibility, to avoid increasing the vulnerability of these households.

Delivering net system benefits

Electricity flexibility can deliver net system impacts that provide benefits for all electricity customers. These are: reduced spot prices, a smoother system-level load profile, reduced demand during network peaks and voltage regulation. Any assessment of the ability of tariffs and other incentives to deliver these system benefits ultimately depends on the approaches used to determine how they affect the household load/generation profile. This is generally performed at quite a superficial level, often using a single load/generation profile, which underestimates the impacts of synergistic interactions between technologies and tariffs.

Spot price impacts occur through the merit order effect, which can be assessed a variety of ways including through regression analysis, the use of operational or dispatch models, the UNSW Nempy model, capacity expansion models and PLEXOS. There don't currently appear to be any research or industry development projects that specifically evaluate the ability of tariff and incentive products to reduce spot prices. This could be addressed through the use of simpler dispatch models for shorter-term assessments and a combination of capacity expansion and dispatch models for the longer-term.

Increasing uptake of solar generation is reducing **minimum system demand** and increasing the **afternoon ramp rate**. Although there don't appear to be any research or industry development projects that specifically evaluate the ability of tariff and incentive products to address these issues, they are being undertaken under the P2025 workplans. As they are developed, they should be incorporated into relevant RACE projects.

There has been only limited assessment of the ability of tariff and incentive products to reduce **demand during network peaks**. The most sophisticated methods used to determine the impacts of load profile changes on network asset costs are used by the DNSPs, and are applied at the distribution feeder, zone substation and sub-transmission substation levels. Long-run marginal cost (LRMC) approaches can be used to correlate capital expenditure on the network with changes to the sizes of demand peaks driven by tariffs or other incentives. RACE projects should ensure that their methods are consistent with the approaches used by DNSPs.

Flexible response to tariffs and incentive products can affect **voltages** because they change the load seen by the network and through solar exports. However, there are also many technical solutions to voltage issues being implemented throughout Australia, and as a rule of thumb, technical issues are best addressed through technical solutions. Thus, there is a need to obtain a better understanding of existing voltage issues and the relative effectiveness and efficiency of different options for resolving them.

7. Gaps in existing research and industry development

This section draws on the previous sections and stakeholder interviews to summarise the state of existing research and industry development. Building on the barrier analysis in Section 6, it identifies gaps in existing research and identifies opportunities for future research projects. It is subdivided into Regulatory aspects; Market considerations; Enabling technologies; Information and communications; Social, cultural and behavioural aspects; and Net system impacts.

This analysis forms the basis for the research questions and priority areas described in Section 8. As such, the section is a useful resource to provide context for the specific research questions, but a summary of it here would duplicate information summarised above and in Section 8.

8. Research questions, priority areas and roadmap

Based on the research gaps identified in Section 7, 30 research questions have been identified, grouped into the seven priority research areas shown in Table E-2.

Table E-2 Priority research areas (not in priority order)

	Priority Area	Description	Number of RQs
A	Regulation & policy	Understanding the regulatory barriers to provision of flexibility incentives, including metering.	**2**
B	Data	Provision of and access to data for customers, industry stakeholders and researchers	**2**
C	Tariff and incentive design	Design and modelling of tariffs and incentives, understanding their influence on household uptake and response, and assessing their efficiency, effectiveness and impact	**15**
D	Enabling technologies	Reducing the barriers to deployment of monitoring and control technologies for enabling flexibility	**8**
E	Supporting household decision making	Understanding how and why households take up and respond to different incentives and opportunities, and developing tools and mechanisms to support them	**18**
F	Household vulnerability	Understanding the impacts of incentives and flexibility mechanisms on household vulnerability, including the diverse contexts described in Section 6.6	**8**
G	Value of flexibility	Understanding the value and system impacts of different flexibility incentives and mechanisms	**6**

Table E-3 maps each of the research questions (RQs) to the priority research areas, with most research questions mapping to more than one area. The brackets indicate a priority research area that is less important. More detailed descriptions of the research questions are presented in Section 8.2 of the main report, and the context for each is described in Section 7.

Table E-3 Research questions mapped to priority areas

RQ#	Research Question	A	B	C	D	E	F	G
RQ1	What impacts do the Default Market Offer (DMO) and Victorian Market Offer (VDO) and the National Energy Retail Law (NERL) and Australian Competition Law (ACL) have on tariff innovation?	A		(C)				
RQ2	What is the value of smart meters to households and to different industry stakeholders, and how can how can this value be leveraged to increase smart meter penetration?	A	B		(D)	(E)		(G)
RQ3	Given the development of datasets such as My Energy Marketplace and the commercially available datasets, what are the gaps in publicly available high-resolution data and how can they be filled?		B					
RQ4	What is the impact of opt-in versus opt-out tariffs on i) household engagement and trust in the electricity system, and ii) household electricity use and load profiles?			C		(E)		
RQ5	To what extent do retailers pass through the costs they are exposed to and why?			C				
RQ6	What are the costs and benefits and other impacts of networks presenting retailers with a network charge based on their aggregated customers?			C				
RQ7	How can embedded network tariffs and other flexibility incentives be designed so that they optimise outcomes for the households on the EN as well as system-level outcomes?			C		(E)		
RQ8	What is the best way to design tariffs so that the benefits of local network use and generation that supports the network (for example with LET/P2P or community batteries) are shared with households?			C		(E)		
RQ9	How do the tariffs/pricing models for at-home and public EV charging interact and affect charging behaviour?			C	(D)	(E)		
RQ10	How can technology installers be better supported (through training, incentives or other means) to help facilitate household flexibility?				D			
RQ11	What types of control technology tools best enable different types of households (including those experiencing vulnerability) to take up and respond to tariffs and other flexibility incentives?				D		(F)	
RQ12	How can (near) real-time data feedback best contribute to enabling household flexibility and long-term behaviour change?				D	(E)	(F)	
RQ13	What is the best way to introduce cost-reflective tariffs?					E		
RQ14	How can the variability of household impacts of market-based incentives (and of the incentives themselves) be minimised and what types of households are best suited to such incentives?			(C)		E		
RQ15	What is the ability of non-financial incentives to increase either uptake of flexibility opportunities and enabling technologies or flexible response to signals?					E		
RQ16	What are the characteristics of tariff comparison and technology assessment tools that best enable different types of households (including those experiencing vulnerability) to assess and make decisions about taking up cost-reflective tariffs and other flexibility opportunities?					E	(F)	
RQ17	What role can community organisations, NGOs and trusted 3rd parties play in supporting households (including those experiencing vulnerability) in decision-making and provision of flexibility?					E		
RQ18	How can we move from a perceived need for customer education to provision (by utilities and aggregators) of accessible opportunities that enable households (including those experiencing vulnerability) to engage in flexibility opportunities, and also increase their understanding through this engagement?					E	(F)	
RQ19	How can the load-specificity of household flexibility be addressed with appropriately targeted incentives and enabling technologies?			(C)	(D)	E		
RQ20	In which conditions are households prepared to trade comfort and convenience, with respect to different energy services, for bill savings (or environmental and social benefits)?				(D)	E	(F)	
RQ21	How do the various approaches to encourage the uptake of non-mandated cost-reflective tariffs compare in effectiveness?			(C)		E		
RQ22	How do the various influences on household behaviour affect price responsiveness?			(C)		E		G
RQ23	What is the household appetite for complexity (e.g., flexibility schemes with multiple contractual variables including cost, capacity, level of control, override, etc.) vs simplicity (e.g., subscription pricing) and for risk vs certainty, and how can innovative business models and contracting address this?			(C)		E		
RQ24	How do the diverse load profiles of households experiencing vulnerability impact their capacity for flexibility? (Priorities G)						F	
RQ25	How can energy rebates and DER subsidies, as well as flexibility incentives, be better designed and targeted to reduce household vulnerability, provide network benefits and improve long-term outcomes for households experiencing vulnerability?			(C)			F	
RQ26	How can more equitable access to DER (including solar, batteries, EVs) and control technologies be achieved, particularly for renters (overcoming the split-incentive) and low-income households (overcoming the barrier of upfront capital costs to unlock lifetime benefits)?				(D)	(E)	F	
RQ27	To calculate accurate baselines used for rewarding demand response there is a need for a thorough understanding of the relationship between net household load (particularly for solar households) and a range of factors including temperature, time of day, day of week, and household characteristics including DER ownership, type and operation.							G
RQ28	What are the impacts of increased DER uptake and household flexibility response on the value of that flexibility and what are the implications for future incentives and cost recovery?							G
RQ29	How do different tariffs/incentives, technologies and behaviour synergistically interact at the individual household level, and how does this translate into LV level and into system-wide impacts and therefore into impacts on other households?			C				G
RQ30	What net system impacts are driven by tariffs and other incentives through electricity flexibility?			(C)				G

Figure E-2 shows the RQs plotted according to their importance and the time and resources needed to address them. The RQs can be broadly divided into those that can be addressed relatively quickly, through literature and market reviews, desktop analysis, modelling and cross-sectional social science research (interviews, focus groups), and those that require market trials of incentives and technologies and/or longitudinal social science research over a longer timeframe. Some RQs might be best addressed through a two-stage process starting with initial desktop analysis and/or stakeholder interviews (labelled ***a***) followed by a longer-term longitudinal market trial (labelled ***b***).

For both trials and modelling of tariffs and incentives, it is important that research outputs include the impacts on households that do not participate, or participate but do not respond, as there will always be households like this, including households experiencing vulnerability.

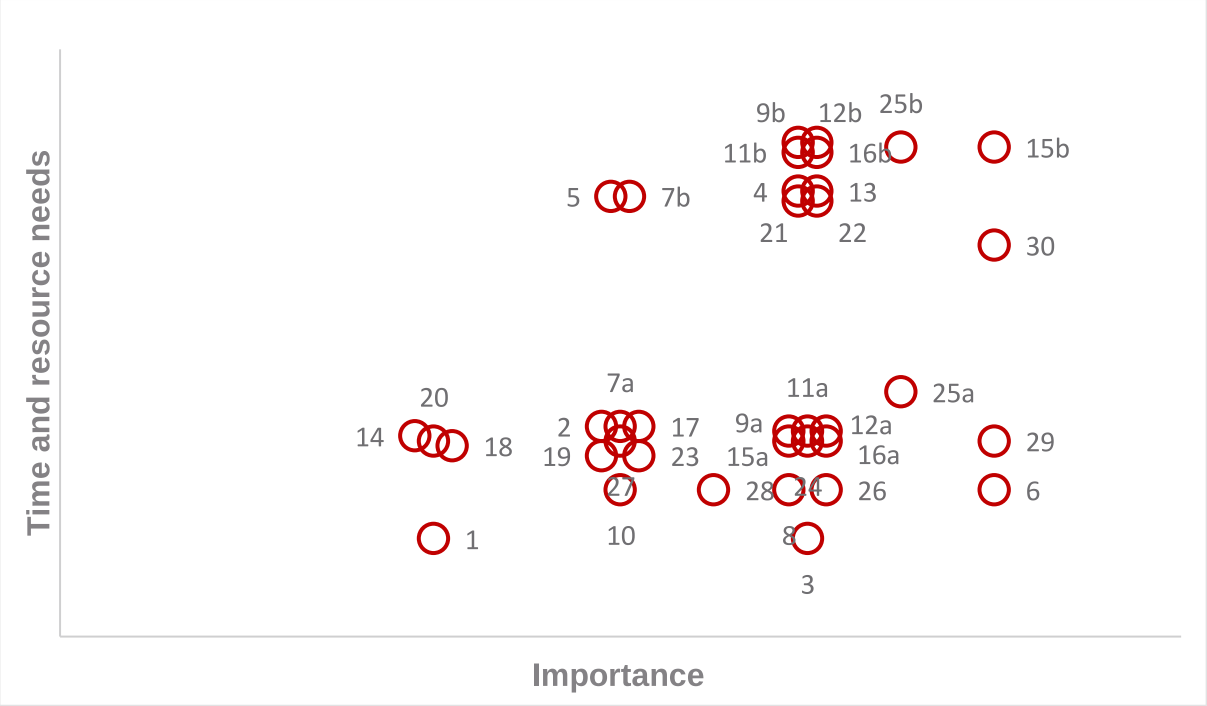

Figure E-2 RQs ranked by importance and time/cost

9. Benefit-Cost assessment for adoption of cost-reflective tariffs and incentives in 2030 and 2035

Modelling undertaken by EPRI is included as a separate report and provides a high-level assessment of the economic value to Australia of accelerated adoption of cost-reflective residential electricity tariffs and customer incentives. The main focus is on direct economic impact to consumers, through their electricity bills and any direct incentives for program participation. In parallel, system-wide avoided costs are also estimated as an alternative measure of economic impact. For each type of tariff or incentive considered, a single generic specification was applied. Direct customer bill impacts are projected based on a household peak load of 5 kW. Systemwide impacts such as avoided generation costs are projected based on an average household contribution to system peak of 2 kW.

Accelerated adoption of cost-reflective tariffs was defined as 90% of consumers enrolled in time-of-use (TOU) tariffs in 2035 (instead of 70%); 70% of consumers enrolled in controlled-load (CL) tariffs (instead of 50%); and 10% enrolled in other direct load control (DLC) tariffs (instead of 1%).

Table E-4. Customer participation rate assuptions for 2035 for accelerated adoption of cost-reflective tariffs/incentives.

Scenario	**Share of customers participating in…**		
	Time-of-use tariff	Direct load control tariff	Controlled load tariff
2021 estimate		1%	25%
Business as usual scenario	70%	1%	50%
Accelerated adoption scenario	90%	10%	70%

This accelerated adoption is projected to yield cumulative, discounted, risk-adjusted direct customer bill benefits of $3.9 billion to 2035. The costs for implementing these programs are approximated at $0.8 billion over the same period, yielding a net overall benefit of approximately $3.2 billion. The accelerated adoption is projected to reduce evening peak by 480 MW under the assumptions incorporate in this study, and to yield cumulative avoided emissions of 1.9 MtCO2eq to 2035.

A range of scenarios compare the effects of increased on-peak/off-peak price ratio in TOU tariffs, as well as high levels of CL tariff adoption and residential battery uptake.

Table E-5. Summary of alternative accelerated adoption scenarios.

Scenario	**Base case value**	**Alternative value**
(1) Accelerated CRT adoption base case	--	--
(2) High on-peak/off-peak TOU rate difference	3:1 (45 / 15 c/kWh)	4:1 (60 / 15 c/kWh)
(3) High CL tariff adoption	70%	90%
(4) High behind-the-meter battery adoption	2.74 GW (548,800 units)	9.60 GW (1,918,400 units)
(5) High DLC tariff adoption	1%	10%

Each of these additional scenarios leads to increased direct customer benefits. Only (2) higher on-peak/off-peak TOU rate difference and (4) higher behind-the-meter battery uptake significantly impact the projected evening peak load reduction, avoided system costs, and avoided emissions.

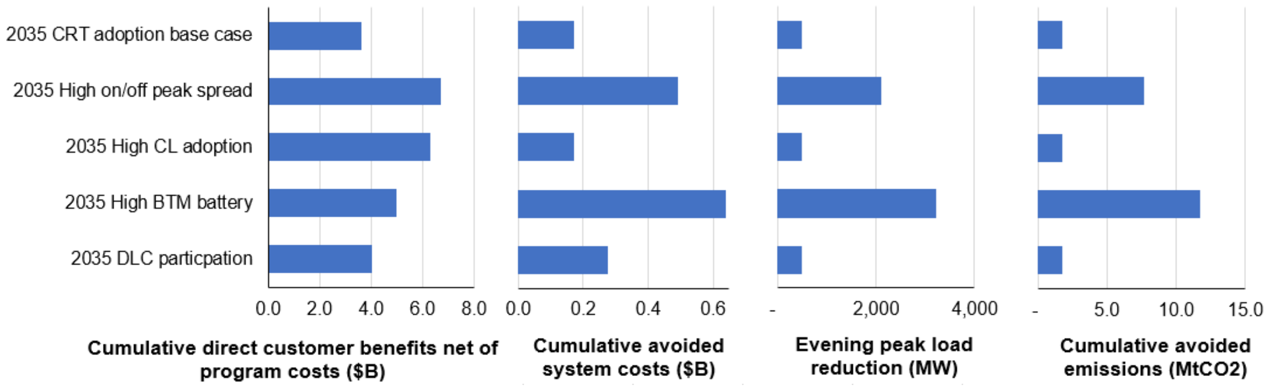

Figure E-3. Summary of projected discounted cumulative impacts in 2035 of different scenarios for tariff/incentive design and battery adoption, relative to the 2035 BAU scenario. Economic benefit values are discounted and risk-adjusted as discussed in the main text.

The following research recommendations derived from the modelling exercise are summarised below and are described in more detail in Section 8.2.1.

i. Characterise (or estimate) the interaction between tariff/incentive design and BTM battery uptake and incorporate into the financial modelling analysis.

ii. Estimate value of “filling the belly” and incorporate this into revised analysis of economic impact.

iii. Investigate and document the impact of enabling technologies on price elasticity of electricity consumption.

iv. Determine likely scenarios for time of residential EV charging and incorporate this into impact assessment for CRT/incentive adoption.

v. Explicitly specify load patterns and price responsiveness of diverse household types.

vi. Compile and incorporate updated network augmentation and operating costs from DNSPs.

vii. Segment this analysis by state and territory.

Contents

List of Appendices

Appendix A: Review of network and retail tariffs

Appendix B: Review of enabling tools

Appendix C: In-depth tool analysis

Appendix D: Review of price elasticity studies

List of Abbreviations

Abbreviation	**Words**
A/C	Air conditioning
AEMC	Australian energy market commission
AEMO	Australian energy market operator
AER	Australian energy regulator
BDR	Behavioural demand response
BESS	Battery energy storage system
BMS	Battery management system
CDR	Community data right
CPP	Critical peak pricing
CRT	Cost-reflective tariff
DCT	Digital comparison tool
DLC	Direct load control
DMO	Default market offer
DNSP	Distribution network service provider
DPV	Distributed photovoltaics
DR	Demand response
DRED	Demand response enabled device
DRM	Demand response mode
DSP	Demand side participation
DUOS	Distribution use of system
EC	Flexibility Capital
EHW	Electric hot water
EN	Embedded network
ENO	Embedded network operator
ENSP	Embedded network service provider
EQ	Energy Queensland
EV	Electric vehicle
FC	Flexibility capital
FCAS	Frequency control ancillary services
FIT	Feed in tariff
HVAC	Heating, ventilation and cooling
IHD	In-home display
IR	Infra-red
LUOS	Local use of system
MASP	Market ancillary services provider
MASS	Market ancillary service specification
MGSA	Market small generation aggregator
MTR	Multiple trading relationship
NEM	National energy market
NER	National electricity rules
NSW	New South Wales
NUOS	Network use of system
PCW	Price comparison website
PIP	Passive-Interactive-Proactive
PP	Pricing proposal
PP	Pool pump
PTR	Peak time rebate
SGA	Small generation aggregator
SITTM	Sticking it to the man
SM	Smart meter
SSC	Solar self-consumption
SWIS	South-west interconnected system
TNSP	Transmission network service provider
TOU	Time of use
TSS	Tariff structure statement
TUOS	Transmission use of system
VDO	Victorian default offer
VIC	Victoria
VPP	Virtual power plant
VPP	Variable peak pricing

1 Introduction

The RACE 2030 H4 Theme ‘Rewarding residential electricity flexibility: User-friendly cost-reflective tariffs and incentives’ aims to develop and demonstrate innovative, flexible and dynamic pricing and incentives for households.[1] It aims to accelerate their adoption and so support the effective deployment and operation of distributed energy resources (DER) including solar PV, batteries, controllable loads and smart appliances. This can provide benefits directly to households (by reducing electricity bills and fulfilling other values) as well as system-wide impacts that benefit other households, such as reduced wholesale spot prices, reduced network peaks and the provision of ancillary services.

This Opportunity Assessment focuses on the following priority challenge areas that were identified through previous consultation with RACE for 2030 partners.

1. Behavioural and social reactions of households to new tariffs and incentives
2. Household support tools
3. Tariff design

It is arranged as follows:

Sections 2 to 5 describe the current state of play with respect to available markets for flexibility, tariffs and other incentives available to households, the mechanisms that can be used to provide flexible response and the tools available to support customers in decision-making around uptake of and response to incentives. Sections 6 to 8 present the barriers to flexible incentives and how these are being addressed by research and industry development activities and analyse the gaps in this research in order to develop a research roadmap for the H4 theme. Section 9 describes an assessment of the potential financial value of household flexibility.

Section 2 ‘Markets for residential electricity flexibility’ provides a summary of the existing and potential markets available for households to provide electricity flexibility[2].

Section 3 ‘Tariffs and other incentives’ details the available network and retail tariffs, as well as their current level of uptake. It also discusses other financial incentives for flexibility and a range of non-financial incentives that can tap into household motivations and values.

Section 4 ‘Mechanisms for electricity flexibility response’ describes the various mechanisms used to respond to tariffs and other incentives. These include energy management behaviour, Battery Management Systems, Home Energy Management Systems, Direct Load Control, Controlled Load, Behavioural Demand Response and Virtual Power Plants.

Section 5 ‘Tools to support household decision-making’ describes the existing tools available to support household decision-making with respect to taking up and/or responding to tariffs and other incentives.

Section 6 ‘**State of research and barrier analysis’** presents a review of the academic literature and findings from industry trials and research and from the regulatory environment. The review covers regulatory and market considerations, metering and control technologies, social, cultural and behavioural issues, information and communication, as well as the specific issues affecting the ability of households experiencing vulnerability. This leads to an analysis of the barriers faced by retailers, networks and aggregators in making tariff and incentive products available to households, as well as the barriers faced by households in taking up and responding to tariff and other incentives.

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[1] We refer to “households” (which are dynamic and multifaceted and subject to multiple influences) rather than “customers” (who are singular and defined by their relationship with the retailer or whoever else is selling them a product).

[2] Electricity flexibility includes any change to end-user electricity use (demand or export) in response to a signal, including tariffs.

Section 7 'Gaps in existing research and industry development' builds on the previous sections as well as feedback from stakeholders to discuss the extent to which the barriers identified and related issues are being addressed by current research and industry development activities, and identifies the gaps that present opportunities for future research projects.

Section 8 'Research questions, priority areas and roadmap' uses the research and development gaps and opportunities to derive a set of outstanding research questions across 7 priority areas. These are prioritised and synthesised into a research roadmap for the H4 theme.

A separate report 'Benefit-Cost assessment for adoption of cost-reflective tariffs and incentives in 2030 and 2035' undertaken by EPRI describes modelling that was undertaken to provide a high-level assessment of the financial potential of household-friendly tariffs and incentives that reward electricity flexibility. It also identifies critical parameters that can influence household uptake and engagement with electricity flexibility, which therefore are identified as priority areas for research and industry development.

Note that the focus here is not so much as providing a comprehensive coverage of all the issues nor to solve all the problems facing the provision of electricity flexibility. It is to identify the research priorities for the H4 theme. Of course, priority areas more suited to industry opportunities will also be identified.

1.1 Conceptual Framework

The conceptual framework shown in Figure 1-1 has informed this report and aims to illustrate the multiple factors that influence residential electricity flexibility. It is conceived from a household perspective and does not purport to show the structure of the electricity system or the relationships between all stakeholders. If it was drawn from the perspective of a retailer, DNSP or aggregator it would look very different (and this would be a valuable exercise), but our focus here is the household.

The starting point for the framework is that, in order to deliver flexibility, households must *first take up an offer* (adopt a tariff, buy a battery, sign-up for a VPP or behavioural demand response trial, etc.) and then provide a *flexible response* to a signal (shift a load to avoid a peak tariff period, reduce demand during a network peak event, charge a battery to absorb excess solar generation, etc.). Both uptake and response are influenced by many factors.

The *end results* of increased flexibility can include reductions to peak demand, peak export, ramp rate and spot-prices, which flow through to reduced household bills, increased DER hosting capacity, lower emissions, higher reliability, jobs and social benefits.

To increase household flexibility, both the uptake and response steps must be incentivised. Possible *household incentives* (described in Section 3) include various types of cost-reflective tariff, other financial rewards such as discounted hardware or payments for reduced demand and non-financial (e.g., environmental or community) benefits. The structure and value of financial incentives are shaped by signals from the wholesale market, network constraints, etc., and also influence the financial outcomes of delivered flexibility. Other, non-financial, incentives and messages can also influence uptake and response, either alone or combined with financial ones.

The degree to which households can respond to these incentives depends on their capacity to do so, sometimes called '*flexibility capital'* which includes their intrinsic *abilities* (health, understanding, etc.) their level of *opportunity* (having appropriate loads, time to engage, insulated homes, money, etc.) and their access to *enabling technology* (including smart meters, data visualisation, control devices, etc.). Their response also depends on their values or internal motivations which, in turn, are shaped by the societal context.

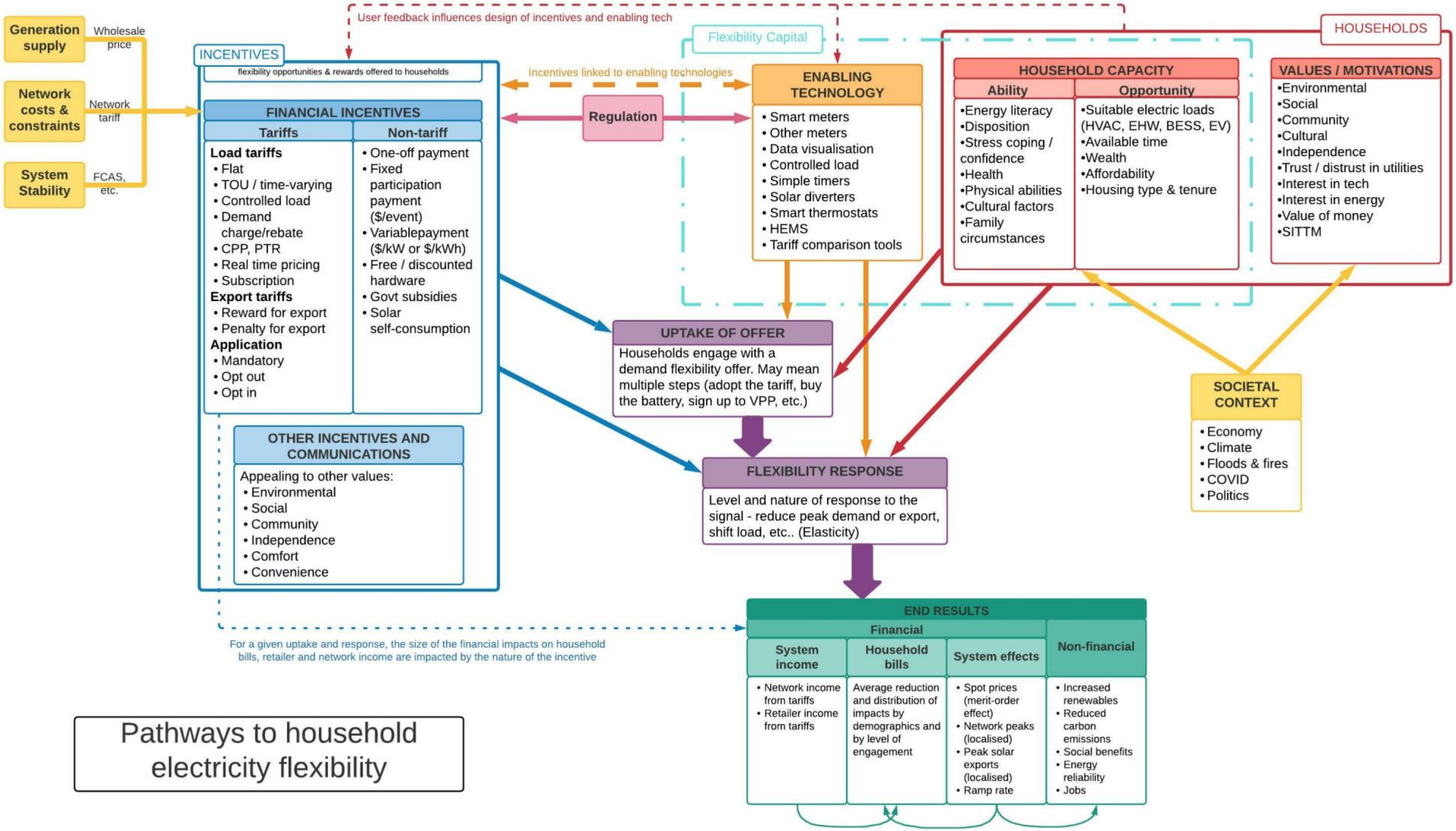

Figure 1-1 Conceptual framework showing pathways to household electricity flexibility and the multiple factors that influence take-up of offers and flexibility response to signals

Because enabling technologies are an important contributor to flexibility capital, there is (or should be) a close interrelation between the types and availability of these technologies and the design and implementation of incentives, with the two sometimes bundled together to create flexibility products and mechanisms. Design and deployment of both incentives and technologies are, of course, strongly influenced by regulation. Feedback from households is an important consideration in the design of incentives, technologies and mechanisms.

The framework suggests that the multiple influences on household uptake and response will preclude ‘one-size fits all’ tariffs and incentives. Successful incentive design requires segmentation of households according to their available loads, capacity and values. It is incumbent on utilities to provide flexibility opportunities that align with household abilities and opportunities to respond.

2 Markets for residential electricity flexibility

There are several existing and potential markets available for households to provide electricity flexibility. Broadly speaking, there are currently three markets that households can potentially participate in: the wholesale spot market, network markets and ancillary services markets. Local energy trading (LET) is a fourth type of market that operates within these other markets.

As discussed in detail in Section 3, residential electricity users can access these markets through a variety of routes. The most common is through tariffs in the retail electricity market, which as discussed below, include a wholesale price component as well as regulated network components (transmission use of system[3], TUOS; distribution use of system, DUOS; which combined for the network use of system, NUOS), which may include time-varying volumetric rates and/or demand or capacity charges. Solar (‘prosumer’) households are able to self-consume their generated electricity or export it, which may attract a feed-in tariff (FIT) from the retailer, related to the wholesale cost of electricity. Using electricity flexibility to respond to tariffs can provide value in the wholesale electricity market by reducing spot prices and helping to maintain minimum system-level operational demand, can also provide value to networks by reducing demand at peak times and by reducing exports.

Households can also use electricity flexibility to participate more directly in the wholesale spot market using commercially available options (through an aggregator) and through a number of virtual power plant (VPP) trials involving retailers and aggregators. Similarly, trials are available to selected households where electricity flexibility can be used to directly provide network support to DNSPs, as well as provide value into ancillary services markets (the provision of frequency controlled ancillary services (FCAS)).

LET, also known as peer-to-peer trading (P2P), is another market where households can use electricity flexibility to generate value for themselves. Instead of responding to fixed tariffs, households can bid into an electricity marketplace where other participants also bid in either demand or generation. The electricity is then allocated according to the matched bids.

Although Embedded Networks could be considered another market, they are essentially just a privately owned network where derivations of currently available tariffs may be used, and so are not considered a separate market here.

Demand Response (DR) can be delivered through direct load control (DLC) of appliances (commonly air conditioning (A/C), electric hot water (EHW), electric vehicles (EVs) or pool pumps) by a 3rd party; behavioural demand response (BDR), which involves householders switching off appliances or changing thermostat settings in response to a message from the 3rd party; or by participation in a VPP trial whereby household battery energy storage systems (BESS), EVs or other appliances are orchestrated to offer aggregated DR to the various markets.

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[3] The ‘use of system’ charges refer to any charges that electricity users pay for the use of the relevant electricity network. These cover costs such as capital expenditure, operation and maintenance.

Depending on the market involved, the 3rd party may be a retailer, DNSP or other aggregator, although there are constraints on which markets different types of aggregator can trade the DR.

2.1 Possible future markets

There are of course many possible future markets for household engagement in electricity flexibility. The success of and level of participation in future VPPs remains to be seen, with the current VPP trials focusing on technical aspects and customer acquisition. Household participation in the trials is subsidised, and so the financial viability of the VPPs is untested.

A two-sided market has been proposed by the Energy Security Board (ESB) to increase the potential for demand side participation in the wholesale market and network support. Consultation with stakeholders is ongoing, including exploring new tariff structures and options for more flexible, locational price signals, as well as development of an appropriate consumer protection framework (Energy Security Board, 2021).

A variation on LET as described above is where households still sell their excess solar to other households or charge their battery using excess solar generation from other households and discharge to meet their neighbours demand, but this does not occur through a marketplace but instead is simply in response to tariffs.

It is important to note that there may be future limitations on markets for DR due to requirements imposed through technical standards and by DNSPs as well as due to direct control by DNSPs and AEMO. Additionally, electricity flexibility successfully incentivised through one market may undermine the business case for some of these emerging markets. For example, a high uptake of and response to cost-reflective tariffs might reduce the need for VPPs that target high spot prices and network demand peaks.

3 Tariffs and other incentives

Incentives for households to provide electricity flexibility include electricity tariffs but also a range of other price and non-price incentives. This section first discusses electricity tariffs (broken down into network tariffs and retail tariffs). It then introduces the other types of incentives through the different types of mechanisms used to respond to them (for example, battery management systems, home energy management systems, Direct Load Control, Behavioural Demand Response and VPPs). It then discusses the various tools available to support household decision-making.

3.1 Electricity tariffs

Electricity tariffs come in many shapes and sizes and can be applied to both consumption and export. Although most households in Australia are on flat tariffs (which provide no price signal for electricity flexibility), a range of time-varying tariffs are available, with the most common being time of use (TOU)[4] and demand tariffs, although tariffs linked to wholesale spot prices are also emerging. Although households face a single retailer tariff, it consists of TUOS, DUOS, jurisdictional scheme charges, wholesale spot price, market fees and retailer margin components. Another type of tariff that enables electricity flexibility, despite essentially being a flat tariff, is a controlled load tariff. Whereas tariffs such as TOU and demand charge require ongoing responses to price signals, controlled load tariffs require a single decision by the household to go onto that tariff, with the load response then being automated, generally by the distribution network service provider (DNSP) through ‘ripple control’. The most common form of retailer export tariffs (which are more payments than tariffs) are FiTs that have been used to drive the uptake of solar PV. These were originally deployed at premium rates but (apart from legacy systems) are now only set by retailers at the avoided cost of generation in the wholesale spot market plus a value for customer acquisition. As part of its ruling on minimum FiT rates (which ‘have regard’ for the avoided social cost of carbon and the avoided human health costs attributable to a reduction in air pollution), the Victorian Essential Services Commission

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[4] While some utilities use TOU to describe time-varying tariffs with two charging periods and rates (peak / off-peak), and ‘flexible tariff’ to describe those with three or more rates, others use TOU as a general term to describe both categories; in this report, we use the more general meaning of TOU.

includes a TOU FiT option with off-peak, shoulder and peak rates.[5] However, as discussed in Section 3.1.2, we are not aware of any Victorian FiTs with TOU rates. The NSW Independent Planning and Regulatory Tribunal (IPART) sets its FiT benchmark based only on the avoided cost of wholesale generation, but has also recently included a draft TOU FiT with seven different rates that are generally higher between 3pm and 7pm, peaking between 5pm and 6pm.[6] As discussed in Section 6.1.1, the AEMC has released a Rule Determination on 'Access, Pricing and Incentive Arrangements for DER' rule determination (hereafter referred to as the AEMC's 'APIA for DER' rule determination) regarding the imposition of network charges for export as well as payments for export at times valued by the DNSP.

Appendix A presents a review of residential network tariffs across all DNSPs in the NEM, as well as a summary of available retail tariffs in the Ausgrid, SAPN and Ergon networks. The key insights are summarised below.

3.1.1 Network tariffs

It is important to note that most households only 'see' the tariff on their electricity bill, where all the various components, including the network charges, have been bundled together by the retailer. Although NUOS charges comprise around 40% to 50% of the average household bill, households are therefore only impacted by their network tariff to the extent that the retailer passes it through (as discussed in Section 3.1.2). Embedded network tariffs are discussed in Section 3.1.3.

3.1.1.1 Available network tariffs

The structure of NUOS can include some or all of:

- Fixed daily charges (c/day)
- Volumetric (c/kWh) charges, which can be flat rate or time varying. The terminology varies but in this report *time of use (TOU)* is used to refer to time-varying tariffs with at least two charging rates (peak and off-peak) or with three or more rates (peak, off-peak, shoulder[7]). There may be 1 or 2 peak periods each day and some tariffs have different periods for weekends and weekdays, or between 2, 3 or 4 seasons.
- Demand charges (c/kW/day or c/kVA/day), are applied to either the monthly peak demand (generally half-hourly) or a rolling 12-month peak demand, within peak demand periods in each day. Like volumetric tariffs, there may be more than one peak demand period each day and it may be different for weekends and weekdays, or between seasons.
- Controlled load (CL) charges are a (usually low) volumetric rate applied to a separately metered circuit, controlled (either by a local timer or remotely using 'ripple control') to only be active during certain periods: Type 1 is only active during a single off-peak period, usually overnight, Type 2 is active for more than one period, but excludes peak periods.

Table A1 in Appendix A includes a review of network tariffs currently available (as at April 2021) to new residential customers in the NEM (as well as some legacy existing tariffs). Horizon Power is not included in this list because it is a vertically integrated utility, combining generation, network and retail services and so doesn't publish separate network tariffs.

Table A1 includes the rates for all tariff components, including demand charges where applied, while Table A2 shows the charging periods for both TOU and demand charges. There is a significant degree of variability in all tariff components, that presumably reflects the different circumstances for each DNSP – see Table 3-1. The lower fixed daily charge rates generally correspond to tariffs with high demand or volumetric charges and the high fixed daily rates correspond to very isolated regions in Ergon's network. The lowest

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[5] https://www.energy.vic.gov.au/renewable-energy/victorian-feed-in-tariff/current-feed-in-tariff
[6] https://www.ipart.nsw.gov.au/Home/Industries/Energy/Reviews/Electricity/Solar-feed-in-tariff-benchmarks-2021-22-to-2023-24
[7] In Victoria, TOU tariffs with 3 charging periods are sometimes called *flexible pricing*, although the term is more often used with a broader meaning.

volumetric rates correspond to a number of TOU tariffs' off-peak periods, and the higher rates correspond to TOU peak rates, again in Ergon's isolated regions. The lowest demand charge rates correspond to introductory/transitional tariffs and the highest demand charge rates correspond to SAPN's residential prosumer tariff, presumably because it targets households with the capacity to reduce their peak demand. Although SAPN's residential prosumer (Solar Sponge) tariff is notable for its public visibility, Endeavour, EvoEnergy and Energex have tariffs with similar structures. It is unclear why the TOU and demand charge tariffs have such a range in peak periods, but narrower periods should more accurately target network peak demand.

The low fixed daily charges for the controlled load tariffs generally, but not always, correspond to higher volumetric charges, and the higher fixed daily charges correspond to tariffs that offer two different periods of availability. The higher volumetric charges correspond to controlled load tariffs with TOU components, and which run for 24 hours per day (only SAPN).

Table 3-1. Default tariff type for each DNSP

Tariff component	**Rate range**	**Period range**
Fixed daily	5.59c/day to 240.57c/day	
Volumetric	2.27c/kWh to 59.91c/kWh	3 to 14 hours/day
Demand	1.1c/kW/day to 84c/kW/day	3 to 8 hours/day
Controlled load fixed daily	0.00c/day to 13.25c/day	
Controlled load	1.46c/kWh to 18.95c/kWh	8 to 24 hours/day

3.1.1.2 Variability and complexity of network tariffs

Although all 12 DNSPs in the NEM offer TOU tariffs as well as demand charges combined with either flat or TOU volumetric charges, there is great diversity in the degree of time-variability (number of different rates, whether they apply on weekends, and whether they apply in different seasons) and the relative weighting of different components.

Figure 3-1 shows the ratio of peak to off-peak charges for network tariffs with a TOU component. There is significant variation between DNSPs, with the ratio of peak to off-peak volumetric charges ranging from 2.0 (Essential Energy's TOU demand charge tariff) and 9.5 (Ausnet's TOU tariff).[8] The 9.5 ratio is for a tariff that has a smaller peak window (4 hours) and runs over three seasons, and of the next four highest ratios, three of them are for Ergon's[9] western region tariffs, and one is for Ausgrid. There is also a significant spread between the TOU demand tariffs, from 2.01 (Essential Energy) to 5.01 (SAPN) to 8.6 (Ausgrid). Apart from transitional tariffs,

Ausgrid has the smallest demand charge (1.39 $/kW/month), followed by Powercor (2.44 $/kW/month), then Ergon (4.00 $/kW/month) and Essential (4.40 $/kW/month), with SAPN having the highest at $25.63/kW/month, so there is no clear correlation between this ratio and the level of the demand charge.

Figure 3-2 shows the ratio of peak volumetric charge to network access charge for network tariffs with a TOU component. Again, there is a very significant spread in ratios between tariffs, ranging from 0.03 (Ergon Energy's block tariffs) to 1.43 days/kWh[10] (United Energy's TOU tariff). The tariffs with lower ratios tend to be either flat tariffs or demand charge tariffs.

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[8] It appears that TasNetwork's TOU demand and Demand tariffs don't have a usage tariff component all, only the demand charge component.

[9] Although Ergon Energy and Energex come under the umbrella of Energy Queensland, they service very different areas and have separate network tariffs.

[10] These rather odd units are the result of dividing the volumetric charge (c/kWh) by the fixed daily charge (c/day), giving days/kWh. Still, it remains a useful metric because it allows a comparison across retailers and with respect to the underlying network tariff.

Figure 3-3 shows the ratio of demand charge to network access charge for network tariffs with a demand charge component. Here the ratio is split clearly into tariffs with a high ratio (SAPN at 1.64 and Jemena at 3.7 days/kWh), and the rest of the tariffs with ratios much less than 1. The high ratios for SAPN and Jemena were due to their high demand charges (23.147 c/kW/day and 20.166 c/kW/day respectively) rather than low daily access charges.

Figure 3-4 compares the energy charge and daily access charge for the networks' controlled load tariffs. Although most have a zero or very low daily access charge, three DNSPs are much higher (Ausgrid, Essential Energy (two tariffs) and TasNetworks). There is significant variation in the energy charges, ranging from 1.46 c/kWh to 6.9 c/kWh. One DNSP (SAPN) offers a choice between a flat and a TOU controlled load tariff. As shown in Figure 3-5, there is also significant variation in the number of hours per day that controlled load power is available. There is something of a trend for higher prices to be available for more hours.

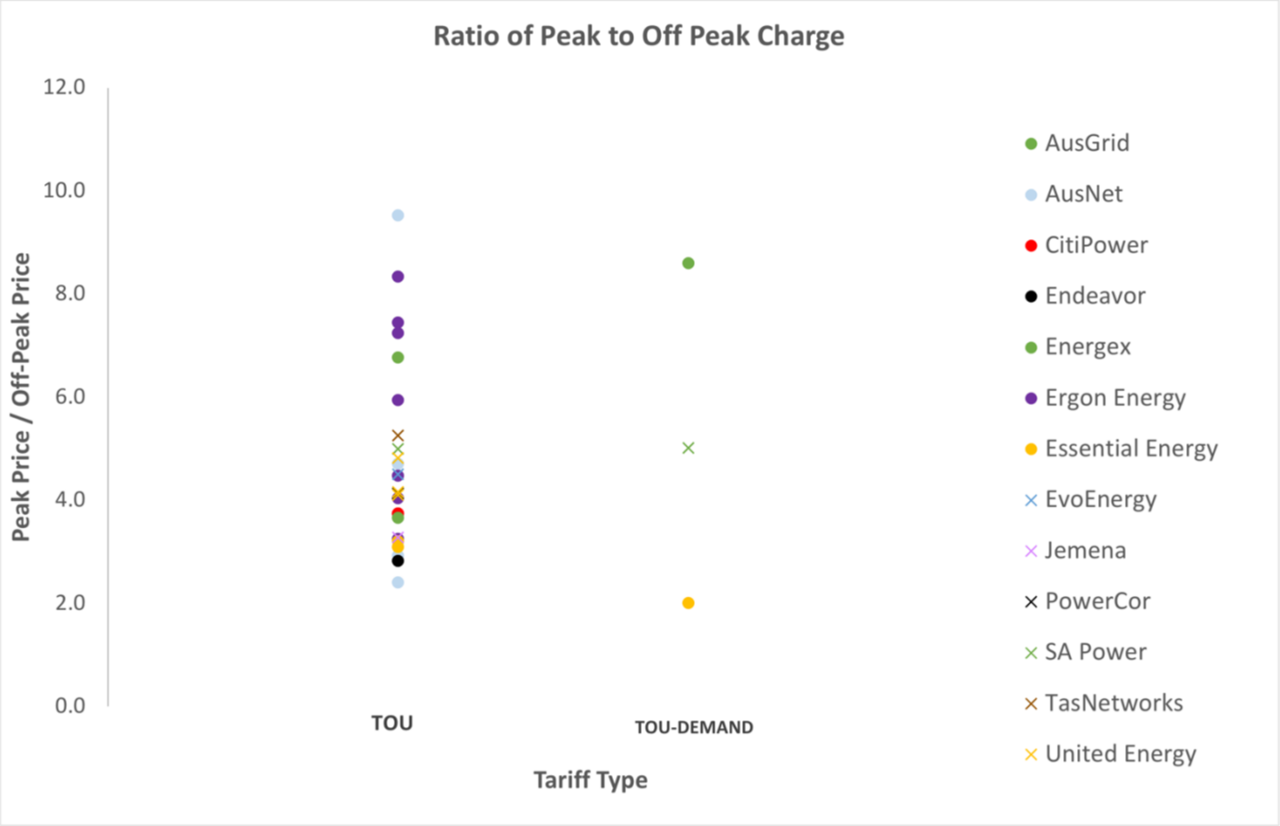

Figure 3-1. Ratio of peak to off-peak charges for network tariffs with a TOU component

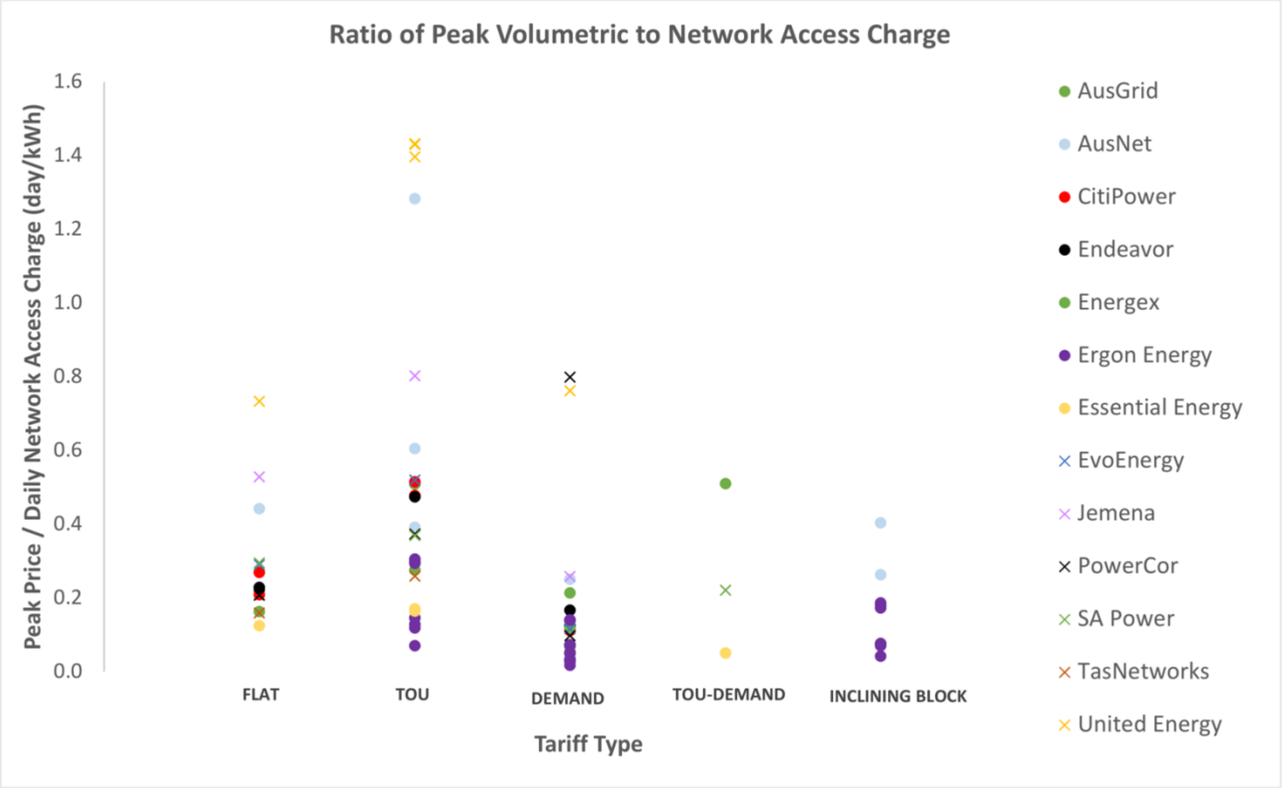

Figure 3-2. Ratio of peak volumetric charge to network access charge for network tariffs with a TOU component

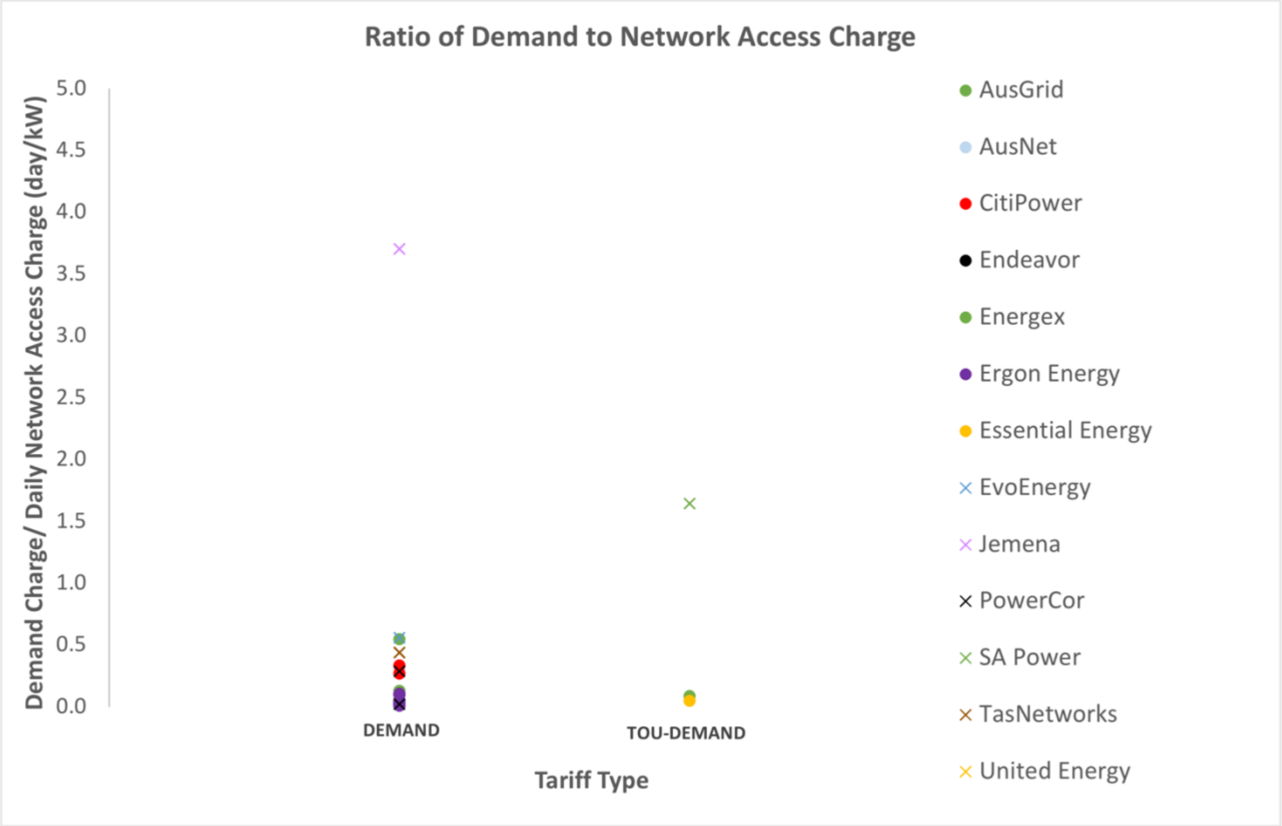

Figure 3-3. Ratio of demand charge to network access charge for network tariffs with a demand charge component

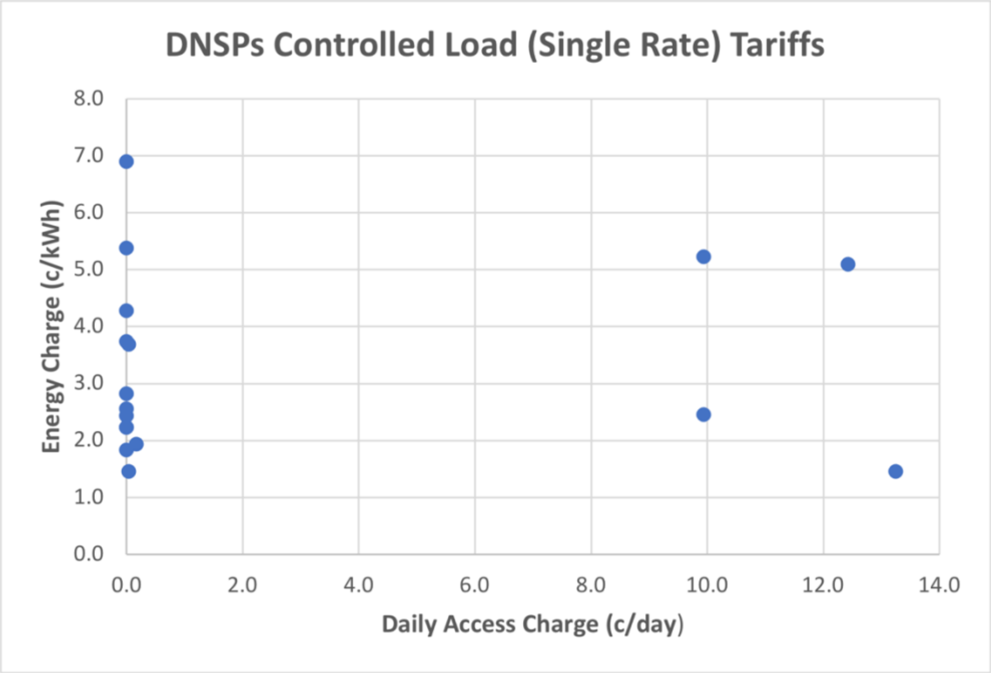

Figure 3-4. Comparison of the energy charge and network access charge for controlled load network tariffs

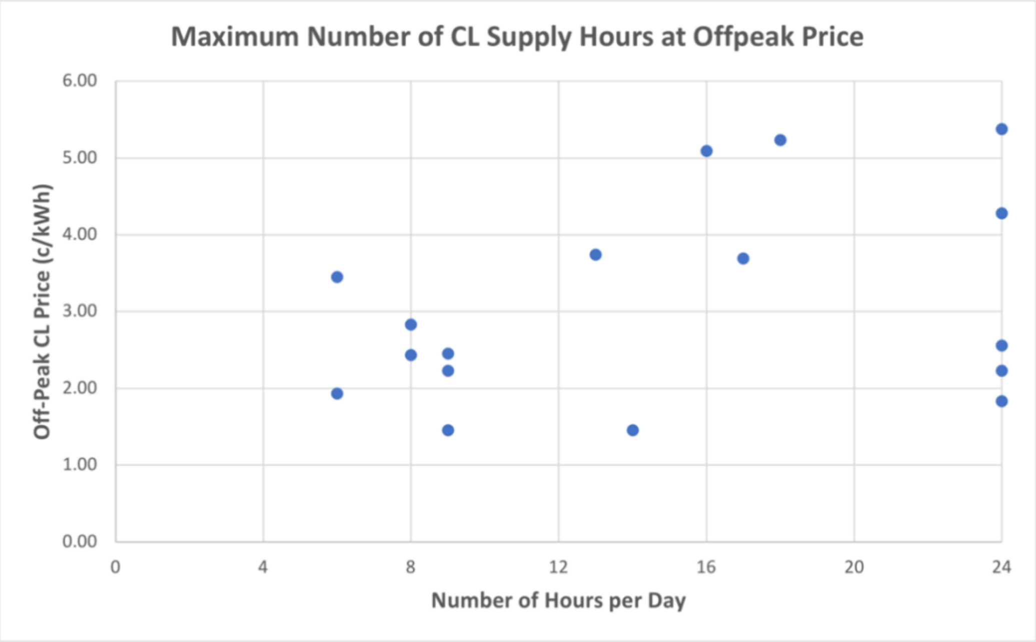

Figure 3-5. Comparison of the off-peak energy charge and the number of hours of availability per day for controlled load network tariffs

The level of complexity in the tariffs can be represented, for comparison by the equation

$$Complexity = Energy\ complexity\ + Demand\ complexity$$

where

$$Energy\ complexity = N_{rates} \times\ N_{day\ types} \times\ N_{seasons}$$

and

$$Demand\ complexity =\ \ N_{demand\ blocks} \times N_{demand\ day\ types} \times\ N_{demand\ seasons}$$

Using this somewhat arbitrary approach, energy complexity for the network tariffs assessed here can be as high as 24 and demand complexity as high as 12. The highest combined complexity was also 24, because tariffs with high energy complexity generally have low demand complexity – see Figure 3-6. Note that some different tariffs had identical complexity values and so occur as a single dot. In all cases bar two the tariffs had either energy complexity or demand complexity, not both. Interestingly, the tariff with the level 6 demand complexity and level 18 energy complexity is Ausgrid's TOU demand tariff, which very few households have taken up. The other tariff with both complexity values was SAPN's Residential Prosumer TOU Demand tariff. These metrics are useful when assessing the extent that the complexity of network tariffs is passed on through retail tariffs structures (see Section 3.1.2).

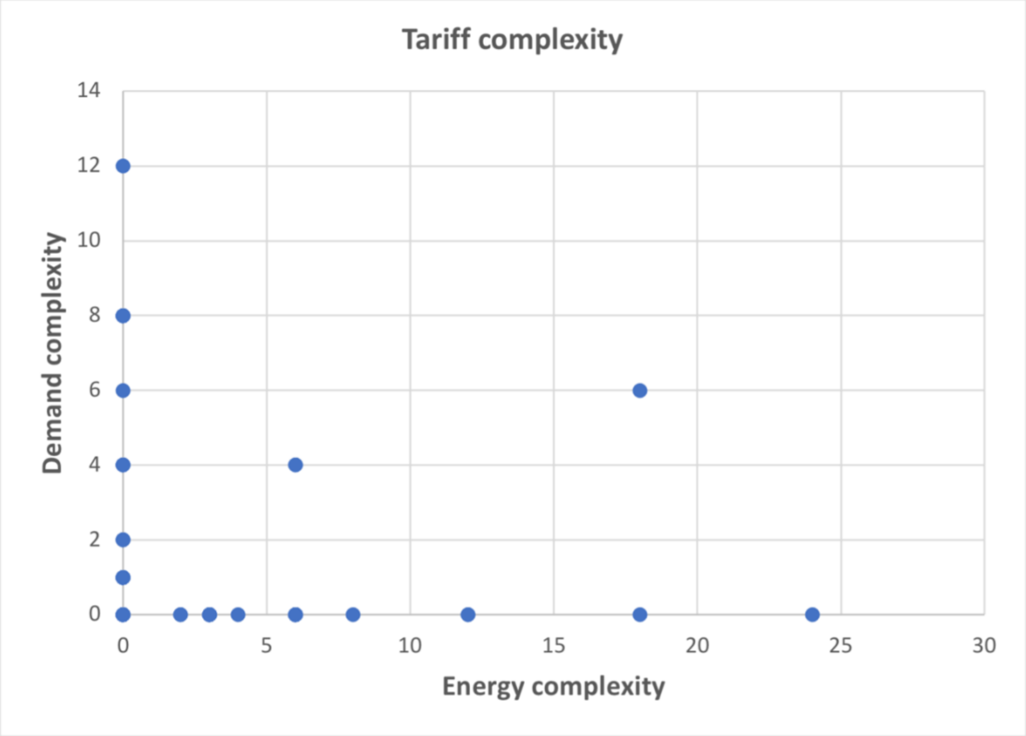

Figure 3-6. Energy complexity versus demand complexity for network tariffs in the NEM

3.1.1.3 Allocation / uptake of network tariffs

Table 3-2 and Figure 3-7 show that some DNSPs no longer make flat tariffs available to new customers, while others apply either a TOU or demand tariff by default but allow households to opt out and choose a flat tariff. However, some others still apply a flat tariff to new customers by default, and only apply a TOU or demand tariff if the household opts into these tariffs. Endeavour, Energex and Ergon also have transitional demand tariffs which introduce the demand structure but with a very low demand charge for a fixed period, after which the household is assigned to standard demand tariff. Ausgrid includes a transitional demand tariff but only for existing customers on flat tariffs replacing faulty metering. Both Ausgrid and Evoenergy have closed flat tariffs to new customers, with the demand tariff being the default. CitiPower's 2021-26 TSS assigns a flat tariff by default, but the AER amended it so that “once small consumers with an EV are identified they must be assigned to a cost reflective network tariff“, which is a TOU tariff with peak rates between 3pm and 9pm (AER, 2021a).

Table 3-2. Default tariff type for each DNSP

DNSP	Default tariff
Ausgrid	Demand/Transitional Demand[11]
AusNet	Unclear
Citi Power	Flat/TOU[12]
Endeavor Energy	Transitional Demand
Energex	Transitional Demand
Ergon Energy	Transitional Demand
Essential Energy	TOU
Evoenergy	Demand
Jemena	TOU
PowerCor	Flat / TOU
SA Power Networks	TOU
TasNetworks	TOU
United Energy	TOU

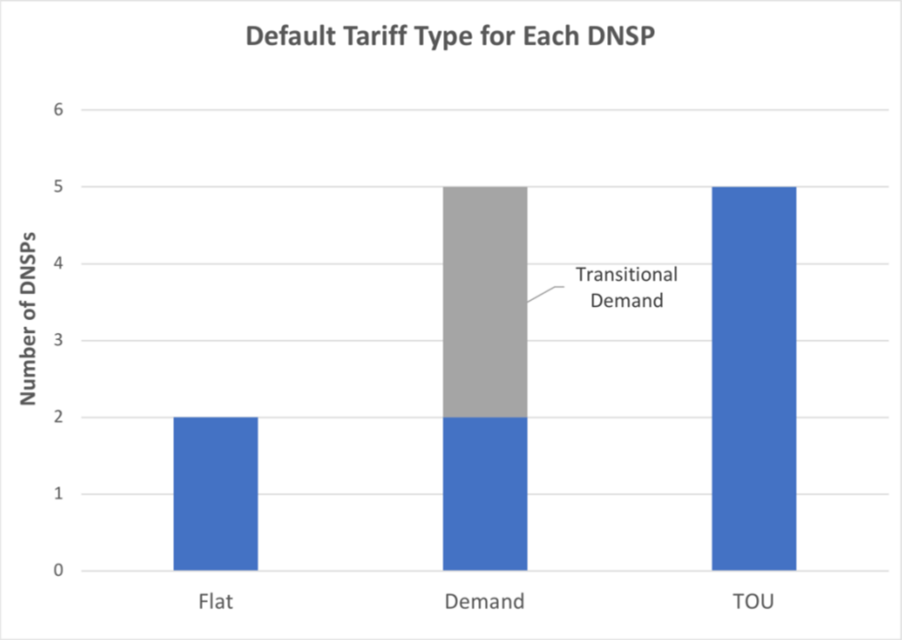

Figure 3-7. Default allocation of new customers to tariff type

Figure 3-8 shows the percentage of households whose retailer faces cost reflective network tariffs, forecast to 2025, based on the DNSP's tariff structure statements (TSS). The higher percentages for Ausgrid and Evoenergy reflect their allocation of demand tariffs to all new customers by default, as well as other DNSPs transitioning from opt-in to opt-out arrangements.

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[11] Ausgrid Transitional Demand tariff is default only for customers previously on a flat tariff replacing a faulty meter

[12] TOU is the default residential tariff for greenfield new connections, new or upgraded solar or battery installations, three-phase upgrades and customers with a dedicated electric vehicle charger with a specified capacity or charging rate of 3.6kW or greater.

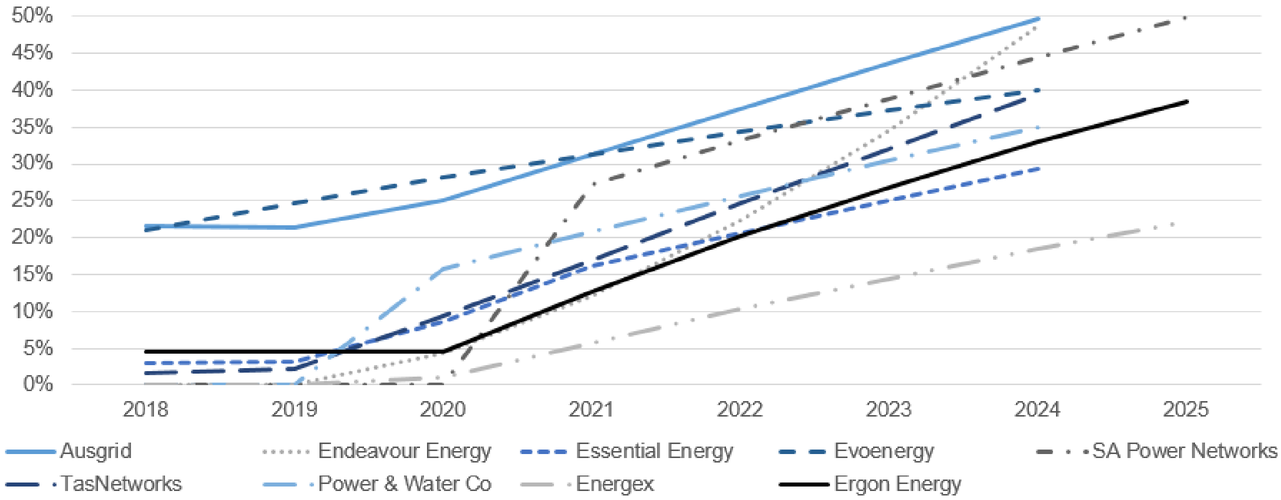

Figure 3-8 Percentage of households whose retailers face cost reflective network tariffs (AER, 2021b)

3.1.1.4 Potential novel network tariff arrangements

Beyond time varying tariffs or conventional demand charges, there are other tariff structures that might better allocate network costs according to the ‘causer pays’ principal and therefore incentivise more efficient use of the distribution network.

Solar export tariffs

The AEMC’s ‘APIA for DER’ draft rule determination would allow DNSPs to apply DUOS charges to solar exports, and to pay households for exports when they are beneficial to the network (AEMC, 2020b). This would allocate a greater proportion of network costs to solar households who currently enjoy lower network charges than other households due to their reduced demand. Proponents argue that solar households are responsible for the network impacts associated with solar export, including high daytime voltages and reverse power flows and should be charged accordingly. Opponents argue that voltages are already too high in order to stop summer cooling loads such as air conditioners breaching the low voltage limits (around 240V-245V rather than 230V), which makes it easy for solar to push the V through the upper limit (253V), and that solar has already provided significant value to household by reducing network demand peaks.[13] Note that this is only a draft determination and that if it is passed, networks will then need to decide how they respond (including passing any such tariffs through a TSS process and the associated community consultation process), and then the retailer needs to decide how they will pass through any such charges. As well as charges being applied to solar exports, it is also possible that households could be paid for exporting at certain times, such as during demand peaks in the late afternoon/evenings. This option is included in Evoenergy’s subthreshold tariff discussed in Section 6.1.1.

The AEMC’s ‘APIA for DER’ draft rule determination included some other proposed changes, such as the removal of clause 6.18.4(a)(3), which states that “retail customers with micro-generation facilities should be treated no less favourably than retail customers without such facilities but with a similar load profile”. The removal of this clause could mean that households with PV systems could be assigned to a special tariff not applied to other households. This is discussed in more detail in Section 6.1.1.

Local use of system charges

Existing NUOS charges, including time-varying and demand charges, are applied at fixed rates regardless of the location of generation and consumption, and therefore do not reflect the actual use of the distribution network. Similarly, TUOS charges are applied to electricity generated and consumed within the

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[13] Opponents also argue that solar PV also reduces wholesale spot prices which provides value to all customers but that is not relevant to the AEMC’s ‘APIA for DER’ rule determination.

distribution network even though such electricity does not use the transmission network. Local use of system charges (LUOS) are an alternative to DUOS and could be applied to electricity that is both generated and used within the same region of the distribution network (such as downstream of the zone substation). This would increase the financial viability of electricity trading between households as well as the storage of excess solar electricity in community batteries for later use by the household. However, it does require some mechanism to track the electricity that is not only generated locally but also used locally, which would require real-time monitoring and costs reconciliation between all involved households. Such trades are also settled outside the current markets, and so would need to be communicated to DNSPs and retailers in some way.

Aggregated NUOS

Retailers currently pay NUOS demand charges based on a customer's monthly or annual peak demand, while network costs are driven by the coincident peak demand of all loads on the network (Passey et al., 2017), or a part of the network. One alternative is for DNSPs to apply their tariff structure (fixed + volumetric + demand) to the aggregated load profile of all a retailer's customers and charge the retailer NUOS based on this aggregated load profile. This is advantageous for the DNSP because, assuming that the retailer wishes to have tariffs that are as flat as possible, it encourages them (the retailer) to undertake measures that target their customers' demand during the coincident peak period. Currently, the standard NUOS approach incentivises the retailer to target the much broader peak defined by the standard network TOU and demand charge tariffs, which may not have as much benefit for the DNSP.

The retailer is free to choose how to do this, including smearing the NUOS cost across all its customers as they already do with spot prices (for example with a flat-rate tariff) and using (targeted) incentives and mechanisms (BDR, DLC, etc.) to reduce demand at the coincident peak times, directly or through an aggregator. Although retailers can, of course, also do all this under the current arrangement (where NUOS is applied to the peaks of households that are on a TOU or demand charge tariff), applying NUOS to aggregated loads may provide an advantage to larger retailers who have more resources to undertake BDR/DLC programs across such a broad range of customers.

Alternatively, the retailer can pass through the NUOS to its customers, with the demand component either applied to the customer's own peak demand (which would generate additional income for the retailer due to the difference between the sum of all its customers peaks and the aggregated peak) or to the customer's contribution to the coincident peak demand (either of the network or of all the retailer's customers on the network). The latter would be much more cost-reflective than a standard demand charge, but households may feel they have less certainty regarding when the demand charge is applied, and so this is only likely to be acceptable when they have a fully automated response (such as a PV/battery home energy management system). This is discussed in detail in Passey et al. (2017).

Tariff variations

Other variations on existing tariffs that are currently being trialled include the following:

- Peak time rebate: where a rebate is paid to the household based on how much they reduce their demand during peak periods. This would require a method to determine the baseline used to calculate the reduction (see Section 6.3.6) which would avoid households artificially inflating their demand prior to a peak period in order to produce a greater apparent reduction. This option is included in Essential Energy's subthreshold tariff discussed in Section 6.1.1.
- Critical peak pricing (CPP): where the household receives 5-10 price signals each year (such as by text) to reduce their demand during critical peak periods.
- Capacity pricing: where each household either nominates a maximum capacity for their electricity connection and pays a monthly fee according to their chosen level, or where the end user's monthly fee is determined by their maximum demand in the previous month (this level may be maintained for a set period such as the following 12 months). These can be used instead of the standard fixed daily charge. These would be most cost-reflective when they align with peak demand periods.

3.1.2 Retail tariffs

3.1.2.1 Available retail tariffs

There is no shortage of choice for households selecting a retail tariff, and an analysis of the thousands of tariffs available across the NEM is beyond the scope of this report. For example, Ausgrid's residential customers can choose from 1059 tariffs offered by 35 retailers, of which 706 have a controlled load rate, 636 have TOU rates while 423 have a flat rate, and 162 have a demand charge. In addition to having TOU, demand charge and controlled load tariffs as described for networks in Section 3.1.1.1, two retailers offer tariffs which give households exposure to wholesale pricing.

Amber Electric allows households to pay the real time wholesale price + NUOS + regulated charges + carbon offset + hedging costs, and solar households receive the wholesale price for exported energy. There is a $15 monthly subscription fee on top of the daily connection and metering charges. Households are supplied with an app to "help you shift your usage away from price spikes" which provides wholesale price information and warnings of forecast price spikes but has no load control capability, and they are trialling a new SmartShift device in South Australia which adds control and optimisation of BESS, EHW and pool pumps.

Powerclub also offers access to wholesale prices and passes through NUOS, with households able to choose a flat rate or TOU network tariff. Households pay a $39 annual subscription, and an additional 28.6c/day supply charge and 0.84c/kWh to cover the retailer's operating costs and margin. Users are provided with a phone app which notifies them of price spikes but offers no load control.

Unlike the Texas retailer, *Griddy*, which exposed its customers to the wholesale price cap of US$9/kWh for up to 87.5 hours during the 2021 winter storms, *Amber* guarantees its customers will not pay a higher average $/kWh rate over a year than the default market offer (DMO), or Victorian default offer (VDO). The retailer is protected by the NEM's cap on cumulative prices[14] which limits their exposure to high price events, as well as the falling wholesale electricity price, relative to the DMO. *Powerclub* users' exposure is limited to the balance of their pre-paid account.

3.1.2.2 Variability and complexity of retail tariffs

Rather than attempting to analyse the complexity of all the retails tariffs available in Australia, we have focused on the Ausgrid and SAPN network areas (where there is retail contestability), as well as the Ergon Energy and Horizon Power areas (where there isn't, although three retailers operate in Ergon's area). We have assessed the best offers from each of the retailers and even this results in a very large number of retail tariffs: 35 for Ausgrid and 21 for SAPN. Details of these tariffs are included in Appendix A. The following compares the network and retailer rates for different types of tariffs. Note that although we compare, for example, the TOU tariff rates, we do not know whether a household with a TOU retail tariff does in fact have an underlying TOU network tariff.

Ausgrid area retailers

Figure 3-9 shows the ratio of peak to off-peak charges for retail tariffs with a TOU component in Ausgrid's area, and Figure 3-10 compares the peak and off-peak charges using a scatterplot (which helps to explain the extent to which each of the two parameters contribute to the ratio). Again, there is a fairly large range in ratios (1.98 to 3.86 for the TOU tariff, and 1.16 to 2.81 for the TOU demand tariff) - although not as large as the 2 to 9.5 range for the network tariffs. It is worth noting that Ausgrid has very few households on the TOU demand tariff, and yet there are retailers in Ausgrid's area that do. The lower ratios for the TOU demand tariffs are expected because of the demand charge. The equivalent ratios for Ausgrid's TOU and TOU demand tariffs are much higher than for all the retailers on their network, meaning that the network tariff price signal is being diluted. This occurs because the retailers' other costs (mainly wholesale spot price costs and retail margin but also environmental fees and other market participation costs) are not being allocated in

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[14] https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Dispatch/Policy_and_Process/Operation-of-the-administered-price-provisions-in-the-national-electricity-market.pdf

the same ratio as the network costs, but instead are more averaged across the different time periods and pricing components.

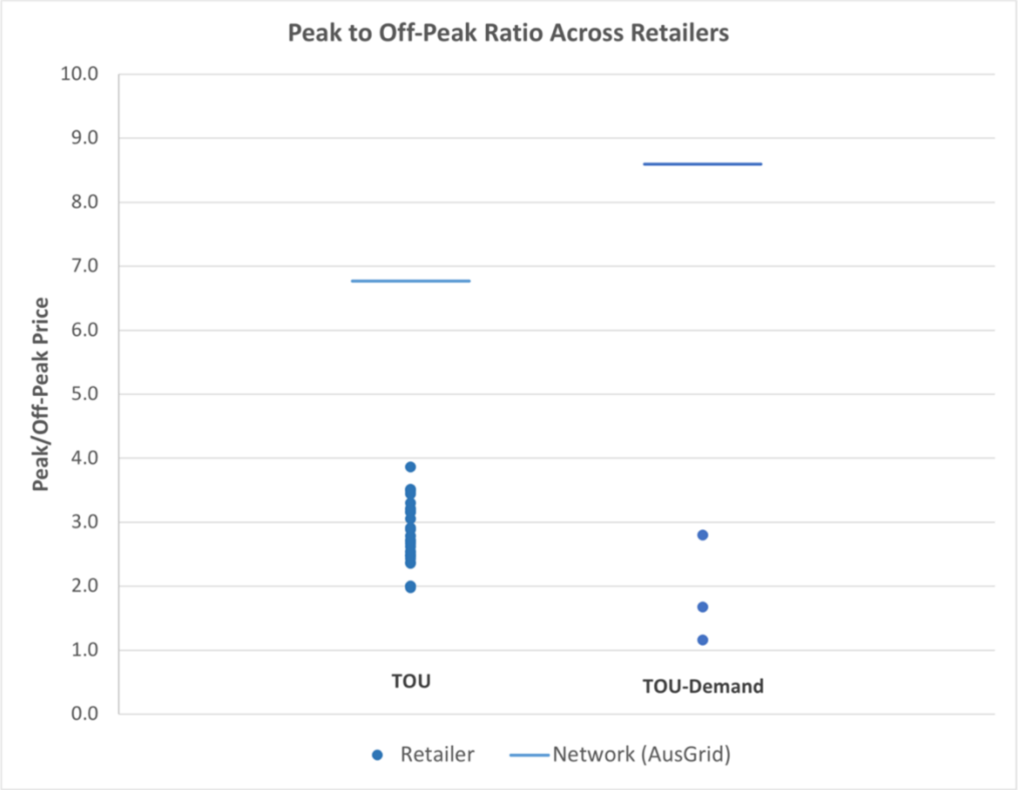

Figure 3-9. Ratio of peak to off-peak charges for retail tariffs with a TOU component in the Ausgrid area

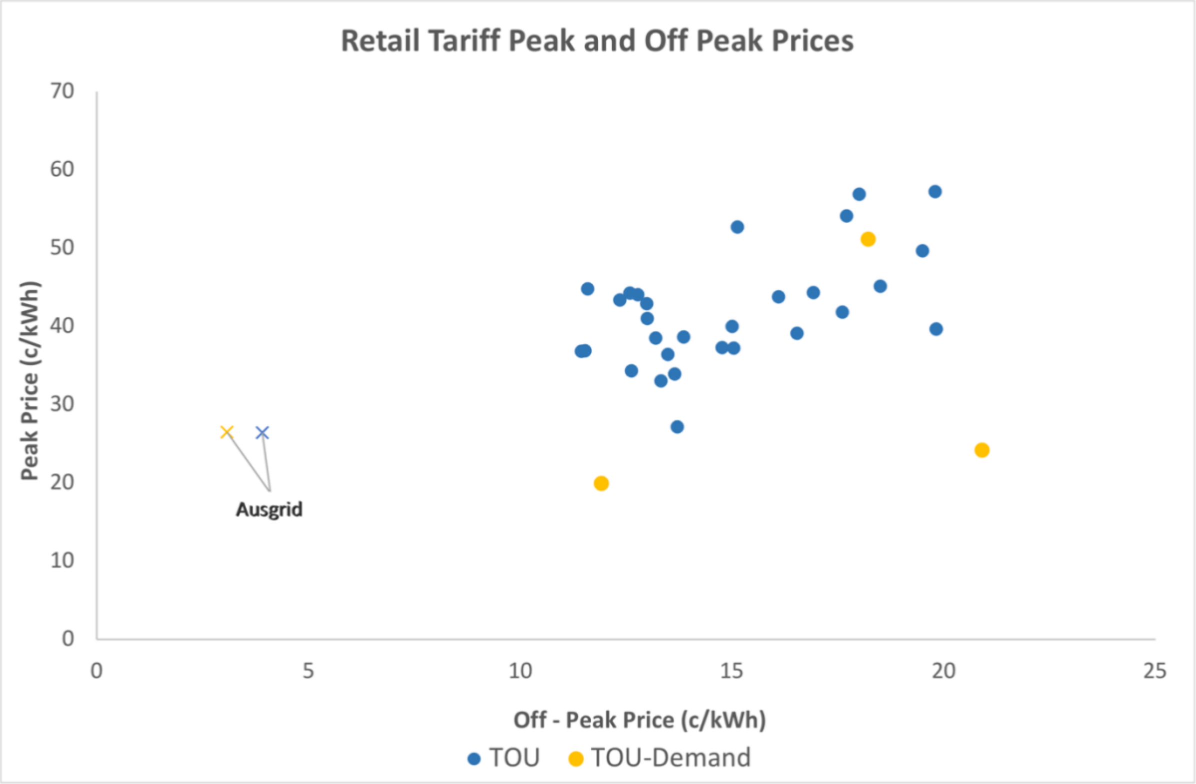

Figure 3-10. Scatterplot of peak to off-peak charges for retail tariffs with a TOU component in the Ausgrid area

Figure 3-11 shows the ratio of peak volumetric charge to retail access charge for retail tariffs with a TOU component in Ausgrid's area, and Figure 3-12 compares the peak volumetric and retail access charges using a scatterplot. The 'peak' rate for the demand charges is just their flat rate. Again, there is a significant range (from 0.13 to 0.77 across the three tariff types), although the demand charge ratios are more tightly clustered (which is to be expected as they are based on the flat usage rate). In this case the equivalent ratios for Ausgrid's TOU and TOU demand tariffs are nearer the centre of the range, with Ausgrid's demand tariff ratio actually being lower than all the retailer tariffs (although this is simply because the 'peak' rate is just the flat usage rate). Figure 3-12 shows that the greater variation in the ratio for both the TOU and TOU demand tariffs is due to differences in both the daily access charge and the peak price.

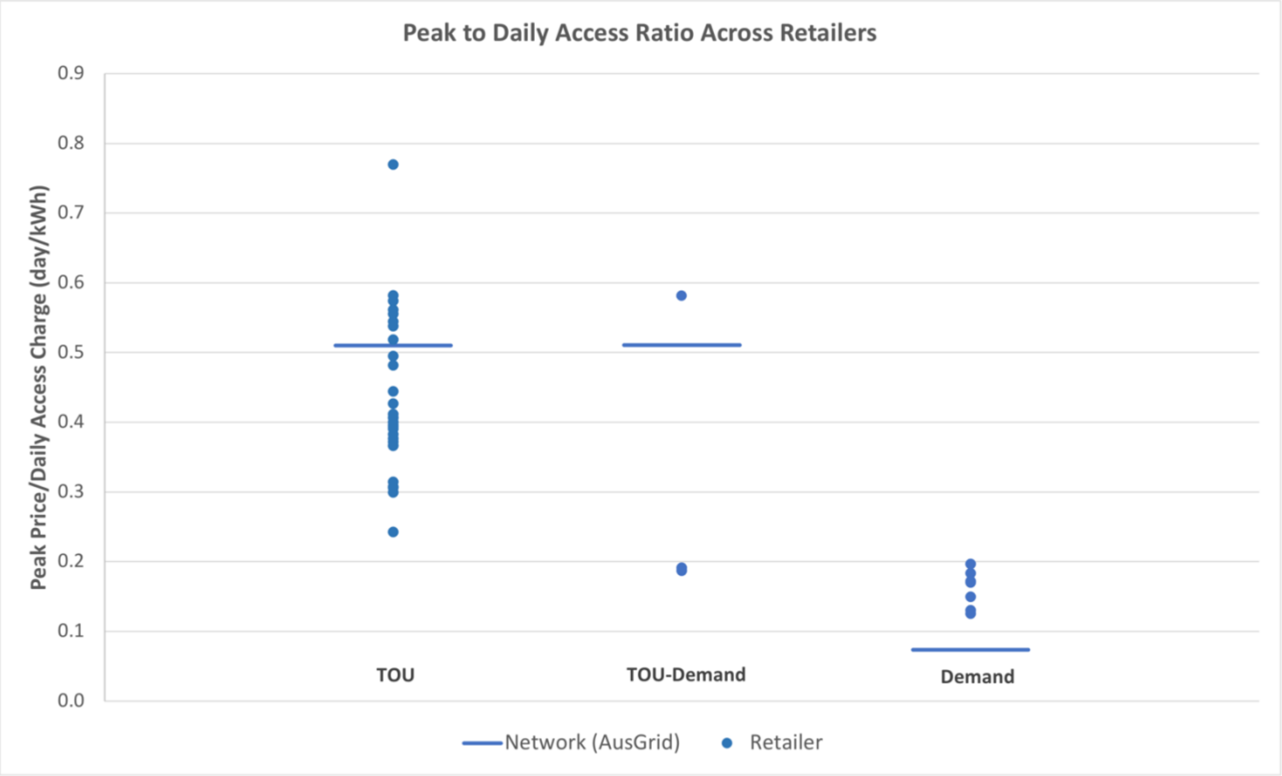

Figure 3-11. Ratio of peak volumetric charge to retail access charge for retail tariffs with a TOU component in the Ausgrid area

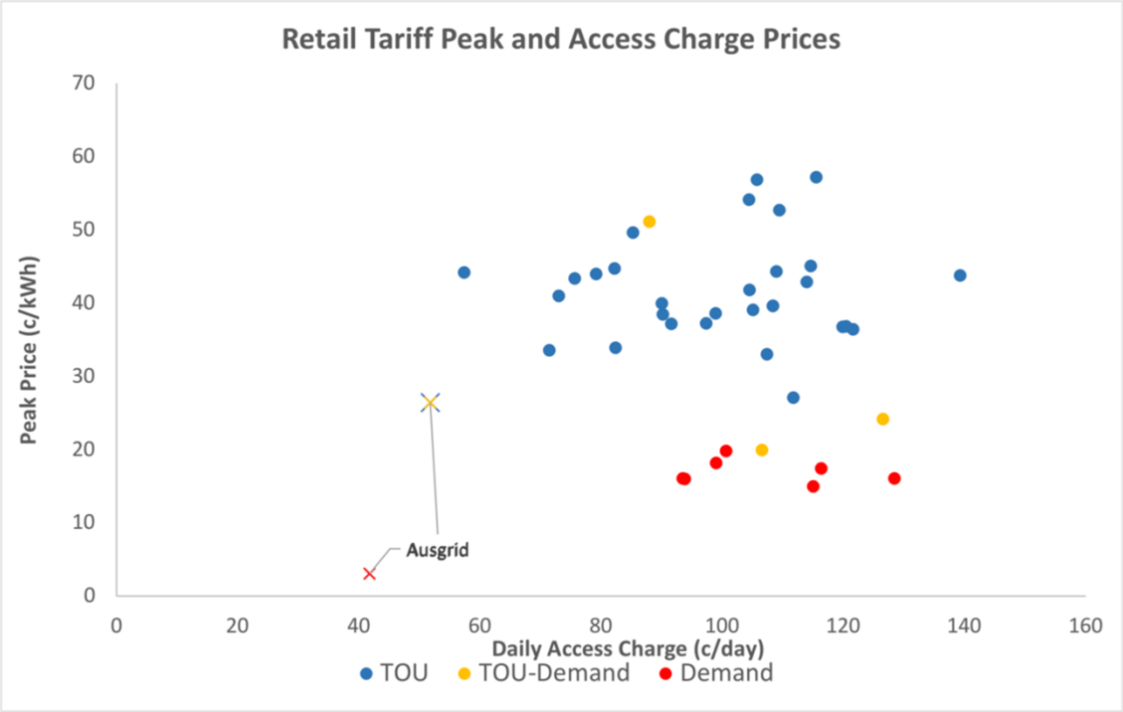

Figure 3-12. Scatterplot of peak volumetric charge to retail access charge for retail tariffs with a TOU component in the Ausgrid area

Figure 3-13 shows the ratio of the peak demand charge to the retail access charge for retail tariffs with a demand charge component in Ausgrid's area, and Figure 3-14 compares the demand and retail access charges using a scatterplot. Here the equivalent ratio for Ausgrid's TOU demand tariff is in the middle of the range (as was the peak rate ratio in Figure 3-11) whereas the ratio for Ausgrid's demand tariff is much higher (which is consistent with the peak rate ratio being lower in Figure 3-11), meaning that, for the demand charge tariff, retailers are effectively choosing to pass some of the demand charge through as higher usage charges during peak periods. Interestingly, as shown in Figure 3-14, the demand charge rates cluster around Ausgrid's demand charge, apart from Red Energy's tariff which has the same rate for high and low periods, and GloBird Energy which has a lower demand charge rate and a slightly higher usage rate.

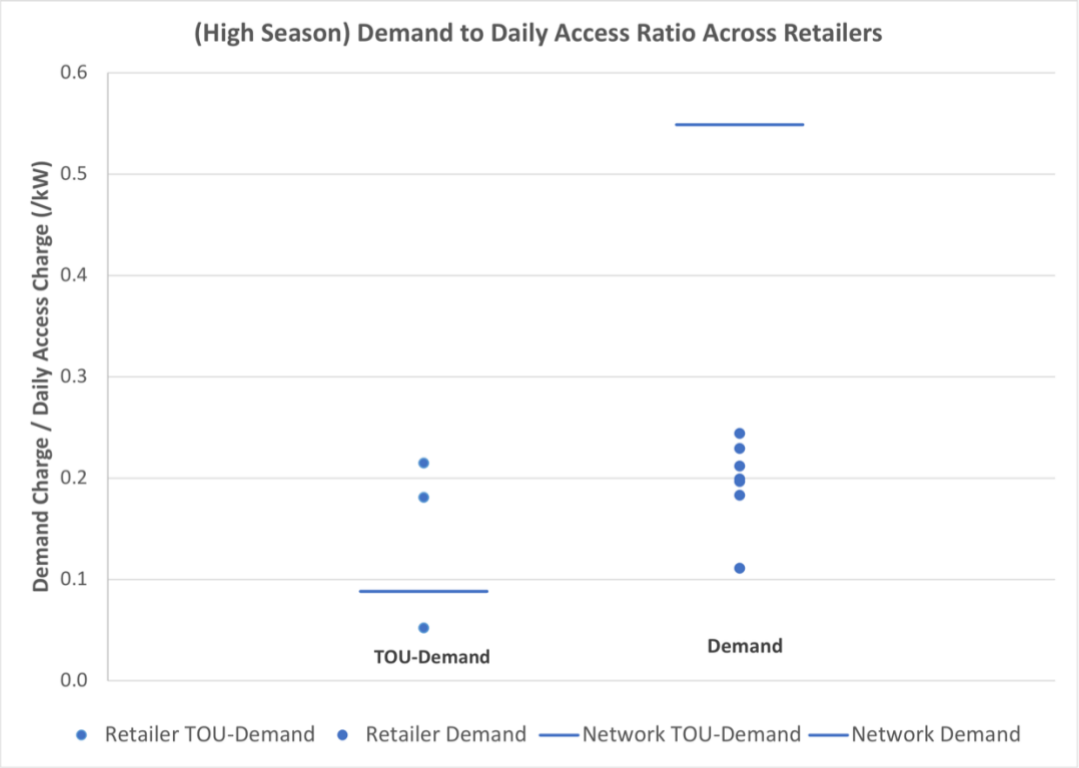

Figure 3-13. Ratio of demand charge to retail access charge for retail tariffs with a demand charge component in the Ausgrid area

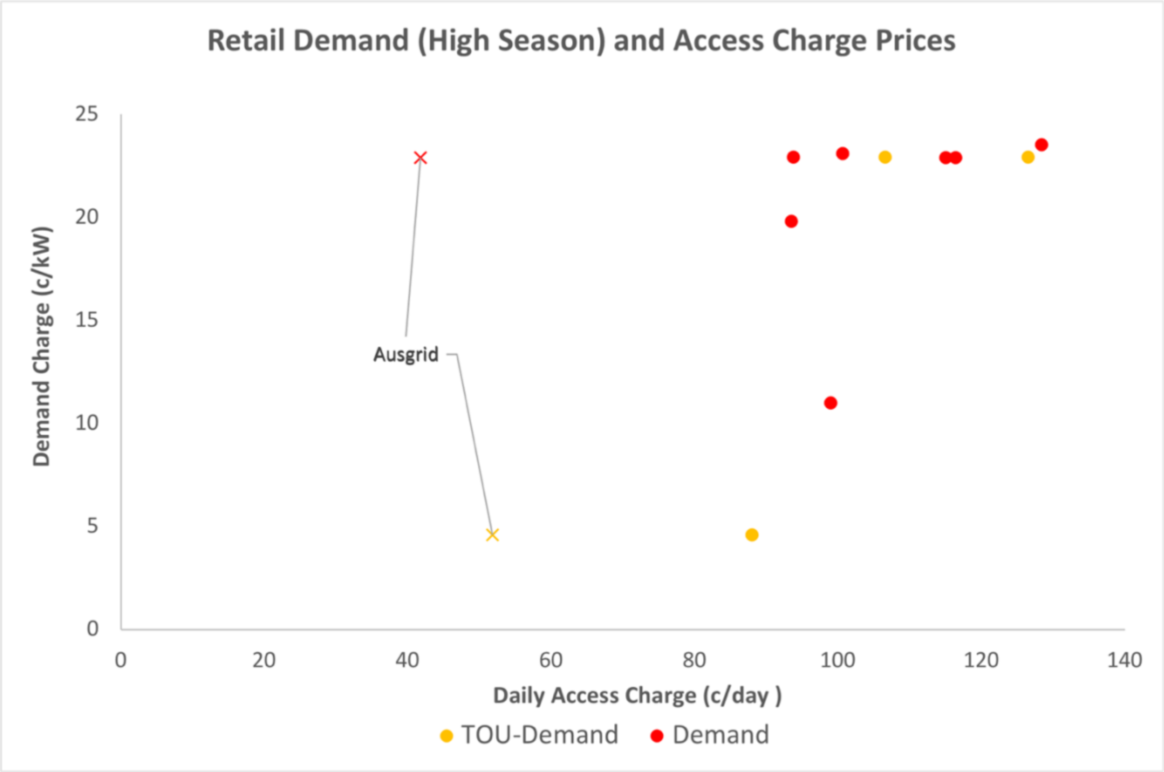

Figure 3-14. Scatterplot of demand charge to retail access charge for retail tariffs with a demand charge component in the Ausgrid area

Figure 3-15 shows the ratio of peak to off-peak charges for retail tariffs with a TOU component in Ausgrid's area and compares them to the equivalent ratio for Ausgrid's network tariffs and the NSW wholesale spot price. It appears that the retailers are basing their peak/off-peak ratios on the NSW spot price, with little attention paid to the network tariff. Figure 3-16 compares the same peak and off-peak rates using a scatterplot. This shows that the peak price of some retailers is actually below the combined network and wholesale peak price, meaning that to avoid losing money they would need to have higher rates in one or more of the other tariff components.

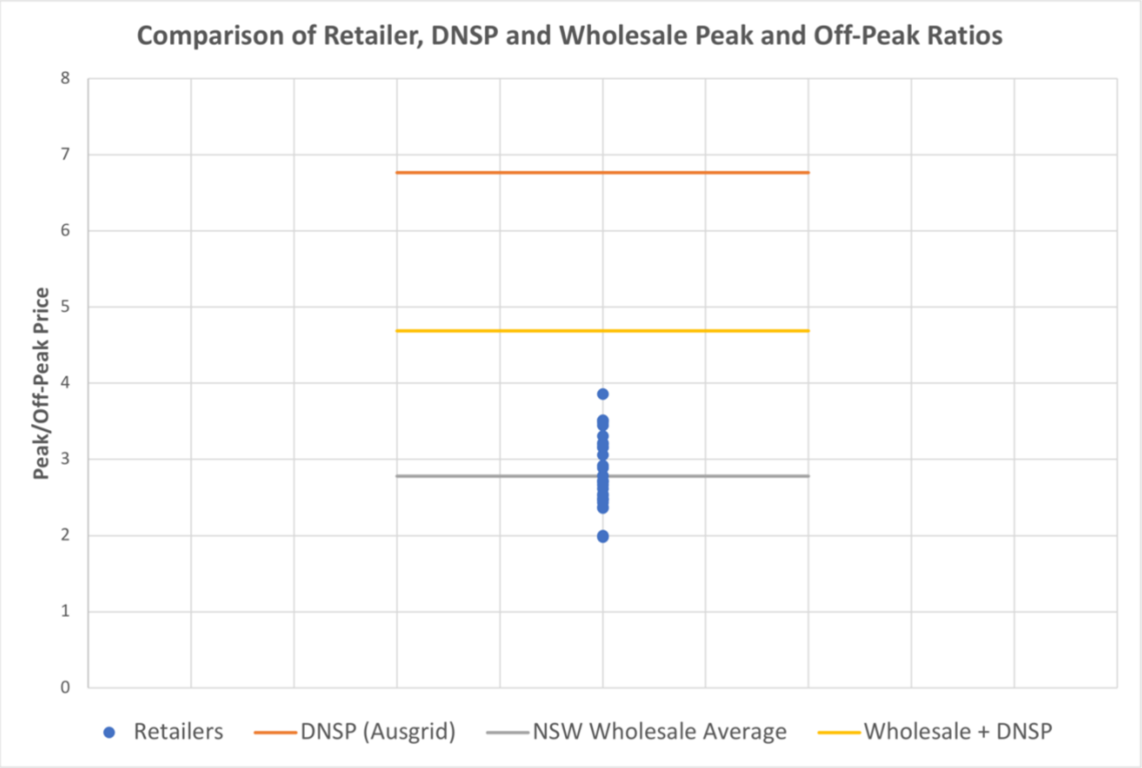

Figure 3-15. Ratio of peak to off-peak charges for retail tariffs with a TOU component in the Ausgrid area, compared to the equivalent ratio of Ausgrid's network tariffs and the NSW wholesale spot price

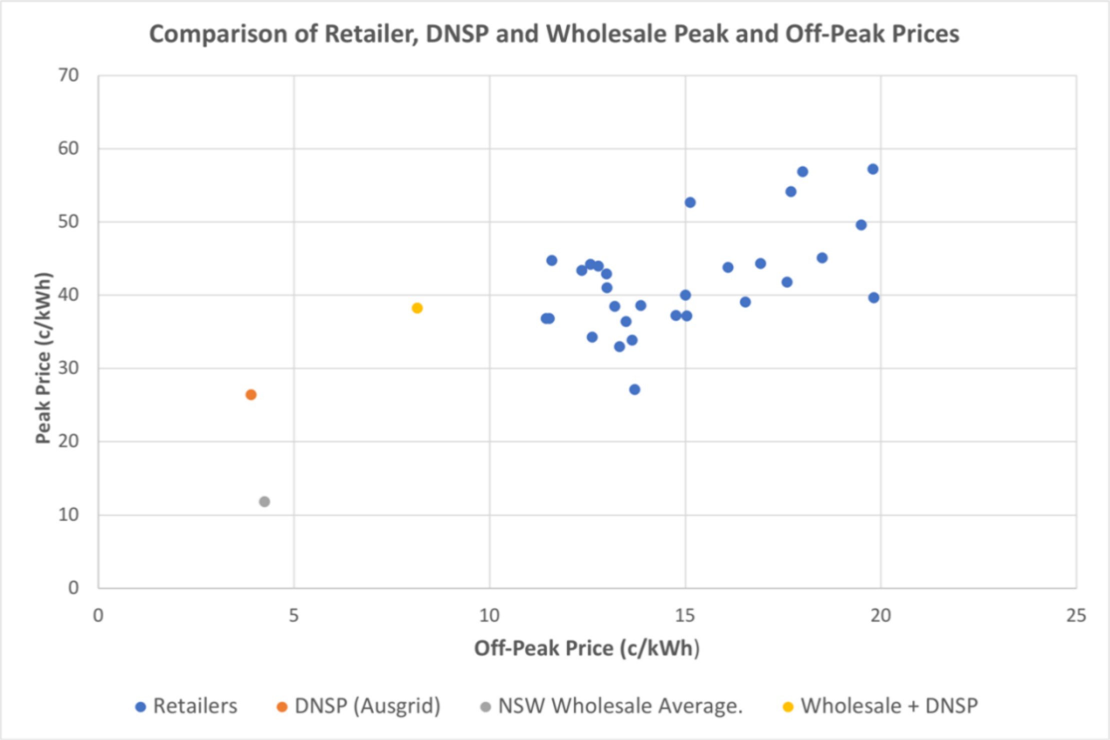

Figure 3-16. Scatterplot of peak to off-peak charges for retail tariffs with a TOU component in the Ausgrid area, compared to the equivalent ratio of Ausgrid's network tariffs and the NSW wholesale spot price

As can be seen in Figure 3-17, most retailer tariffs don't follow Ausgrid's charging structure, and this is the case across TOU, TOU-demand and demand charge tariffs. Figure 3-18 shows the energy complexity and demand complexity for the retail tariffs in Ausgrid's area, as well as for Ausgrid's network tariffs. Note that some different tariffs had identical complexity values and so occur as a single dot. As occurred for network tariffs, those with high energy complexity generally have low demand complexity, although there are some outliers, two of which have a combined complexity greater than the energy complexity. The different complexity values for the retailer and Ausgrid network tariffs show how the structures are not necessarily carried through.

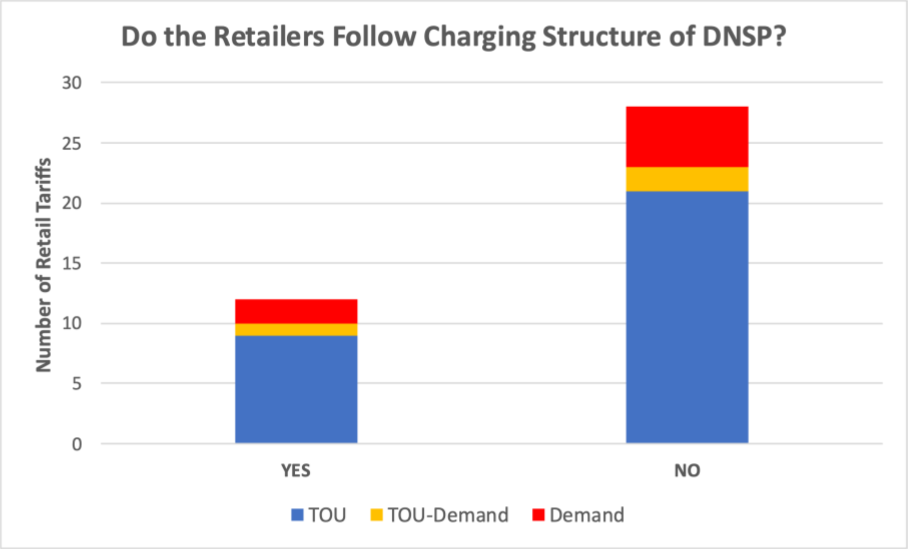

Figure 3-17. Do retailers follow Ausgrid's charging structure?

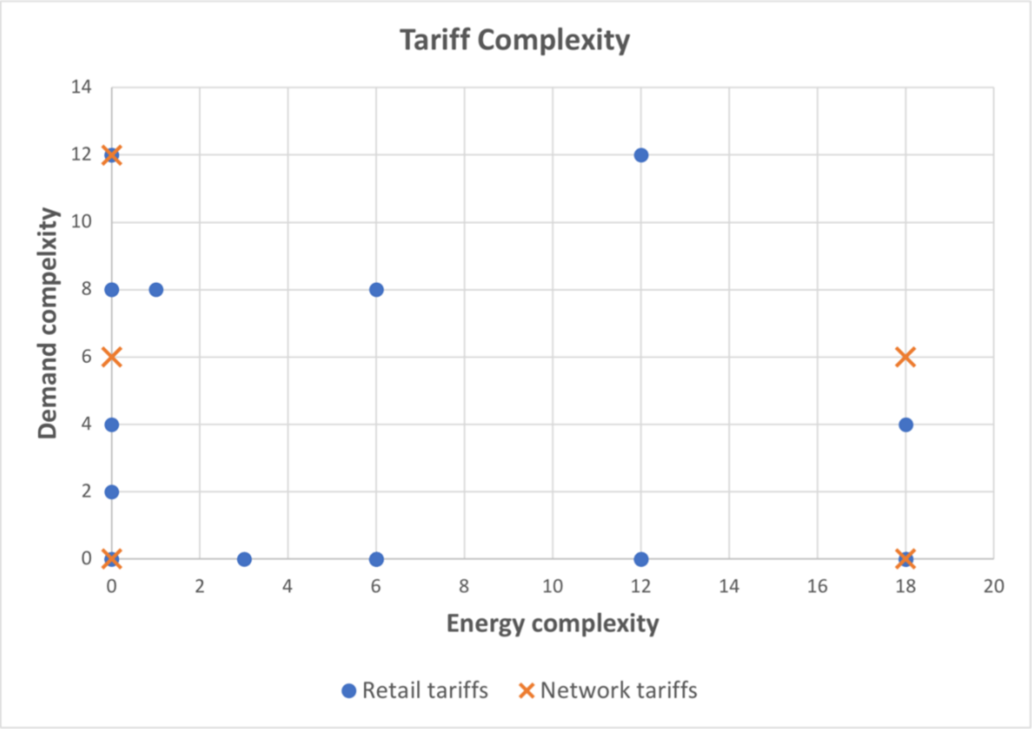

Figure 3-18. Energy complexity versus demand complexity for retail tariffs and Ausgrid's network tariffs

Figure 3-19 compares the energy charge and daily access charge for the retailers' controlled load tariffs. In most cases the energy charge has been increased to be between 15c/kWh and 20c/kWh for both the CL1 and CL2 tariffs[15]. For about half the DNSPs, the daily access charge for CL1 has been increased, but interestingly, some of the CL2 daily access charges have been reduced to zero despite the network component being 12.4c/day. This all shows that different retailers are taking very different approaches to passing through the controlled load charges, and therefore different levels of risk.

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[15] Under Ausgrid's CL1 supply is usually available for 6 hours from 10pm to 7am and under their CL2 supply is available for 16 hours/day including more than 6 hours between 8pm and 7am and 4 hours between 7am and 5pm.

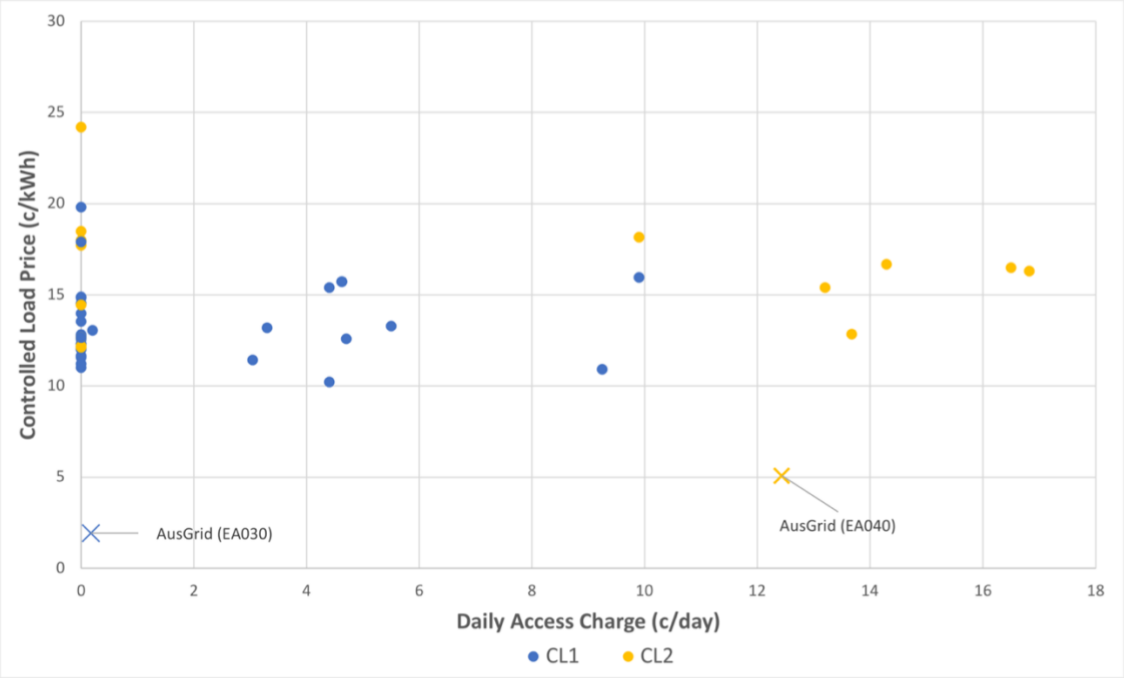

Figure 3-19. Comparison of the energy charge and Access charge for controlled load retail tariffs in the Ausgrid area

Figure 3-20 compares the peak rates from the TOU tariffs to the available FiTs for each retailer. This comparison is made as it represents the greatest value obtainable by solar households from shifting load from peak periods to the middle of the day (where the marginal electricity rate is the FiT rate because electricity used at this time means the household loses that rate). Although retailers generally set their FiT rates to be equal to the avoided cost of buying electricity from the wholesale spot market, there is still quite a spread in rates around current spot prices, with some retailers offering no payment at all. Higher rates are most likely to assist with customer acquisition.

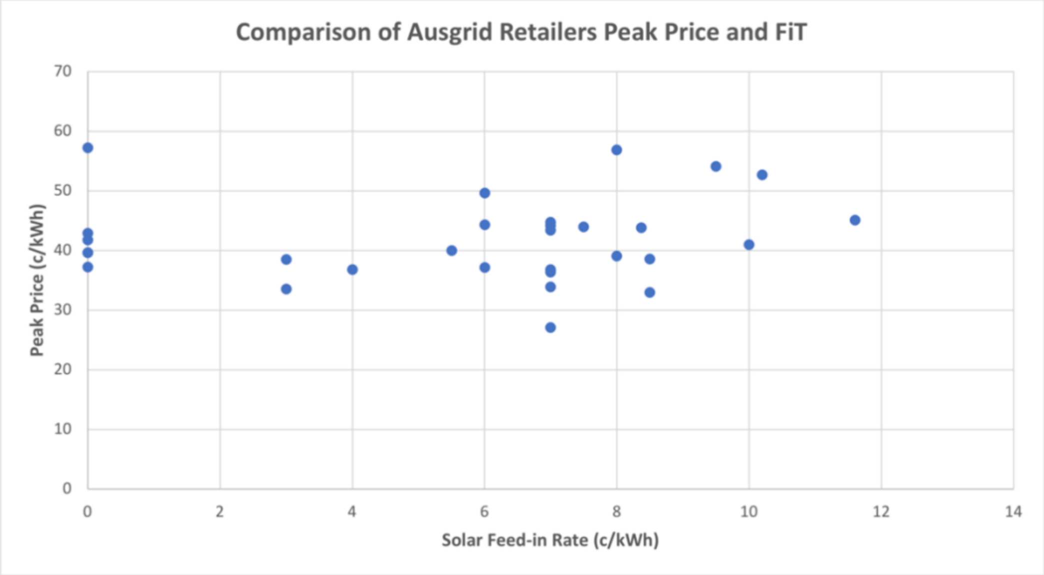

Figure 3-20. Comparison of the TOU peak rate and the FiT rate for retail tariffs in the Ausgrid area

SAPN area retailers

Figure 3-21 shows the ratio of peak to off-peak charges for retail tariffs with a TOU component in SAPN's area, and Figure 3-22 compares the peak and off-peak charges using a scatterplot (which helps to explain the extent to which each of the two parameters contribute to the ratio). Again, there is a reasonable range in ratios for the TOU tariff (1.52 to 2.8 although less for the TOU demand tariff (1.66 to 2.00) - although not as large as the 2 to 9.5 range for the network tariffs. The generally lower ratios for the TOU demand tariffs are expected because of the demand charge. As for Ausgrid, the equivalent ratios for SAPN's TOU and TOU demand tariffs are much higher than for all the retailers on their network, indicating that the network tariff price signal is not being fully passed through.[16]

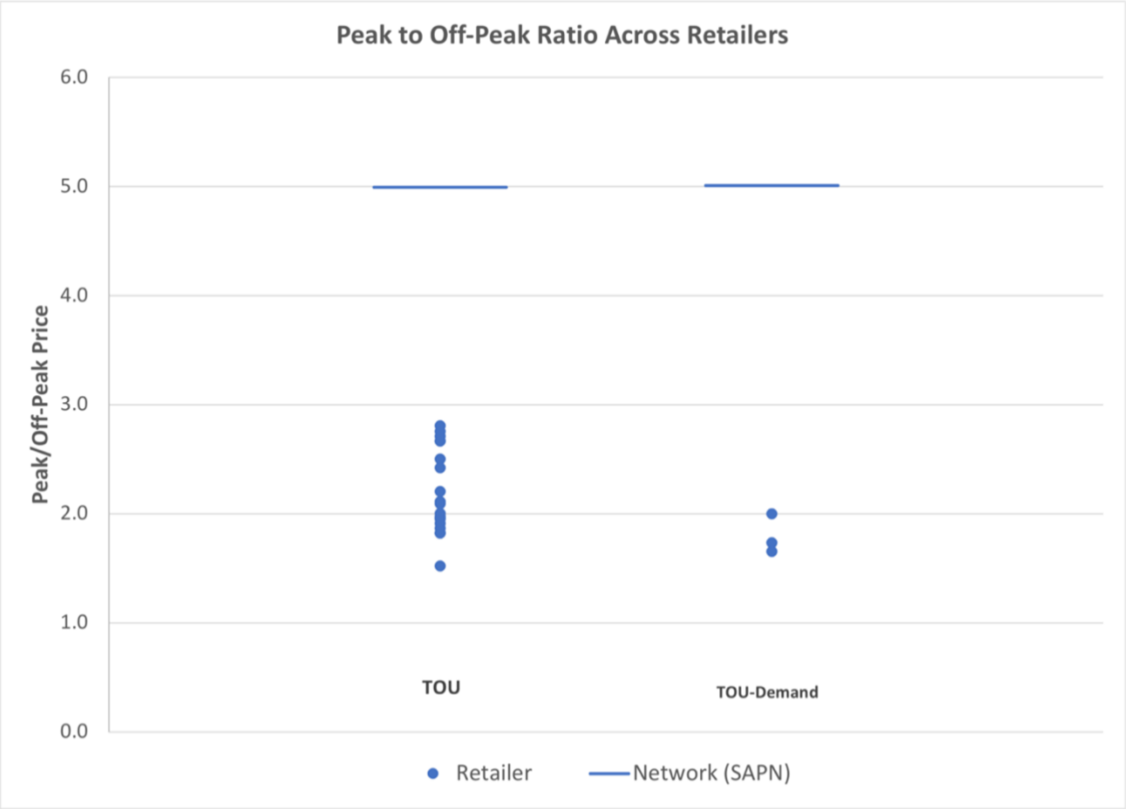

Figure 3-21. Ratio of Peak to Off-peak charges for retail tariffs with a TOU component in SAPN's area

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[16] As for Ausgrid, this occurs because the retailers' other costs (mainly wholesale spot price costs) are not being allocated in the same ratio as the network costs, but instead are more averaged across the different time periods.

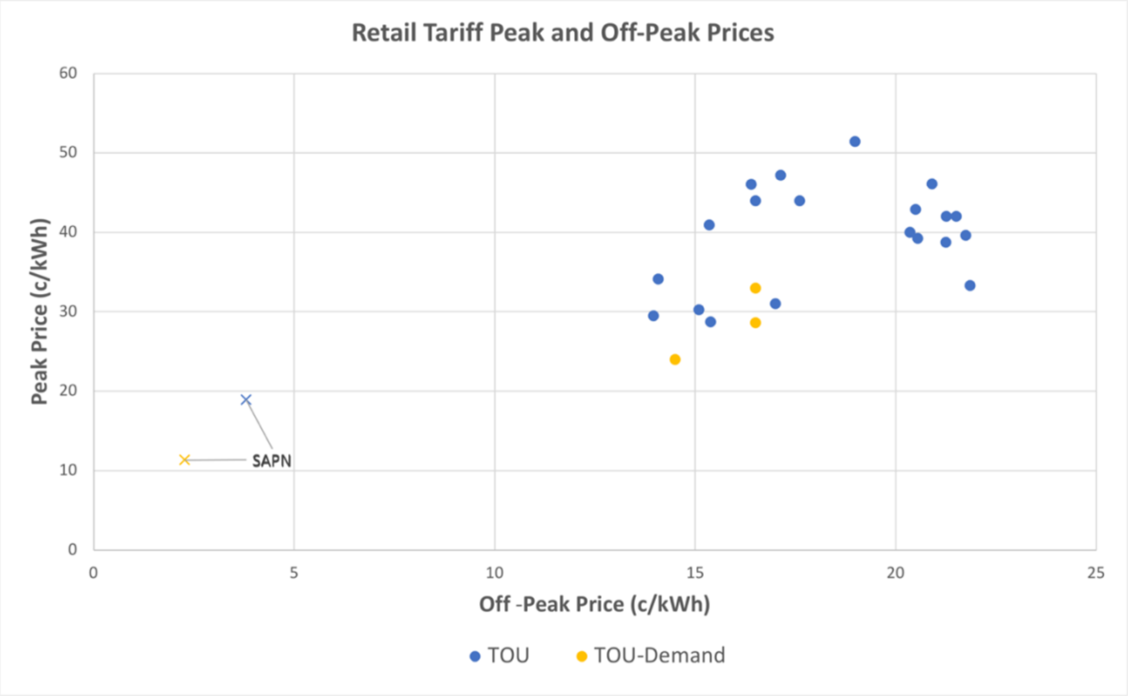

Figure 3-22. Ratio of Peak to Off-peak charges for retail tariffs with a TOU component in SAPN's area

Figure 3-23 shows the ratio of peak volumetric charge to retail access charge for retail tariffs with a TOU component in SAPN's area, and Figure 3-24 compares the peak volumetric and retail access charges using a scatterplot. The retailers' TOU-demand and demand tariffs have been combined into the same column because SAPN does not have a pure demand tariff. The 'peak' rate for the demand charges is just their flat rate. Again, there is a significant range (from 0.16 to 0.59 across the two tariff types), with the demand charge ratios being slightly more tightly clustered (which is to be expected as they are based on the flat usage rate). In this case the equivalent ratios for SAPNs TOU tariff is nearer the centre of the range, with SAPN's TOU demand tariffs being slightly lower than most of the retailer tariffs. Figure 3-24 shows that the variation in the ratio for both the TOU and TOU demand tariffs is due to differences in both the daily access charge and the peak price.

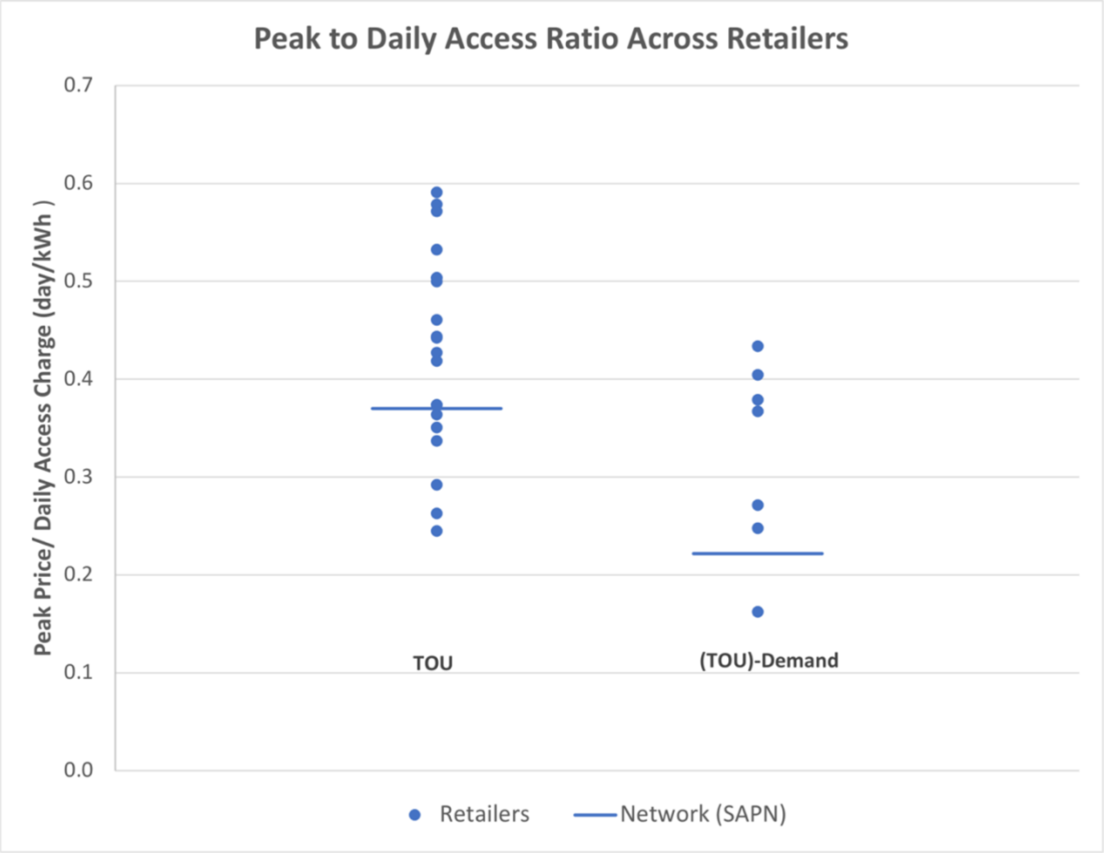

Figure 3-23. Ratio of peak volumetric charge to retail access charge for retail tariffs with a TOU component in SAPN's area

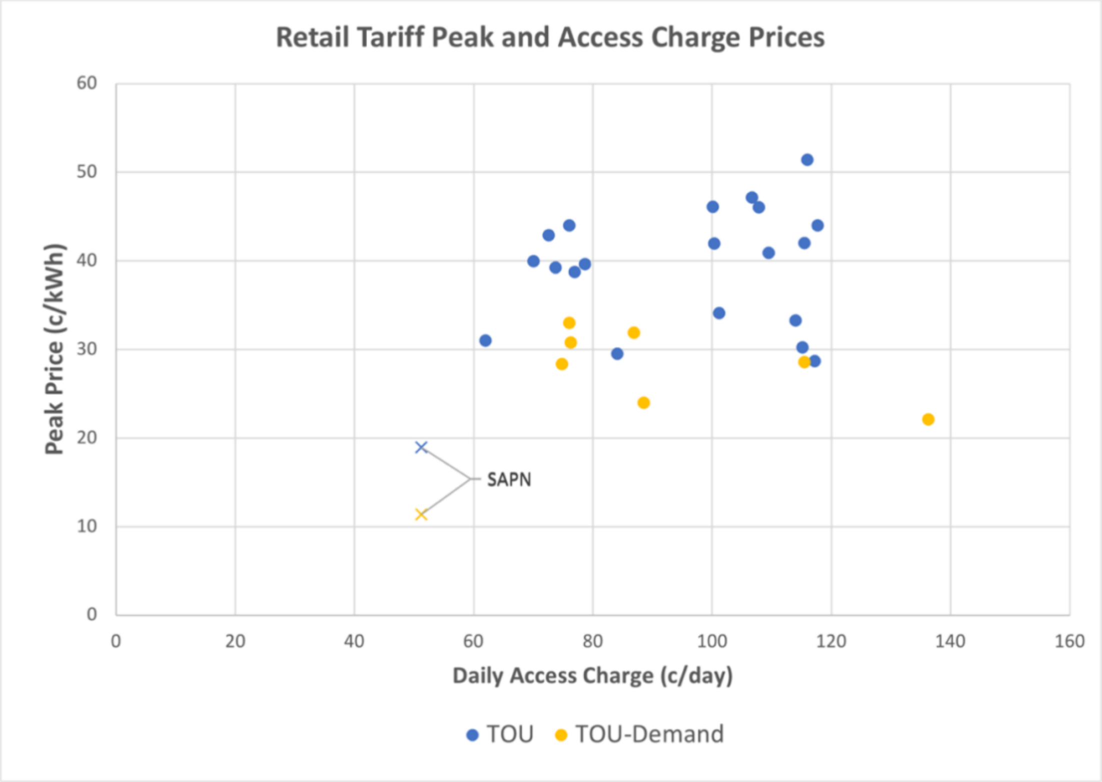

Figure 3-24. Ratio of peak volumetric charge to retail access charge for retail tariffs with a TOU component in SAPN's area

Figure 3-25 shows the ratio of the peak demand charge to the retail access charge for retail tariffs with a demand charge component in SAPN's area, and Figure 3-26 compares the demand and retail access charges using a scatterplot. Here the equivalent ratio for SAPN's TOU demand tariff is higher (which is consistent with it being lower than most retail values in Figure 3-23), meaning that retailers are effectively choosing to pass some of the demand charge through as higher usage charges during peak periods. Unlike in Ausgrid's area (shown in Figure 3-14), the demand charge rates do not cluster around SAPN's rate.

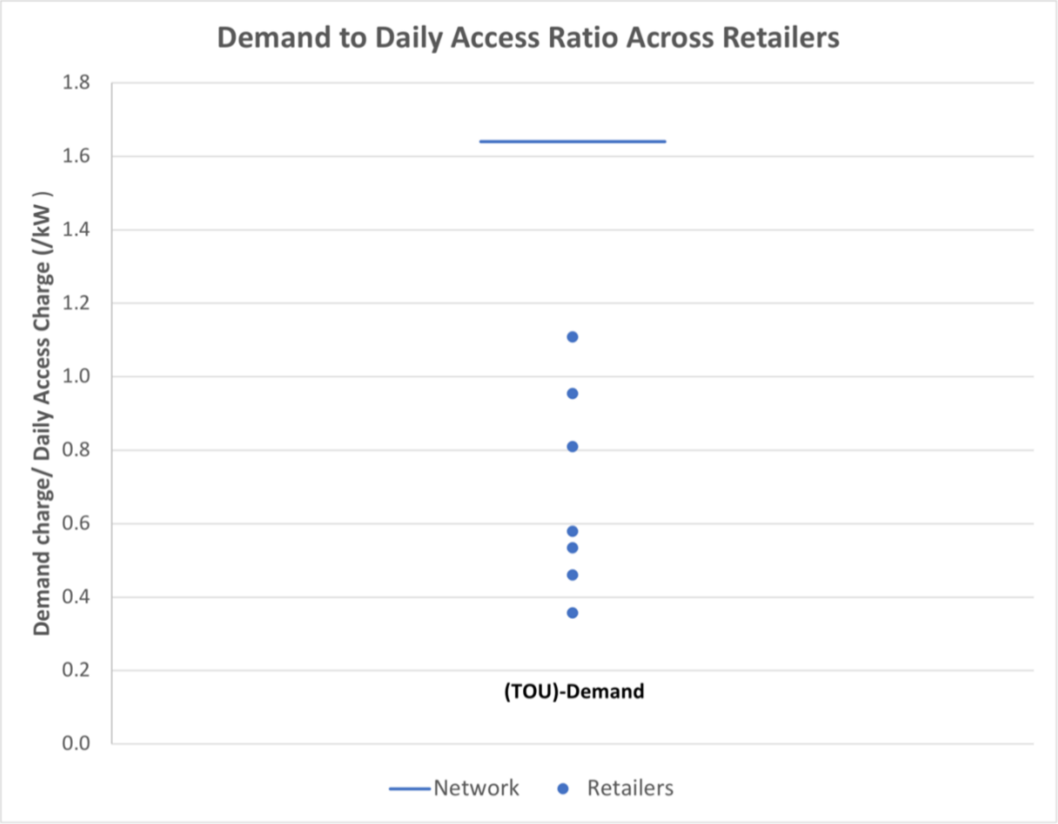

Figure 3-25. Ratio of demand charge to retail access charge for retail tariffs with a demand charge component in SAPN's area

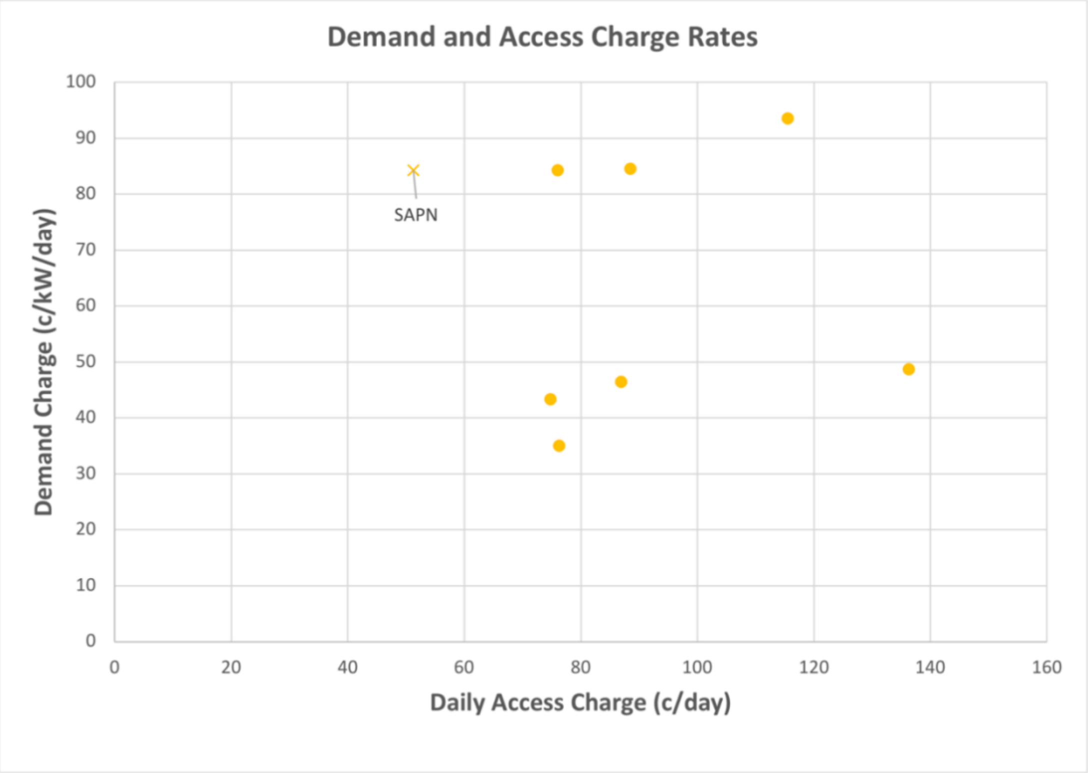

Figure 3-26. Ratio of demand charge to retail access charge for retail tariffs with a demand charge component in SAPN's area

Figure 3-27 shows the ratio of peak to off-peak charges for retail tariffs with a TOU component in SAPN's area and compares them to the equivalent ratio for SAPN's network tariffs and the NSW wholesale spot price. As occurred in Ausgrid's area, it appears that the retailers are basing their peak/off-peak ratios on the SA spot price, with little attention paid to the network tariff. Figure 3-28 compares the same peak and off-peak rates using a scatterplot. Unlike in Ausgrid's area, none of the retailers' peak prices are below the combined network and wholesale peak price.

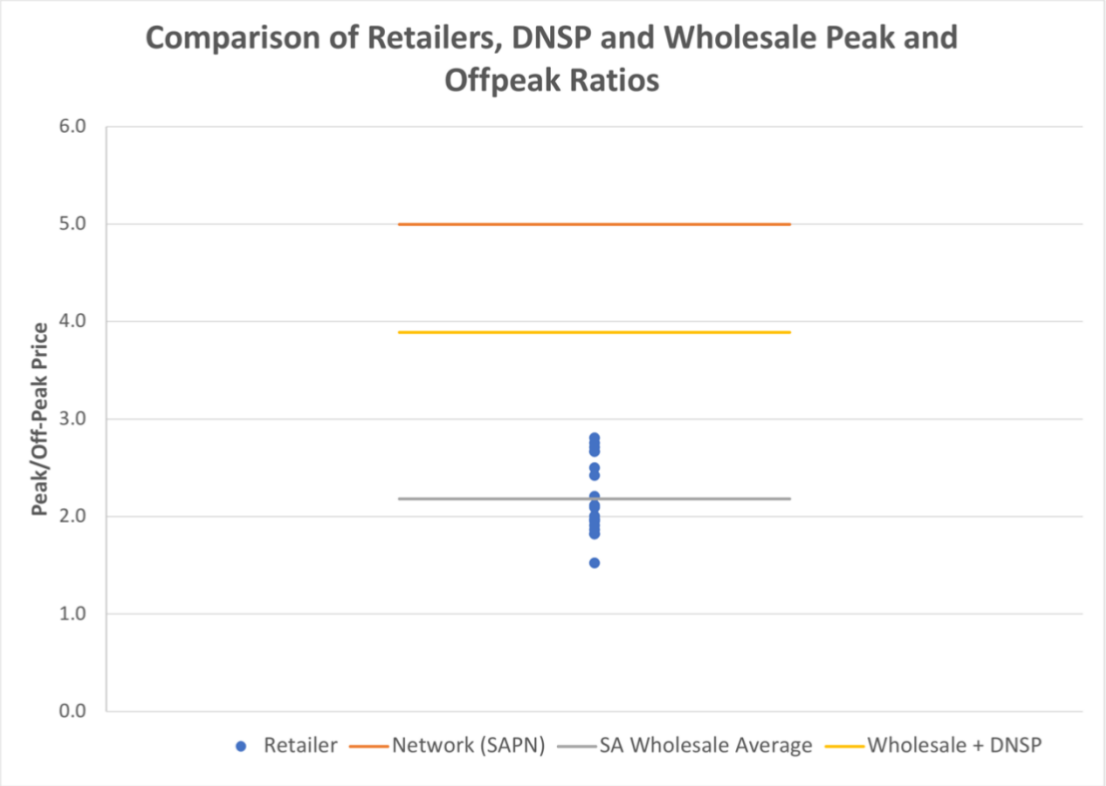

Figure 3-27. Ratio of peak to off-peak charges for retail tariffs with a TOU component in the Ausgrid area, compared to the equivalent ratio of Ausgrid's network tariffs and the NSW wholesale spot price

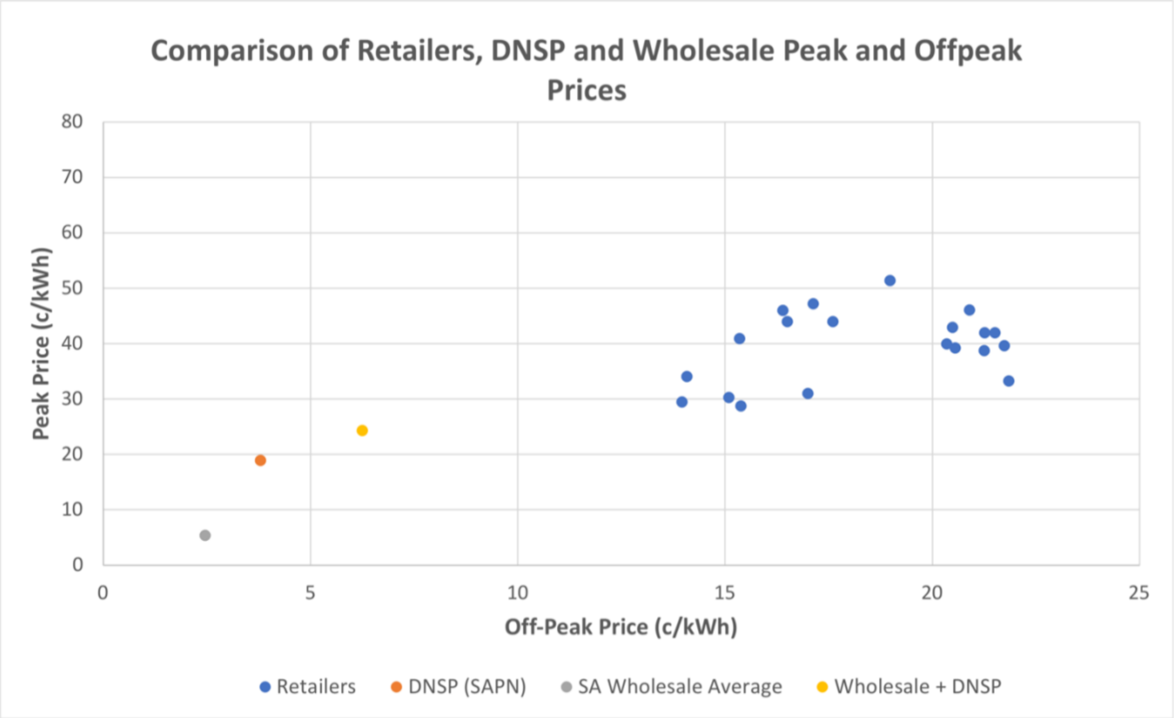

Figure 3-28. Scatterplot of peak to off-peak charges for retail tariffs with a TOU component in the Ausgrid area, compared to the equivalent ratio of Ausgrid's network tariffs and the NSW wholesale spot price

As can be seen in Figure 3-29, unlike as occurred for Ausgrid, most retailer tariffs do follow SAPN's TOU charging structure, although most don't follow the prosumer/demand structure which includes both TOU and demand charge components (they commonly remove the TOU component while retaining the demand charge component). Figure 3-30 shows the energy complexity and demand complexity for the retail tariffs in SAPN's area, as well as for SAPN's network tariffs. Note that some different tariffs had identical complexity values and so occur as a single dot. As occurred for network tariffs, those with high energy complexity generally have low demand complexity - although three demand charge tariffs had an energy complexity value of 6 and a demand complexity value of 4, making 10 in total. The different complexity values for the retailer and SAPN network tariffs show how the structures are not necessarily carried through, although the variation in complexity is less than occurred for Ausgrid.

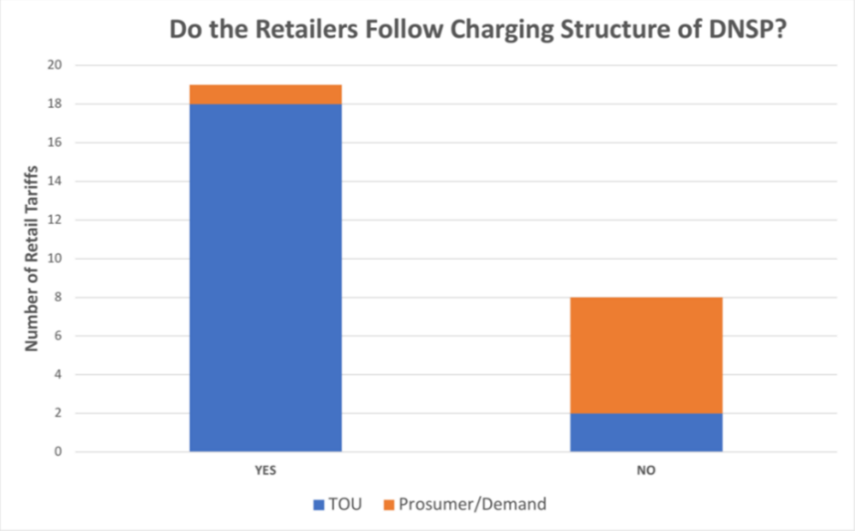

Figure 3-29. Do retailers follow SAPN's charging structure?

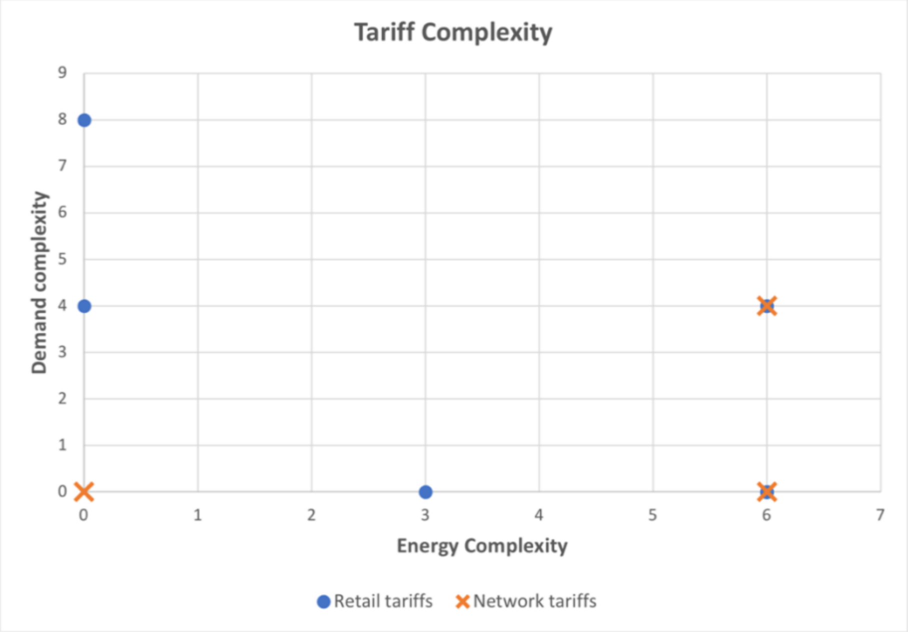

Figure 3-30. Energy complexity versus demand complexity for retails tariffs and SAPN's network tariffs

SAPN’s controlled load tariffs do not include a daily access charge, but do include different peak, shoulder and off-peak rates. One of the retailers’ controlled load tariffs includes a daily access charge, six include the three peak, shoulder and off-peak rates, two include only the off-peak rate and the rest include both the peak and off-peak rates but they are the same.

Figure 3-31 shows the rates for the different components of the controlled load tariffs in SAPN’s area. In all cases the retailer off-peak and shoulder rates are much higher than SAPN’s. Where the off-peak and peak rates are identical, they are lower than SAPN’s peak rates. Many of the retailer peak rates are much higher than SAPN’s. Figure 3-32 compares the ratio of the peak to off-peak rates to the off-peak rate. A peak/off-peak ratio of 1 means the controlled load is a single rate. The higher off-peak rates mean that the peak/off-peak ratio is much lower, and so SAPN’s price signal is being diluted. Again, it is clear that different retailers are taking very different approaches to passing through the controlled load charges, and therefore different levels of risk.

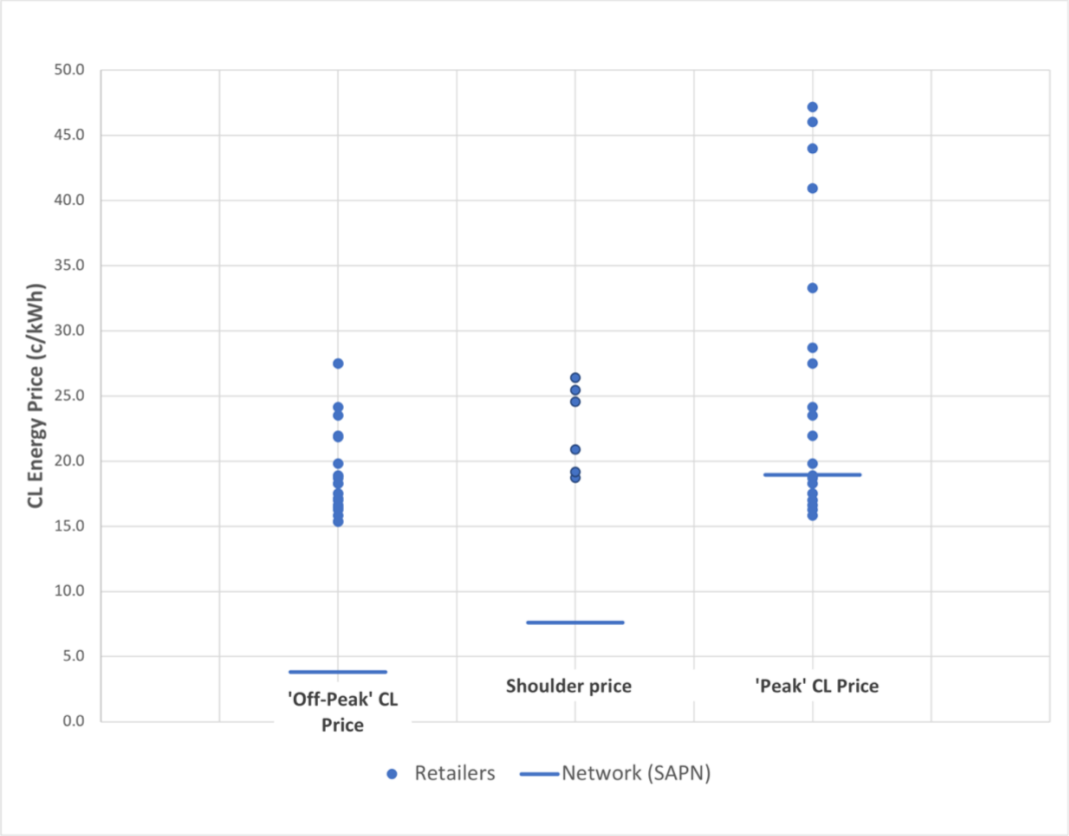

Figure 3-31. Ratio of Demand charge to retail access charge for retail tariffs with a demand charge component in SAPN’s area

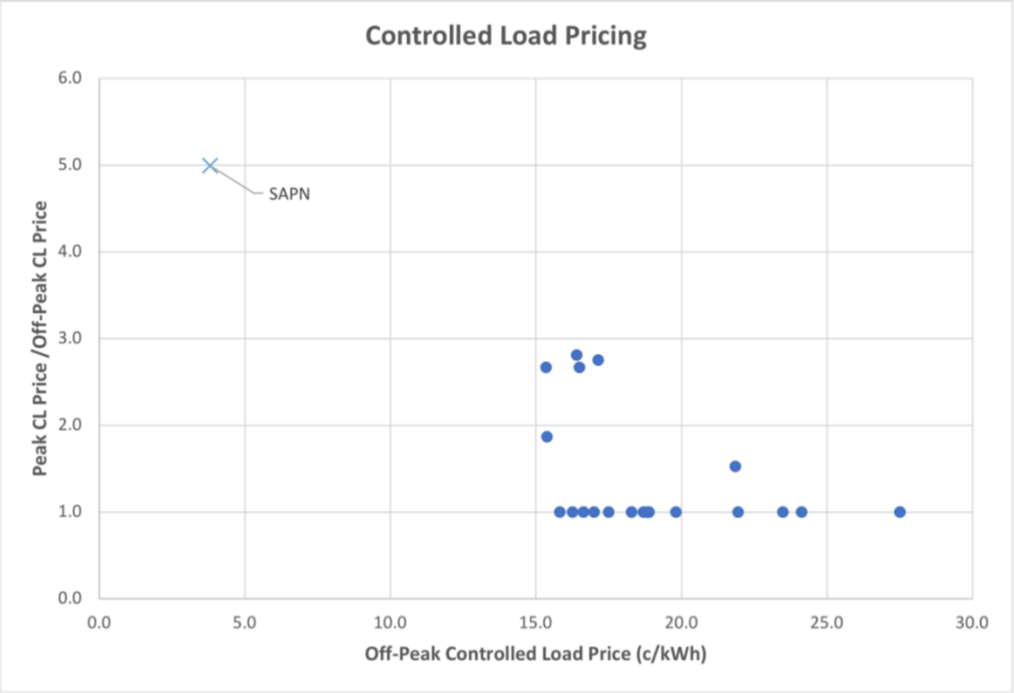

Figure 3-32. Comparison of the Peak/off-peak energy charge and Access charge for controlled load retail tariffs in SAPN's area

Figure 3-33 compares the peak rates from the TOU tariffs to the available FiTs for each retailer. This comparison is made as it represents the greatest value obtainable from shifting load from peak periods to the middle of the day. Although retailers generally set their FiT rates to be equal to the avoided cost of buying electricity from the wholesale spot market, there is still quite a spread in rates around current spot prices, with some retailers offering no payment at all. Higher rates are most likely to assist with customer acquisition.

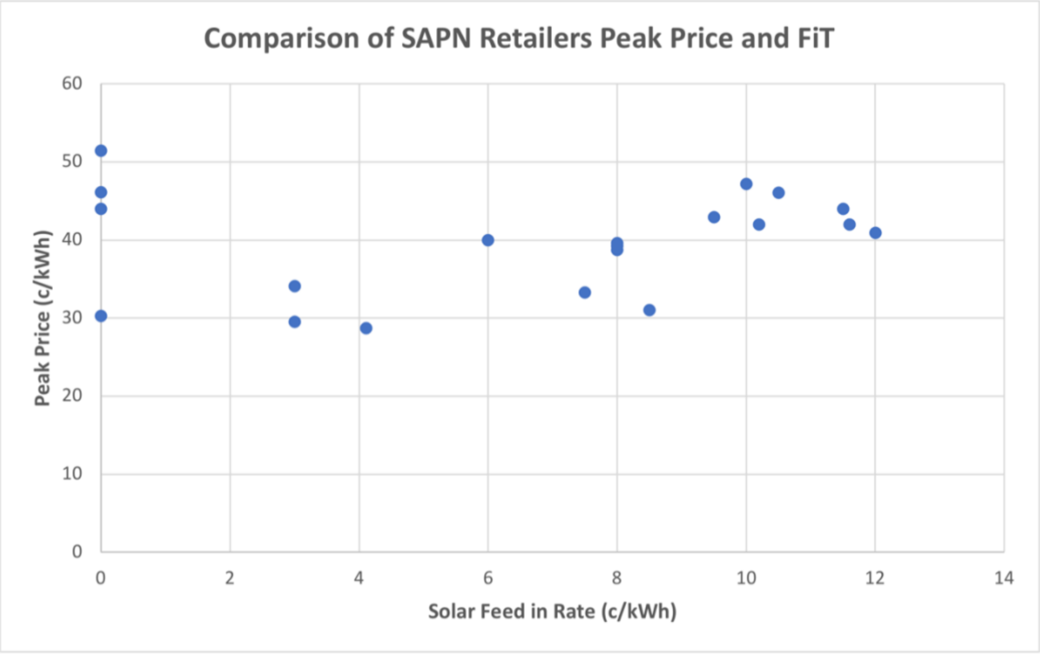

Figure 3-33. Comparison of the TOU peak rate and the FiT rate for retail tariffs in the SAPN area

Ergon Energy area retailers

Although the Ergon Energy is a vertically integrated utility and so has both network and retail arms, two other retailers operate in Ergon's network area: LPE and Globird Energy. Figure 3-34 shows the ratio of peak to off-peak charges for retail tariffs with a TOU component in Ergon's area, and Figure 3-35 compares the peak and off-peak charges using a scatterplot (which helps to explain the extent to which each of the two parameters contribute to the ratio). A clear difference of these charts to the charts for Ausgrid and SAPN is that there are more network tariffs than retailer tariffs. Two of the retailer tariffs are from Ergon with one each from LPE and Globird Energy. It can be seen that the network tariffs cover a large range and that each retailer appears to apply the same tariff no matter which part of the Ergon network they are operating in. As for Ausgrid and SAPN, the equivalent ratios for Ergon's tariffs are higher than for all the retailers on their network (apart from Mount Isa), mainly because the off-peak price is higher, especially in the West Region, indicating that the network tariff price signal is not being fully passed through.[17]

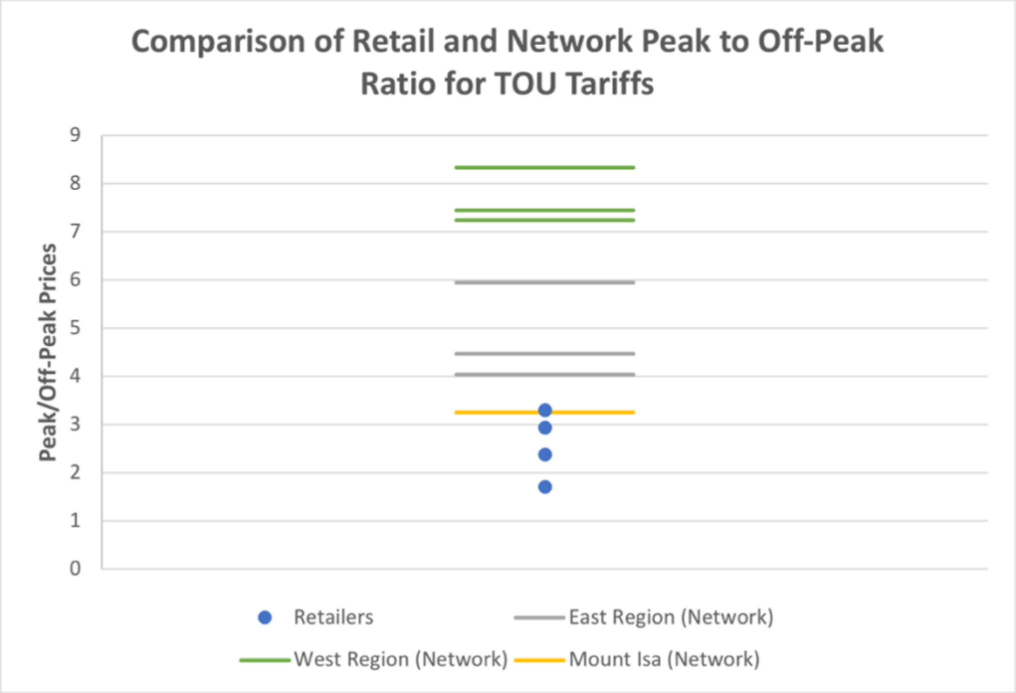

Figure 3-34. Ratio of Peak to Off-peak charges for retail tariffs with a TOU component in Ergon's area

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[17] Again, this occurs because the retailers' other costs (mainly wholesale spot price costs) are not being allocated in the same ratio as the network costs, but instead are more averaged across the different time periods.

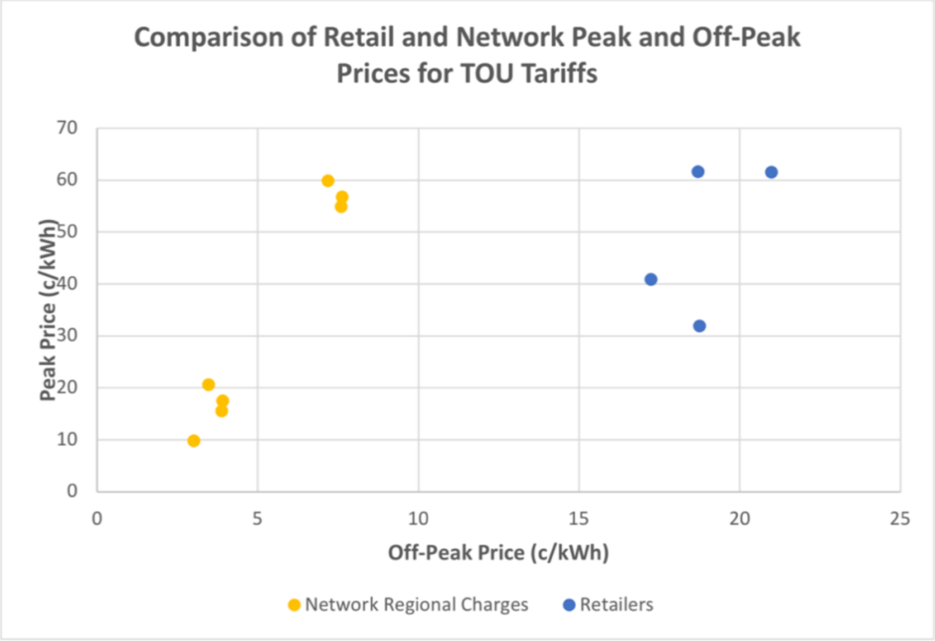

Figure 3-35. Ratio of Peak to Off-peak charges for retail tariffs with a TOU component in Ergon's area

Figure 3-36 shows the ratio of peak volumetric charge to retail access charge for TOU and demand charge retail tariffs in Ergon's area, and Figure 3-37 compares the peak volumetric and retail access charges using a scatterplot. The 'peak' rate for the demand charges is just their flat rate. Again, there is a significant range (from 0.17 to 0.75 across the two tariff types), with the demand charge ratios being slightly more tightly clustered (which is to be expected as they are based on the flat usage rate). In this case the equivalent ratios for Ergon's tariffs are all lower than the retailer tariffs. Figure 3-37 shows that the variation in the ratio for both the TOU and demand tariffs is mainly due to differences in the peak price.

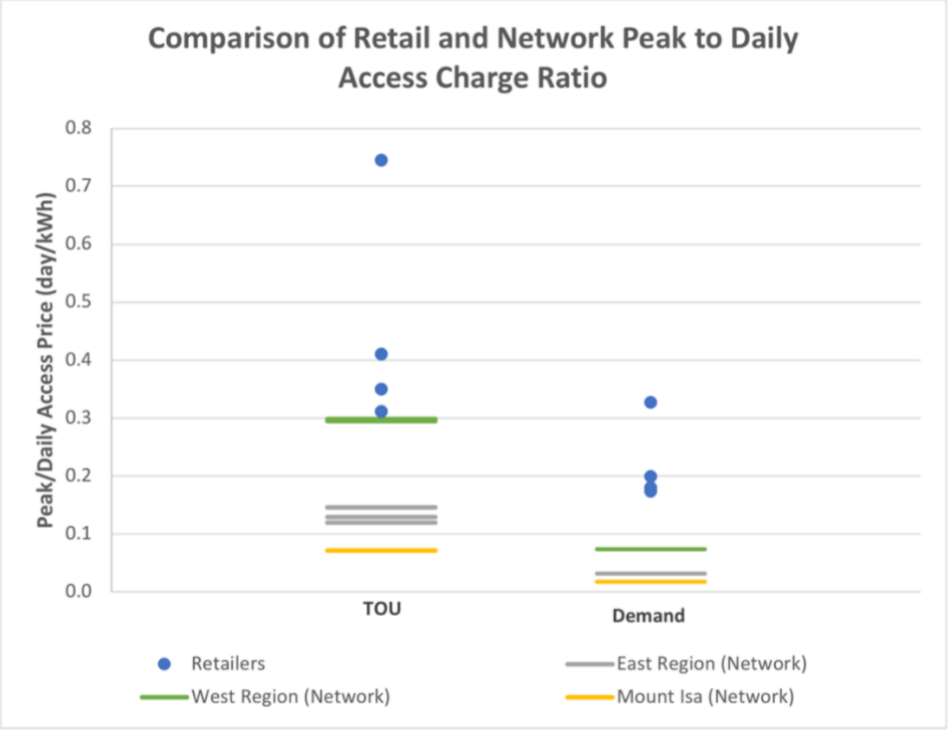

Figure 3-36. Ratio of Peak Volumetric charge to retail access charge for retail tariffs with a TOU component in Ergon's area

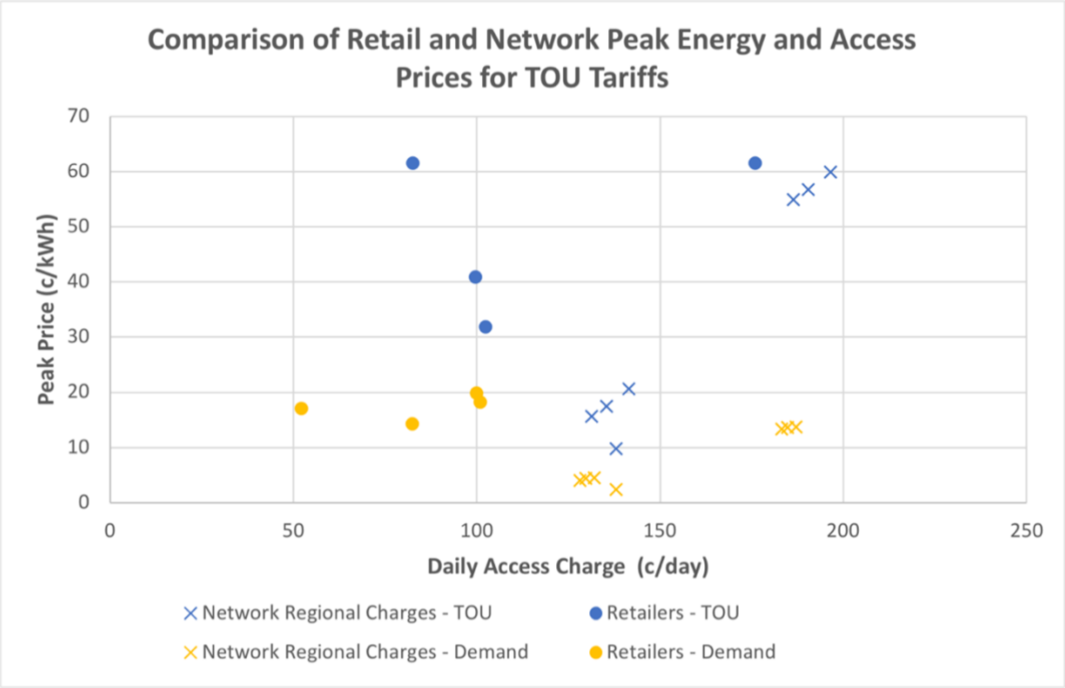

Figure 3-37. Ratio of Peak Volumetric charge to retail access charge for retail tariffs with a TOU component in Ergon's area

Figure 3-38 shows the ratio of the peak demand charge to the access charge for retail tariffs with a demand charge component in Ergon's area, and Figure 3-39 compares the demand and access charges using a scatterplot. The outlier with the very large demand charge is an Ergon retail tariff with half the normal daily access charge; and is presumably intended for households with flat loads. The three network tariffs with higher demand charges are from Ergon's western region. In general, the retailers have higher usage charges but lower daily charges and lower/similar demand charges.

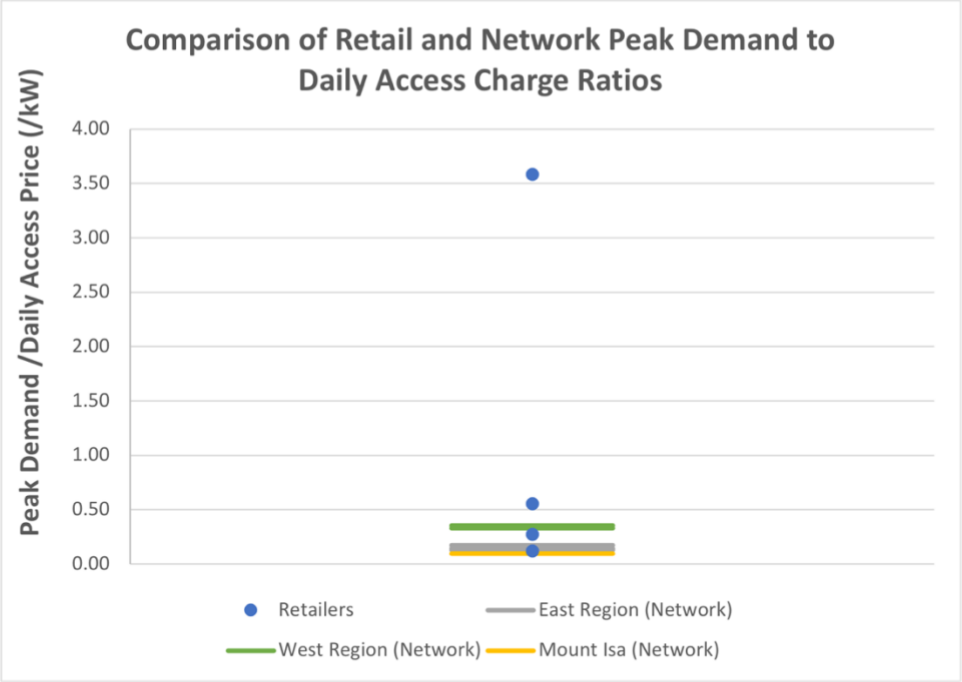

Figure 3-38. Ratio of Demand charge to retail access charge for retail tariffs with a demand charge component in Ergon's area

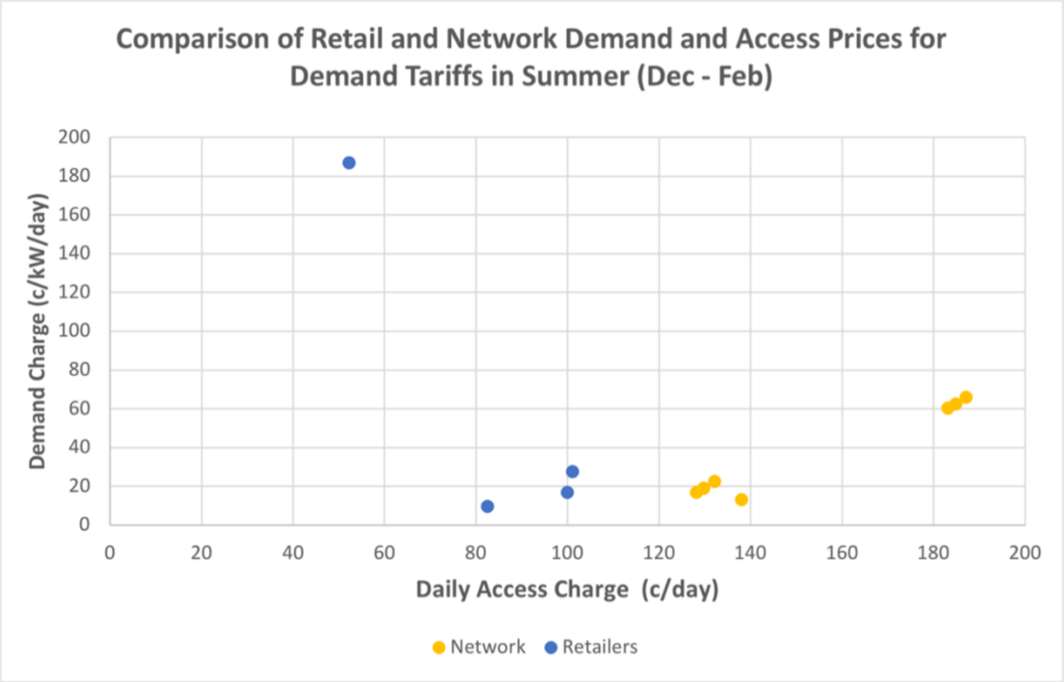

Figure 3-39. Ratio of Demand charge to retail access charge for retail tariffs with a demand charge component in Ergon's area

As can be seen in Figure 3-40, unlike SAPN but like Ausgrid, most retailer tariffs do not follow Ergon's TOU or demand charging structures. Figure 3-41 shows the energy complexity and demand complexity for the retail tariffs in Ergon's area, as well as for Ergon's network tariffs. Note that some different tariffs had identical complexity values and so occur as a single dot. In this case, all the tariffs either have energy complexity or demand complexity, with the highest demand complexity demonstrated by retail tariffs and highest energy complexity by network tariffs. Again, the different complexity values for the retailer and Ergon network tariffs show how the structures are not necessarily carried through, although the variation in complexity is less than occurred for either Ausgrid or SAPN.

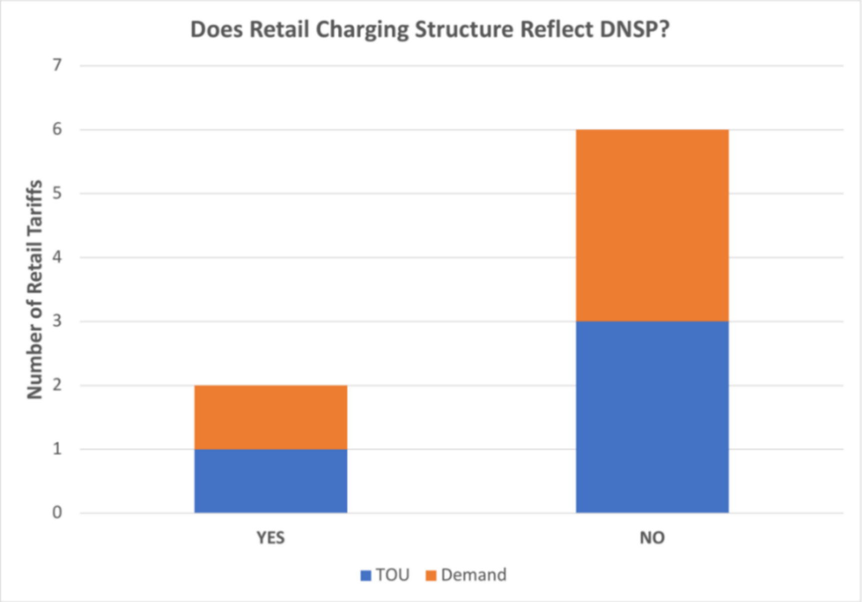

Figure 3-40. Do retailers follow Ergon's charging structure?

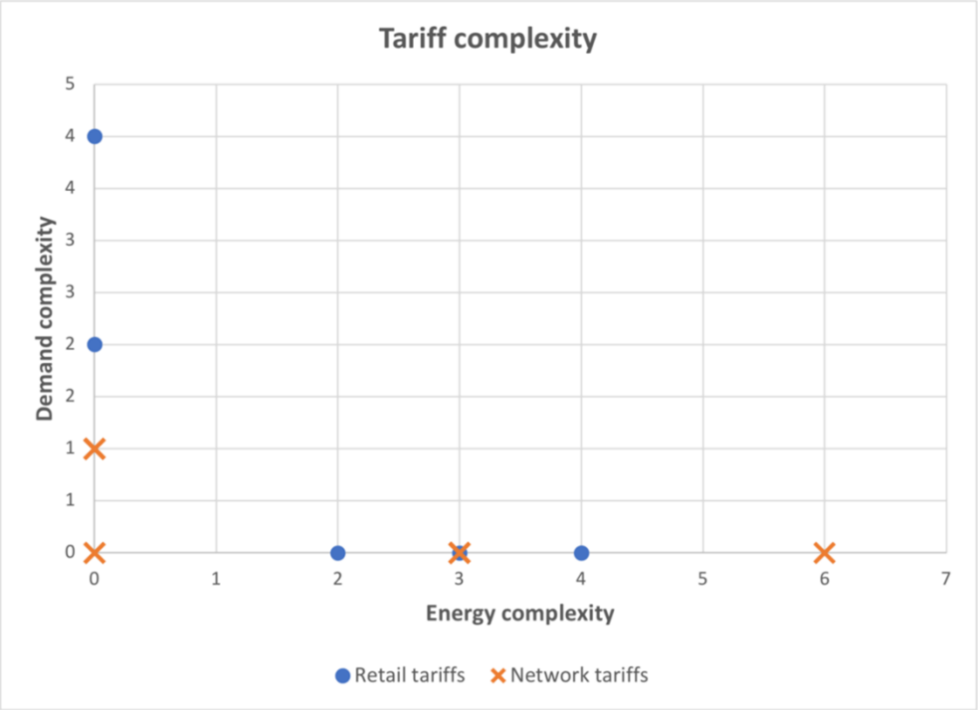

Figure 3-41. Energy complexity versus demand complexity for retails tariffs and SAPN's network tariffs

Figure 3-42 compares the energy charge for the retailers' controlled load tariffs to the equivalent network charges. Note that Ergon's controlled load tariffs don't include a daily access charge. In all cases the retailer charge is much higher than Ergon's charge.

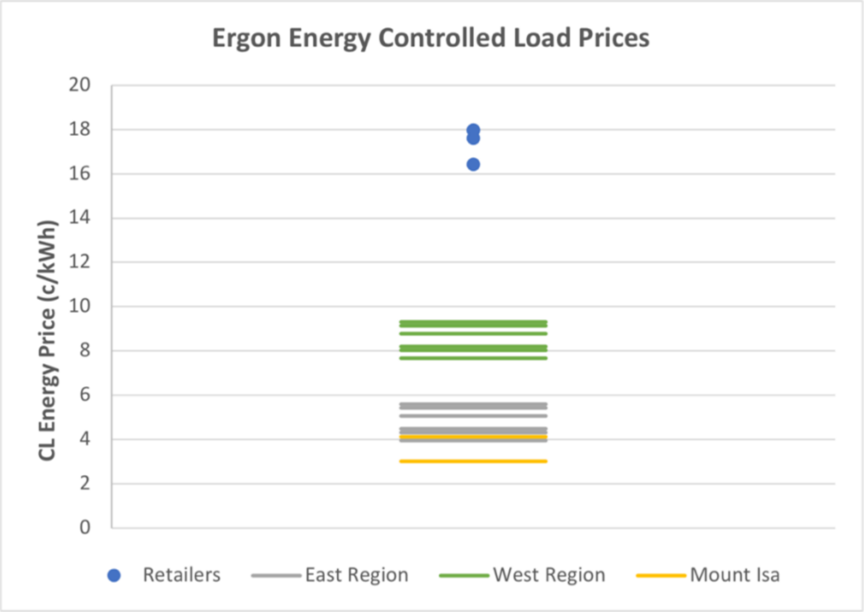

Figure 3-42. Comparison of the Energy charge for controlled load retail tariffs in Ergon's area

Horizon Power area retailers

Horizon Power provides electricity to all Western Australia apart from the South West Interconnected System (SWIS).[18] Being a vertically integrated utility, Horizon Power doesn't publish separate network and retail tariffs, and in fact, apart from in Broome and Port Hedland, all households have access to only one tariff (A2 residential tariff) unless the location is for both residential and commercial purposes (K2 Combined use tariff) – see Table 3-3. Households in Broome and Port Hedland have access to the MyPower tariff.[19] This has a very low usage charge (10c/kWh) and a capacity charge in the form of a higher daily charge based on the amount of electricity used each hour during the peak period (1pm to 8pm weekdays).

These tariff rates are heavily subsidised through the Tariff Equalisation Contribution from customers on the SWIS under the Uniform Tariff Policy, with the average subsidy estimated to be $3,972/customer for 2020/21.[20]

Table 3-3. Tariffs available to households (include GST)

Tariff	Supply charge ($/day)	Variable charge (c/kWh)	
A2 Residential Tariff	1.0333	28.89229	
K2 Combined Use Tariff	1.8234	30.1107	0 – 20 kWh/day
		28.3753	20 – 1,650 kWh/day
		31.9921	> 1,650 kWh/day
MyPower tariffs	$1.12	10	1.5kWh/peak hour
	$2.42	10	3kWh/peak hour
	$4.90	10	5kWh/peak hour
	$8.07	10	7kWh/peak hour
	$12.17	10	10kWh/peak hour
	$24.79	10	15kWh/peak hour

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[18] A map is available here https://www.horizonpower.com.au/about-us/our-service-area/

[19] https://www.horizonpower.com.au/mypower/

[20] https://www.horizonpower.com.au/media/5634/electricity-fees-and-charges-brochure-2020-21.pdf

3.1.2.3 Uptake of cost-reflective retail tariffs

Time-varying tariffs

A pre-requisite for a household to take up a time-varying (TOU or flexible) tariff is installation of an interval (Type 5) or smart (Type 4) meter. As of June 2020, 42% of NEM customers had smart meters, but outside Victoria (where smart meters are mandatory) penetration drops to 17.4% (AEMC, 2020d). More detail of smart meter penetration is provided in Section 5.4.

However, most households with smart meters do not have time-varying tariffs. Only 22.8% of households in the NEM (excluding Victoria) were on any kind of cost-reflective tariff by June 2020 (Australian Energy Regulator, 2021)[21]. Table 3-4 shows the variation across jurisdictions for households with smart meters, with 39% of NSW households and nearly half of Tasmanian households on time varying tariffs, compared to very low penetrations in South Australia and Queensland. In Victoria, despite the mandatory rollout of smart meters, only 19.3% of households were on a TOU tariff by June 2019 (ACCC, 2020b).

Table 3-4. Percentage of households with smart meters on time varying tariffs (Australian Energy Regulator 2021)

Jurisdiction	Flat or Block (with CL)	Flat or Block (without CL)	TOU
NEM (excluding VIC)	53%	25%	23%
ACT	72%	10%	18%
NSW	43%	18%	39%
QLD	62%	37%	1%
SA	63%	33%	4%
TAS	50%	2%	47%

Recipients of NSW government energy rebates and energy social programs are more likely to be on a flat tariff with CL (37%) and less likely to be on a TOU tariff (7.5%) than other households (DPIE, 2020).

Figure 3-43 (which is a repeat of Figure 3-8) shows the percentage of all households (not just those with smart meters) on all types of cost-reflective tariffs for nine DNSPs and the projected increase to 2025: based on AER estimates using data drawn from DNSP Tariff Structure Statements. The projected increasing uptake – approaching 50% for NSW, TAS, ACT and NT by 2025 – is driven by DNSPs shifting from opt-in to opt-out arrangements for cost-reflective tariffs. Amber’s wholesale pricing tariff has 10,000 customers (with a target of 40,000 by the end of 2021), predominantly in Victoria due to the high penetration of smart meters.

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[21] This includes 1.1% of customers on a TOU tariff who do not have an underlying time-varying network tariff. It also includes customers with ‘dumb’ interval meters as well as smart meters.

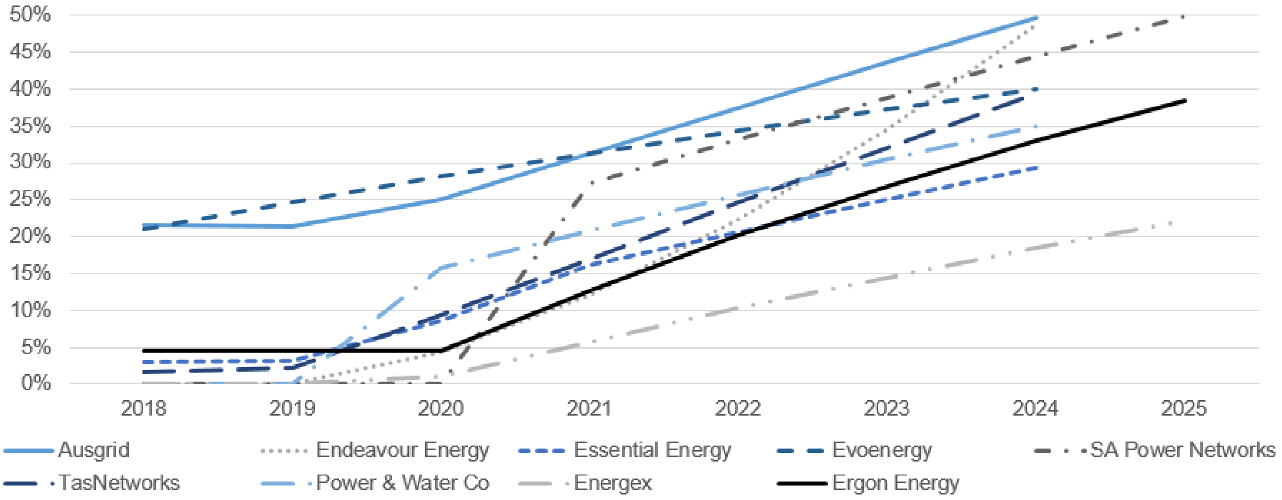

Figure 3-43 Projected percentage of households whose retailers face cost reflective network tariffs (duplicate of Figure 3-8) (AER, 2021b)

Market concentration and switching

There are 40 active retailers for small customers in the NEM . However although the dominance of the "big three" (AGL Energy, Origin Energy, Energy Australia) is declining, they still hold 63% of market share (Australian Energy Regulator 2020). In NSW, 8 new retailers joined the market in 2019-20, increasing the total to 33 (with 38 brands), while the NSW market share of the big 3 reduced from 83.4% in 2018-19 to 81.7% (IPART, 2020).

This high number of retailers can be seen as a sign of a healthy market, but it can also be argued that having more retailers is not all positive and leads to higher costs associated with attracting and retaining customers, costs which are eventually passed on to households (PIAC in IPART, 2020).

Switching rates, between retailers and between tariffs, are commonly used as an indicator of user engagement, so it is disappointing that, NEM-wide, switching between retailers is at a three-year low of 19% (AEMC, 2020a), while switching between plans is stable at 26% (ECA, 2020). Indeed, while 88% of NSW households are on market offers (IPART, 2020), 30-40% of Australian energy users have never switched energy retailers or tariffs (ECA, 2019). Conversely, low levels of switching could indicate high levels of customer satisfaction. In any case, assessment of household engagement should consider more than just switching and encompass other ways of engaging in broader energy matters (PIAC in IPART, 2020), including management of energy use, investment in DER, etc.

Non-price competition in NSW is expanding (IPART, 2020), with retailers differentiating their products through non-financial benefits, including carbon-neutral energy, locked-in tariffs for up to 2 years, loyalty discounts, tariffs bundled with solar and battery system, not-for-profit operation, community or charity benefits. This may be in response to the DMO because it has flattened the variation between market offers, and so retailers must be more innovative to find different ways to compete.

3.1.3 Embedded network tariffs

It is estimated that over half a million households buy their electricity through an embedded network (EN) (AEMC, 2019). In an EN, electricity is purchased at the parent meter with a commercial tariff (allocated according to the connection voltage and the aggregate annual consumption of all customers in the EN) applied to the aggregated electricity consumption of all the customers in the EN, and then sold on to households through an EN retail tariff applied at the child meters. The wholesale / retail component of the parent tariff, determined through negotiation between the Embedded network service provider (ENSP) or Embedded network operator (ENO) and the retailer, is typically lower than a residential tariff and either flat or TOU. The network component is regulated and typically includes a TOU charge for consumption and a demand charge based on annual or monthly peak demand, so has a high degree of cost-reflectivity.

Although these cost-reflective TNSP and DNSP network charges were introduced earlier for commercial customers than for residential ones, and so are applied to all ENs at the parent meter, customers in embedded networks will only face these to the extent that they are passed through by their ENO. The costs of the embedded network itself cannot be paid through tariffs but instead must be paid through some sort of separate fee, although of course the savings made by the ENO from the difference between tariffs at the parent meter and at the child meters can effectively contribute to meeting the embedded network's costs. In practice, the tariffs applied to customers within the EN comprise only volumetric (flat or TOU) and fixed charges.

The difference between the commercial tariff applied to aggregated load at the parent meter and typical retail tariffs means there is significant room for the ENO to set retail tariffs at a competitive rate. Rates for a flat or TOU tariff structure can therefore be set to ensure that all customers are better off staying within the EN. Under "Power of Choice", EN customers have the right to leave the EN and move "on market", so competitive tariffs are necessary to ensure customer retention.

However, in setting the customer-facing tariff within an EN, passing the demand charge component of the parent tariff through to customers is more difficult. If a demand charge is applied to the peak demand of each customer, it could theoretically be set at a lower rate than the demand component of the parent tariff, because the sum of individual customer peaks (which occur at different times) is higher than the aggregated peak. However, customers with peaky loads will generally be worse off with a demand charge included in their tariff than on a tariff with only consumption charges. These customers are therefore incentivised to move on-market and choose a flat or TOU tariff, so the EN will receive minimal revenue from a demand charge and will lose revenue through loss of customers. A residential EN tariff that includes a demand charge is therefore only viable if demand charges are mandated for all new residential customers in the retail market (Roberts et al., (Under review)). This is different to the situation in the broader market where a retailer has greater choice of customers.

3.2 Other incentives

3.2.1 Other financial incentives

Apart from tariffs, financial incentives for electricity flexibility can be offered to households in many different forms. The following are used in existing flexibility products or have been used in trials of the flexibility mechanisms discussed in Section 4:

- One-off payment for signing-up to a scheme
- Fixed payment for participation in each DR event, which can be based on self-reporting, achieving a minimum kWh demand reduction during an event or a minimum kW reduction throughout an event, relative to a baseline calculated from the household's specific load or average load.
- A range of payments dependant on meeting specific demand reduction targets (in kWh or kW)
- Variable payment dependant on achieved demand reduction ($/kWh)
- Payments for participation in surveys (e.g., describing proposed or actual DR behaviours undertaken during an event) or for accessing educational material
- Payment for participation in all the events of a programme
- Subsidised or free technology, such as BESS, PV, monitoring or control technology. This can include government subsidies (e.g., South Australian Home Battery Scheme)
- Low-cost finance to purchase enabling technology (e.g., NSW Empowering Homes scheme offering interest-free finance for PV and BESS)

3.2.2 Non-financial incentives

It is sometimes assumed that, while early adoption of residential solar PV was driven by environmental, social and independence concerns, mainstreaming this technology relies solely on the financial benefits.

However, there is evidence of greater complexity, with adoption decisions driven by the alignment of, e.g., financial *and* economic incentives (Roberts, 2020) and the need to combine economic and belief-based models when analysing these decisions (Duncan, 2013, Grimm et al., 2019).

Similarly, findings from previous consumer studies suggest that energy consumers’ predominant primary motivation for participating in demand response is to reduce energy bills (for example, Simpson and Clifton, 2017). Because of this, the role of non-financial incentives is sometimes overlooked but environmental and societal benefits are also significant (e.g., AGL, 2018). A systematic review of DR academic and grey literature (Parrish et al., 2020) found that, while financial benefits are the most common motivation for demand response, a minority of trials found environmental and social benefits found to be more important. Indeed, “46% of household consumers report that they would be willing to reduce their energy use *without* a financial incentive” (ECA, 2020). It is therefore important to consider the broad range of motivations that drive people’s behaviour and decision-making and the potential for non-financial incentives to increase household flexibility, either alone or in concert with financial incentives.

Environmental benefits: 80% of Australians think we are already experiencing the impact of climate change, 83% support the phase out of coal-fired power stations and 79% rank solar in their top three preferred energy sources (Quicke and Bennett, 2020). Explaining the environmental benefits of increased flexibility, which include increased PV hosting capacity and reduced use of fossil fuels, can therefore help to motivate households. Sundt and Rehdanz (2015) found that, in general, people are willing to pay extra on their electricity bills for renewable generation, while Asensio and Delmas (2015) found that messaging about the environmental and health impacts of electricity production (such as mass of pollutants, increased childhood asthma, and cancer) achieved greater behavioural energy savings than messaging about financial benefits.

Network benefits: Although public distrust of the electricity system in general is widespread, some households understand the distribution network as a community resource and see value in supporting grid management and reducing network costs for all consumers. However, this may be contingent on the sense that they are being asked to contribute their fair share (Roberts et al., 2020). As with environmental benefits, tapping into these motivations requires a high level of engagement with households, as well as transparency around the distribution of network costs and benefits. More broadly, as Endeavour Energy reported from their *PeakSaver* programme, “personal communication and explanations about the purpose of demand management programs improved householder satisfaction and demand response”(Ben-David, 2020).

Community motivations: Messaging about environmental, network or social benefits can also be combined with an appeal to collective identity or community purpose: “Join the club” of people working to improve the environment / network / society. A more direct appeal to social and community motivations is to incentivise flexibility through community rewards, including payments to charity or to community organisations or schools. A number of DR trials have explored this, with mixed results. Typically, Jemena’s Power Changers trial found community incentives to be less effective than personal ones but attracted a different segment of end users (Jemena, 2019). Action for community benefit is contingent on the perception that costs and benefits are being distributed fairly. For incentive design, as for market design, “despite its elusiveness, fairness must be a central consideration […] if it is to gain enduring community acceptance. Great care needs to be taken to understand the community’ standard of fairness.”

Combining these incentives with financial rewards are likely to improve response, both through appealing to different groups of customers and providing multiple reasons for an individual or household to participate. However, there is also a danger of financial incentives “crowding out” other motivations (Powershop and Behavioural Insights Team, 2019).

There is also a range of other motivations that may work against flexibility. For example, a desire for a*utonomy / independence* from energy companies is a recognised motivator of uptake DER (particularly solar PV), but could work against uptake of flexibility mechanisms that involve 3rd parties controlling or orchestrating households devices, or that decrease self-consumption of on-site renewables (Roberts et al., 2020). Desire for *convenience or control* can help motivate households to use HEMS or other control technologies but can also decrease households’ willingness to provide flexibility.

4 Mechanisms for electricity flexibility response

There are many ways that households can respond to tariffs or to other incentives, and these are summarised in Table 4-1, along with the other types of mechanisms that are currently used to achieve changes to electricity use or generation. They include behaviour change (which could be energy management behaviour[22] or Behavioural Demand Response, BDR), third party control of appliances (Direct Load Control) or of inverters or batteries (for example aggregated into a VPP). Additionally, battery management systems (BMS) and home energy management systems (HEMS) can respond to tariff signals and/or to solar generation and household consumption.

Table 4-1 indicates which of these mechanisms involves behaviour change (those marked ✓ require behaviour change, while [✓] indicates the possibility of behaviour change), which involve automation of loads or DER, and which involve control by an external 3rd party orchestrating a flexibility response across multiple households.

The mechanisms are described in more detail below, with examples of existing trials and market schemes and some of their key findings summarised in Table 4-2, Table 4-3 and Table 4-4.

4.1 Energy management behaviour

The simplest mechanism for demand flexibility, from a technological perspective, is households changing their demand manually in response to a time-varying tariff or, for solar households, to use excess solar generation. (This is distinct from BDR below, as it does not include behaviour in response to a signal for a specific event, nor is there any orchestration across households.) This includes reducing electricity use as well as shifting it from peak tariff periods to off-peak periods, or from times of low solar generation (or high household consumption) to times of high excess generation. For solar households, the financial driver for increasing solar self-consumption is the difference between the FiT offered for exports and the tariff charged for grid consumption. However, non-financial incentives are also important, including reducing household carbon emissions, maximising benefit from sunk investment in the PV system, energy independence and SITTM.

Typically, this includes:

1. manually shifting appliance use – dishwashers, washing-machines, dryers, pool-pumps - to off-peak times or the middle of the day, which relies on household daytime occupation;
2. turning off air-conditioners or adjusting their temperature or power settings; it may also involve pre-cooling (or pre-heating) during off-peak or solar periods.

Potential impacts include reduced peak demand and reduced daytime solar export, as well as shifting the demand peak to the end of the peak period. As discussed further in Section 6.4, households' ability to reduce or shift loads in this way is dependent on having available loads and is subject to a range of lifestyle, social and other constraints. In particular, the most commonly available flexible and manually-controllable loads (washing machines and dishwashers) are relatively small.

4.2 Battery management systems

All home battery energy storage systems (BESS) include battery management systems (BMS). While more sophisticated systems have the ability to respond to external signals or may be orchestrated into a VPP (see Section 4.7), most operate in a simple "load-following" mode designed to increase solar self-consumption and minimise imports from the grid. In this mode, the BESS is charged whenever solar generation exceeds household load and discharges whenever load exceeds generation. The benefit to households is derived from a FIT that is lower than the import tariff. System benefits include demand

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[22] This refers to any behaviour the household uses to manage their electricity use or generation, except when automated or directed by an external 3rd party.

reductions during spot price and network peak periods of approximately 1/3 of that delivered by BESS orchestrated to deliberately achieve those ends (Zhou et al., under review) as well as increased minimum demand.

Table 4-1 Types of electricity flexibility response

Mechanism	**Load / DER**	**Behaviour change**	**Automation**	**Orchestration**	**Signal**	**Market**	**Enabling technology**
Energy management behaviour	Household appliances	✓	×	×	Time-varying tariffs or solar self-consumption	Indirectly in network and wholesale markets	None necessary, but visualisation of smart meter or load monitoring data can assist
Battery **M**anagement **S**ystem	BESS	×	✓	×	Time-varying tariffs or solar self-consumption or export payment	Indirectly in network and wholesale markets	Monitoring of PV, load and BESS; BESS control
Home **E**nergy **M**anagement **S**ystem	PV, EHW, A/C, EV, Household appliances	[✓]	✓	×	Time-varying tariffs or solar self-consumption	Indirectly in network and wholesale markets	Various: load and PV monitoring, timers, smart switches, smart thermostats, smart chargers, IR A/C control, diverters…
Direct **L**oad **C**ontrol	A/C, EHW, EV, Pool pump	[✓]	✓	✓	External signal controlling DRED or circuit switch or (for A/C) thermostat or IR	Network services and indirectly in wholesale markets	DREDs, IR A/C controllers, smart thermostats & switches, controlled via 3G/4G, wi-fi or ripple control
Controlled **L**oad	EHW, Pool pump	[✓]	✓	✓	Responding to tariff period	Network services and indirectly in wholesale markets	Local timer, ripple control or smart meter relay
Behavioural **D**emand **R**esponse	A/C or household appliances	✓	×	✓	SMS/Email notification	Network services	Smart meter or other load monitoring to measure response
Virtual **P**ower **P**lant	PV, BESS, EHW, EV, Pool pump	[✓]	✓	✓	3G or wi-fi responding to market prices	Wholesale, network and FCAS	3G/4G or wi-fi control of BMS, relays, charger

With a time-varying tariff, some BMS (such as the Reposit add-on control device) can also be set to charge the BESS from the grid during off-peak tariff periods and discharge during peak tariff periods. If the BMS has connectivity through wi-fi or 3G/4G it may be able to respond to wholesale price signals (for households on a wholesale pass-through tariff), without orchestration from a 3rd party. Where it responds to notifications of network constraints or is part of an aggregated engagement in FCAS markets, through 3rd party orchestration, it would be considered as a VPP, discussed below in Section 4.7.

4.3 Home energy management systems

The term Home Energy Management System (HEMS) is used here to describe any form of locally automated control of household loads that can be reduced or shifted in response to a tariff or in order to increase solar self-consumption, as opposed to responding to a direct external signal or being orchestrated by a third party (which would be described here as DLC or VPP).

At the simplest level, this includes ‘dumb’ timers, whether integrated into appliances or installed between plug and socket, to control washing machines, driers or dishwashers, or installed in switchboards to control EHW or pool pumps. These can be set to schedule appliance use during off-peak periods or at times of likely high solar generation.

Integration of wi-fi or 3G/4G communications into devices enables remote control of appliances through online dashboards, phone apps or voice activated platforms such as *Google Home*. Note that HEMS do not necessarily reduce energy consumption or improve energy performance, as the convenience they provide can also lead to increased energy use in pursuit of greater comfort, such as by pre-cooling the house on the way home.

The next level of HEMS includes decision-making based on tariff signals or on the level of excess solar generation. For solar households, examples include *Fronius Energy Management* or *Solar Analytic’s* trialled Intelligent HW timer (Yildiz et al., 2021), which use real-time monitoring of solar generation and total household consumption to determine excess solar generation and switch EHW on or off accordingly through a relay. While these relay-based systems allow EHW (or potentially other loads) to be switched on or off, and can therefore result in grid imported electricity being used for water heating, water diverters such as *CatchPower* use power electronics to match the power sent to EHW exactly to the available excess solar generation.

With control of multiple devices, optimisation of energy use is possible – for example allocating excess solar generation to EHW or pool pumps – or integration of loads and a battery.

4.4 Direct load control

Direct load control (DLC) describes control of households’ appliances (commonly air-conditioner, electric hot water or pool pump) by a third-party.

Apart from controlled load (Section 4.5 below), Energex / Energy Queensland’s (EQ) *PeakSmart* programme has by far the greatest uptake of all DLC programs in Australia. *PeakSmart* uses EQ’s ripple control to reduce the demand of Demand Response Mode (DRM)-enabled air-conditioners during a handful of 2-4 hour network peak events each year.[23] Participants are incentivised through a $200 - $400 discount on purchase of a DRED-enabled A/C unit. *PeakSmart* has evolved since 2017 through a number of trials, including Energex’s *Cool change* programme, to a mass programme with 120,000 participants, incorporating lessons learned in earlier iterations, including that “*customers are fatigued of changing their energy behaviour to compensate for continually rising energy costs [and] are now seeking and adopting technology solutions*” and the importance of industry partners. Participants are recruited through A/C retailers and installers, with installers offered an additional financial incentive increasing their competitiveness for bulk installations in new residential developments.

Other DLC schemes (see Table 4-2) which focus on A/C control include AGL’s *Peak Energy Rewards – Managed for You*, Ausgrid’s *CoolSaver* and *Power 2U*, Energy Australia’s *Mass Market DR Programme*, Zen Ecosystem’s *Zen Air Trial*, AusNet’s *PeakPartners* and Powercor & CitiPower’s *Energy Partners*. Incentives offered to participants include upfront payments for signing up, free devices (offering benefits such as online remote control), payments for participating in each event, fixed annual payments or payments linked to achieved DR. Many earlier trials have been characterised by the challenges and costs of participant recruitment and device installation, limitations of control technologies and difficulties in verifying responses (see Section 5.7.1).

Technologies used in these trials include 3G devices communicating with A/C via DRM signals to limit power consumption to 75% or 50% of rated power and smart thermostats to alter temperature settings by a few degrees during events. Some more recent trials are using plug-and-play infrared A/C control devices,

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[23] A list of *PeakSmart* events can be found at https://www.energex.com.au/home/control-your-energy/managing-electricity-demand/peak-demand/peaksmart-events

such as Sensibo or ZenAir, eliminating installation costs. Temperature control, rather than limiting A/C power through DRM settings, also allows for pre-cooling, decreasing temperature settings for a period before the event to reduce impacts on comfort.

CoolSaver achieved DR of 1.5kW/household (using DRM2) and 1kW using DRM3 for A/C systems above 10kW and only 0.7kW for 4-10kW systems; and is now focused only on the larger systems. AusNet *PeakPartners* report an average household peak reduction of 40%, while *EnergyPartners* averaged 0.66kW/household. However, for participating households, achieved DR depends on availability of the load - i.e., whether the A/C is switched on and at what temperature and power setting – and there are challenges to assessing the level of DR achieved (see Section 5.7.1).

While DLC of A/C is focused on reducing peak demand to help manage network constraints, DLC of other loads can also be used to increase demand to absorb excess solar generation in the middle of the day to help manage voltage excursions.

Water heating accounts for around 23% of residential energy consumption in Australia (REMP, 2012) and more than half of households have EWH (immersive resistive heater or heat-pumps) (E3 Equipment Energy Efficiency, 2012). Trials of DLC with EHW include Ausgrid's 2011- 2015 DM trials and a 2021 large-scale ARENA funded trial by Rheem & Solahart.

AGL's *Managed for You* programme offered DRM control of EV charging as well as A/C, while Energy Australia's *Mass Market DR* used 'smart isolation switches' to provide circuit-level control of any device, but both schemes were withdrawn due to technology and installation issues. Pooled Energy's demonstration project aims to aggregate the load of 5,000 household pool pumps to provide network services and reduce peak demand.

Compared to BDR (Section 4.6), DLC enables shorter notice periods (Energy Synapse, 2020) and higher levels of event participation.

4.5 Controlled load

The most prevalent form of DLC is controlled load (CL), where specific household loads, commonly electric hot water (EHW) or pool pumps, are controlled by a DNSP, either remotely using ripple control or through a local timer.

In the Ausgrid network, for example, 60% of residential water heating is electric, with at least 500,000 EWH systems on controlled load and another ~ 400,000 on continuous supply (Ausgrid, 2016). Although there is lack of published data, similar proportions are reported, anecdotally, for other NSW DNSPs. In SA, around 90% of EWH is on CL and it is thought that around 50% of EHW systems in QLD are on CL.

There are technical challenges to repurposing CL signalling to switch on loads (particularly EHW) at times of peak solar generation. The equipment used for ripple control is old and may be approaching end of life in some cases, while resetting manual timers requires a truck roll and, therefore, expense. As smart meters are deployed, their switching capability (via a communication modem in the meter) can be used to control CL. This also removes CL from direct control of the DNSP to the Metering Co-ordinator, but retailers are incentivised to align the CL to the DNSPs off-peak tariff periods. Endeavour Energy are trialling *Off peak Plus*, working with Intellihub smart meters to remotely control EHW systems to act as a 'solar soak' for local generation[24], but this requires a partnership with ten retailers to facilitate the meter upgrades[25].

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[24] https://utilitymagazine.com.au/smart-meter-installations-for-off-peak-electricity-systems/

[25] https://bit.ly/3g2OulO

Table 4-2 Summary of DLC trials and schemes

Organisation	Project	Load	Date(s)	Enabling technology	Notification	Incentives	Key finding(s)
AGL	Peak Energy Rewards - Managed For You	A/C, EV	2017-> current	Originally, DRM control of A/C and EVs using Wattwatchers device or Zen thermostat. Now Sensibo Infrared control of A/C	SMS before event. Reply with 'Yes' and AGL will automate response	Free device, sign up bonus and per-event payment	DRED incompatibility, functionality and installation issues led to replacement with self-install Sensibo device
Endeavour	CoolSaver	A/C		Wireless DRM control of Aircon	SMS,push and email notification before event	Fixed annual payment	Householders lower thermostat temp to counter DRM power reduction
Energy Queensland	PeakSmart	A/C	Current	Ripple control driving DRM control of A/C.	None	$400 upfront discount on A/C (>10kW)	Issues with retrofitting tech; moved to new installations only, with incentives for installers.
Ausgrid	CoolSaver, now Power2U	A/C	2013 -> Current	Ripple control & 3G driving DRM control of A/C	None	Gift card for participation in all events	
Energy Australia	DR Programme - Mass Market	A/C, pool pump, other	2020	Circuit level control of devices	Series of notifications pre-event		DLC needs segmented plug & play technology. Available data insufficient to profile households.
Zen Ecosystems	PI Zen Air Trial	A/C	2017-2020	ZenAir (self-install) IR control of A/C	Precools house (-3 degrees) prior to event	Free Zen Air	Households used override to ensure comfort. Unable to verify DR due to data issues
AusNet, Powercor, CitiPower,	Peak Partners	A/C	2017-2019	BDR: real-time data portal			
Rheem / Solahart	Active Hot Water Control	EHW	2021 ->	Solahart Powerstore - grid interactive, electric HW heater			
Pooled Energy	Pooled Energy Demonstration	Pool pump	2017 -> Current				
Solar Analytics	Smart Hot Water Control	EHW	2019-2020	Wattwatchers device with switching capability + delay timer relay		Maximising solar self-consumption	
Endeavour Energy / Intellihub	Off peak Plus	EHW	2021	Intellihub smart meter with remote EHW switching		Soaking up local solar generation	

4.6 Behavioural demand response

Behavioural demand response (BDR) involves households changing their energy behaviour – usually changing air-conditioning thermostats or power settings or turning off appliances – in response to a signal. It has been explored in the NEM through a number of historic and current trials.

Households are notified of peak events by email and/or SMS, typically day-ahead and then within an hour of the event, with an additional notification at the end of the event. However, AGL found the day-ahead notification to be unnecessary and could be removed (AGL, 2019). While some trials used SMS and/or email to communicate with households, others use bespoke phone apps. Messages range from generalised "use less energy" to specific directions to increase thermostat settings, unplug appliances, avoid doing the laundry, turn of lights, close curtains to help maintain household temperature, or even suggestions to go to the local shopping centre. Schemes that included near real-time feedback of energy use generally report greater achieved DR and positive user feedback.

Financial incentives include payments for signing up to a trial, fixed payments for participation in each event, bonus payments for participation in all events, payment for meeting a personalised target reduction in energy (or power), payment per (estimated) kWh of delivered DR, payments for completing post-event surveys (used to estimate the level of DR) and entry into a holiday prize draw. While variable rewards incentivise greater demand reduction, compared to binary rewards for event participation, they rely on greater knowledge of the level of DR, and therefore on accurate estimates of counterfactual 'baseline' energy demand. Additionally, AGL found that variable incentives "confuse and disengage" participants, in line with households' established preference for simplicity in electricity pricing.

While most trials focused on personal financial rewards, community rewards – for local schools or community groups – have also been used and, although "financial rewards were more appealing than altruistic rewards" (Energy Australia Mass Market BDR), AGL's *Managed By You* programme reported that "many customers consider the monetary value of their rewards to be insignificant but explained that this wasn't their primary motivation for participating" and Jemena's *Power Changers* suggested that they can increase total DR achieved by appealing to a different user cohort.

BDR avoids the cost and technical challenges of installing the control and communications devices required for DLC and allows households to remain in control of their energy use and to opt out of a specific event without effort. A common finding from multiple trials is that households need the ability to opt out of specific events and/or BDR programmes at any time. BDR can therefore be seen as an 'easy route in' for households to participate in demand response, but many of the trial reports have noted the importance – and high cost - of effective household engagement which is "paramount and ongoing" (Energy Australia Mass Market BDR), from recruitment to reporting of results. This includes long form communications to convey the basic concept of demand response, the loads and behaviours likely to achieve significant results and clear, consistent safety messaging to dissuade households experiencing vulnerability from foregoing safe household temperature in the pursuit of financial rewards.

Moreover, although Energy Australia and Jemena's Energy Saving Reward Program found that "motivation is either altruistic or financial", many of the schemes recognise that households have multiple motivations and combine financial rewards with recruitment messaging that appeals to more altruistic or community values, including "help the grid", "cut down on waste" and "join the club". Unsurprisingly, Zen Ecosystems found that the impact of their "help the grid" message was high during a period of relatively high blackouts (summer 2017/18) but declined in cooler months with greater supply reliability. Although Powershop's *Curb your Power* report warns of the danger of financial incentives "crowding out" intrinsic motives, there is some evidence that combining material incentives with value-driven messaging can strengthen recruitment and engage a wider range of participants.

Enova Energy trialled BDR requests without offering a reward, based on community / grid benefits (and lowering Enova's wholesale costs and therefore benefiting all their customers) and report a positive (but unquantified) response, but suggest that this may have relied on their unique position as a community-owned retailer and that, for other retailers, "it could even backfire, with customers deliberately using more power just to spite them." However, Endeavour Energy's *PeakSaver* BDR report also found that "while financial rewards were still important for many households, some were willing to respond to non-financial peak alerts once they understood peak demand.” Clearly, the relationship and level of trust between utilities and households is a crucial factor in the potential success of non-financial incentives and messaging.

Most BDR trials reported positive outcomes, based either on self-reported household participation in events or on estimated levels of demand reduction, using CAISO ’10 of 10’, ARENA-AEMO baseline, or variations of these methods (see Section 6.3.6 for a discussion of the challenges of baseline estimation). Reported average power reduction is in the range 0.24-0.90 kW, but this masks the variability between households. For example, for AGL’s Peak Energy Rewards scheme, 80% of the achieved DR was delivered by 20% of participants. Some trials observed increased pre-cooling load before events and ‘bounce-back’ after as air-conditioners were restored to full power.

While all these trials use BDR to target peak demand, there is potential application in increasing demand to manage high reverse power flow or high network voltages, but there is a risk of increasing total energy use and perverse outcomes such as a clothes drier being used to soak up solar when it’s sunny.

Table 4-3 Summary of behavioural demand response trials

Organisation	**Project**	**Date(s)**	**Notification**	**Incentives**	**Baseline / Verification**	**Messaging**	**Monitoring technology**	**Key finding(s)**
Endeavour	PeakSaver / CommunitySaver / PowerSaver	-> Current	In-app notification	$1.50/kWh gift card. Suggest using cinema tickets to incentivise leaving the house during events	Based on demand in preceding business days adjusted to use on day of event	Some users respond without financial reward, but distrust is an issue. Community challenges: "learn and earn", make a pledge", "take an action"	Smart Meter and mobile app	Not attractive to energy efficient households. High cost of marketing and education.
Energy Australia	Mass Market / Energy Saving Reward Program / Power Response	2017-> Current	SMS / Email	Now: $1/event participation + $2/kWh bill credits	AEMO adjusted 10-day average baseline. But it's not representative and not suitable for solar households	Effective household engagement is paramount and ongoing – education, branding, style, safety and voluntary nature are important"	Smart meter	Financial rewards were more appealing than altruistic rewards for MM households. Low smart meter penetration is challenging.
Enova Energy	Voluntary customer response	2019-21	Afternoon of event: email, SMS, social media	No direct reward. Community benefit based on saving retailer cost and lowering prices for all Enova customers.		Reduce unnecessary usage, if it’s safe to do so, during specified hours.		Decision to send requests has to balance potential impact, cost of communication and the risk of overloading customer messaging.
Jemena	Power Changers	2017 - 2018		$20/event for participation plus rewards for surveys, as personal gift card or community reward.	Target set as % of average (using CAISO 10 in 10). And DR measured by comparison with control group of similar households.	Included “Learn and earn” education about electricity market	Smart Meter and mobile app	Biased towards users with low consumption. Community incentives less effective than personal but

								attracted different cohort.
Origin Energy	Origin Spike	2020	Email / SMS	PayPal cash or gift cards for reaching goal set.	CAISO 10 by 10	Gamification: challenge to reduce energy use with small behaviour changes"	Spike platform	
Powershop	Curb Your Power	2017-2021		Evolved to: $10 to curb 10% throughout event AND 1kWh AND min 0.05kWh/h throughout	AEMO baseline: net load for solar households doesn't correlate with temp.	Tested prize draw, "Join the club", Community (charity) rewards.	Smart meter and monitoring app	Message by default has greater impact than moral appeals, education or economic incentives.
United Energy	Summer Saver	2015 - 2020	In app notification and 15-min data updates	"Moved from participation payment to $5/kWh + 50% bonus for all 3 hours		Behaviour suggestions including pre-cooling, close blinds, unplug appliances.	Mobile app & gamification	Near real-time data drove higher engagement.
Zen Ecosystems	RACV and Planet Innovation Behavioural programs	2017-2020	SMS		AEMO Adjusted Baseline. Then modified to “linear baseline”	“Help the Grid” was strong motivator in 17/18 (awareness of blackouts) but far less impactful later.		Costs of the incentives provided not covered by the value of DR delivered. Lack of data access.

4.7 Virtual power plants

In broad terms, a virtual power plant (VPP) refers to coordination of aggregated resources to deliver system services and participate in electricity markets (AEMO, 2020a). This can include solar PV, BESS and controllable loads such as A/C, EHW, EVs or pool pumps. However, the majority of VPP trials and currently available VPP products involve aggregation of home BESS (or PV-BESS) (schemes involving aggregation of EHW and A/C loads are generally considered DLC or BDR). Current and historic VPPs use aggregated BESS to manage network peak demand, participate in the wholesale spot market and/or provide system services through participation in some or all of 6 contingency FCAS markets (5s, 60s and 300s, raise and lower)[26].

DNSPs including SAPN, Evoenergy, Endeavour Energy, Ausgrid and Horizon Power have successfully trialled VPPs to manage network demand peaks and help to defer network upgrades, although Ausgrid's trial achieved savings equivalent to $100/year per household which would be insufficient to incentivise them to invest in a battery.

A number of VPPs have demonstrated participation in the wholesale market, charging batteries prior to forecast high price events and during negative price events, and discharging during high price events. Recent participants in AEMO's VPP demonstration project 'value stack' wholesale market participation with provision of frequency services, as well as response to minimum demand. Their earnings suggest that the greatest value is achieved from participation in FCAS markets, with "the amount of revenue earnt by VPP participants strongly correlated to the occurrence of power system events, how responsive they are to market signals, and how many contingency FCAS markets they participate in." (AEMO, 2021a)

Table 4-4 shows the VPP offers available to households as of March 2021 (Solar Choice, 2021). Business models are very diverse, including schemes connected to BESS purchase and 'BYO' schemes. Some are restricted to a single battery or inverter manufacturer, but many now offer API integration for 2 or more brands, with, for example, Discover Energy aiming to cover 70-80% of the inverter market in 2021.[27] Incentives offered include a discounted BESS (or PV-BESS), ongoing bill credits (which can be fixed or dependent on VPP earnings) or access to VPP-specific tariffs, including for solar exports.

Assistance with equipment purchases in SA generally include around $2,000 subsidy from the SA Government's Home Battery Scheme. Elsewhere, they are mostly presented as PV-BESS system costs or take the form of finance deals with payments over the contract term, and there is a lack of transparency about the size of the user benefit. Bill credits are variously quoted as $20 per event, $220 per year or are estimated dependent on the kWh delivered and the number of events. VPP-specific tariffs are presented as payments for export, up to $0.45/kWh in addition to standard retail FIT but in several cases applied to a limited total of exports. While these tariff-based incentives are presented in language familiar to existing solar owners, it is far from straightforward, even for technically knowledgeable households, to predict the total benefit from VPP participation or to compare incentives across different VPP schemes.

Research into household attitudes to VPPs suggests a strong preference for short-term contracts or opt-out anytime arrangements due to uncertainty in VPP earnings and in potential future offers (Roberts et al., 2020), and most current offers have either no or 12 month contracts. The longest (10 year) contract with Pilico Energy is attached to weekly payments for a PV and BESS system, and participants can opt out by paying the outstanding hardware costs. Similarly, households can buy out of the 5-year contract for Origin's VPP which is linked to a significant upfront hardware discount. However, PowerClub's Powerbank and Energy Australia's PowerResponse involve 2- and 3-year contracts, respectively, for households bringing their own batteries to the scheme.

Households' reasons for buying home batteries include increasing electricity supply reliability and independence from the energy system. Existing battery owners (targeted by BYO battery schemes) are particularly likely to have bought batteries for non-financial reasons and may be ambivalent about giving up

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[26] The exception to this is Rheem's ARENA-funded *Active Hot Water Control* project, which aims to establish a VPP using 2,400 domestic EHW systems to participate in the wholesale market and provide network services.
[27] https://reneweconomy.com.au/open-platform-vpp-retailer-discover-energy-offers-45c-solar-fit/

control of their battery even if the financial benefits are clear (Roberts et al., 2020), while prospective battery owners may also want to retain some part of the battery for their “own use”. Many of the available schemes recognise this and restrict VPP use of the battery to a proportion (commonly 80%) of its capacity, although Origin’s VPP reserves the right to fully discharge the battery. Tesla/Energy locals also restrict the number of discharges for VPP use to 50 per year to allay household concerns about reducing battery life through VPP participation.

Participants in the AEMO VPP demonstrations are more likely to be male, aged 50 or over, without dependent children and living in a free-standing house in a metropolitan area (AEMO, 2021c). They are motivated by electricity bill savings and accessing government subsidies on batteries, as well as (to a lesser degree) community / environmental motivations and desire for a back-up energy supply. Satisfaction levels vary with the VPPs, particularly amongst less engaged and more financially focused participants, some of whom are disappointed with the financial returns (AEMO, 2021c).

Table 4-4 Available VPP offers 23/3/21 (Solar Quotes 2021)

VPP provider	Approved batteries	Battery subsidy	Feed-in tariffs offered	BESS capacity reserved for homeowner	Contract term length
Tesla Energy Plan / Energy locals	Tesla Powerwall only	$2,000 Powerwall subsidy.	7.5c FIT	20% reserved; max 50 discharge cycles / yr	12 months min
Ausgrid *iPower2U*	LG Chem, SolaX, BYD	Paid /kWh of export during events.	Dependant on retailer	Not specified	Not specified
Discover Energy	Compatible with Goodwe, Sungrow, SolarEdge or Alpha-ESS hybrid inverters	No subsidy - BYO battery. 50-50 profit share on trades	45c/kWh first 300 kWh/quarter, 25c next 300kWh, 9c after that	No reserve	None
Energy Australia *Power response*	Tesla Powerwall, Redback ("Bring Your Own Battery")	$200 joining credit, flat $20 credit paid per event	Standard FIT for regular discharge, flat $20 credit per event	20%; max 20 events / year	3 years
Members Energy	Eveready, Telsa Powerwall, Hive, AlphaESS	Households pay $1.10 daily membership fee	Market rate for export with minimum feed-in 6c-10c	20%	None
Plico Energy	Pylontech	Households pay $36.50/week for 6.6kW PV and 7.2kWh BESS	Standard Synergy tariffs	15%	10 years
PowerClub *PowerBank*	Sonnen only for now	$500 credit for first 20 members	29c usage tariff, 11.5c feed-in tariff.	TBD	2 years
ShineHub/Powershop *ChargeForce*	Alpha-ESS	$2,000 battery subsidy (in SA only)	$0.45c/kWh plus retailer FIT	10%	None
Social Energy	Duracell "Energy Bank" or SolaX "Triple Power"	No battery subsidy - high feed-in tariff instead	40c/kWh for 1st 300 kWh/ quarter – then market FiT	No reserve	None
SonnenFlat	SonnenBatterie Eco and SonnenBatterie Hybrid	Flat monthly rate for energy allowance, min $49 for 4MWh. BYO PV & battery	e.g. Ausgrid, FIT of 8c/kWh for export above 1,210kWh	No reserve	None
AGL *Bring your own battery*	LG Chem RESU "HV" or Tesla Powerwall 2	$1,000 battery subsidy. $100 bill credit sign-on bonus. $45 bill credit per quarter.	No VPP-specific tariffs – standard AGL plan.	Powerwall: 20%. LG Chem RESU: Varies	12 months
Origin Virtual Power Plant	BYD C-Box HV	6.4kWh BESS for $4,790. Min $300 bill credit in yr 1	No specific tariff - standard Origin plan	No reserve	5 years

5 Tools to support household decision-making and flexibility

There is a variety of tools to support household decision-making with respect to taking up a tariff and/or responding to tariffs or other market signals. These can be subdivided into four categories:

1. Retailer comparison
2. Technology assessment
3. Monitoring
4. Control technology

The accompanying spreadsheet 'Tools to support customer decision-making' provides a detailed breakdown of the different characteristics of the tools currently available for retailer comparison, technology assessment and monitoring. As discussed in Section 5.4, smart meters are being progressively rolled out to households. This has the potential to add a layer of complexity for households, making the other tools discussed here all the more important (Australian Energy Regulator, 2020). The following summarises the current state of play for these four types of tool.

5.1 Retailer comparison

Such tools are readily available to compare different retailers and types of tariffs (assuming the user has internet access and speaks English).

They include Energy Made Easy, Victoria's Energy Compare and Northern Territory's 'Choosing a Power Retailer'[28]. They are relatively easy to use to identify tariff offers, although the sheer number of retailers, with 40 active across the NEM (AEMC, 2020a), and tariffs presented is confusing for some users. However, they do not present other characteristics of retailers (e.g., corporate responsibility issues such as ownership of fossil fuel assets or community benefits) that could affect household decisions. Additionally, unless the customer uploads interval data, the tool cannot accurately identify the most advantageous tariff for them, particularly when including demand tariffs or more complex TOU structures.

There is also a range of sites, such as Canstar, Compare the Market, iSelect and Accurassi (which operates as a white-label service for multiple sites). Although some consumer advocates see commercial sites as more likely to offer innovative services such as integrating DER data with usage data to offer advice on DER purchases (Energy Consumers Australia, 2020a), most select from a limited panel of retailers and some receive a commission or referral fee for directing new customers to retailers (Kollmorgen, 2021).

These tools may also provide information on how to understand energy bills and how to reduce them, and Vic Energy Compare provides information on government rebates that may be available. None really allow the comparison of specific tariffs (where the user selects different tariffs to see the impact on their bill), and none help with working out the benefits of electricity flexibility. Because demand charges may not be included in the bill calculation unless users upload interval data, identification of the cheapest tariff may be misleading. Energy Made Easy does not give clear information about innovative tariffs such as wholesale pricing (Section 3.1.2.1) and users could easily mistake them for flat rate tariffs.

According to the AER, awareness of Energy Made Easy and Victorian Energy Compare remains low. Enhancements were made to Energy Made Easy in early 2020 to simplify the user experience and increase the site's capability to compare innovative offers.

5.2 Technology assessment

Some tools are available (again assuming the user has internet access and speaks English) to assess the size of solar PV and battery systems, including financial outcomes and technical characteristics. In increasing order of complexity, these include the Solar Choice Solar and Battery Calculator, the APVI

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[28] https://www.powerwater.com.au/customers/power/choosing-a-power-retailer

SunSPoT tool, Renew’s Solar and Battery Calculator and Open Solar. Tools that include more options and provide more comprehensive information require more input data and are more complex to use. All the technology assessment tools allow a comparison of specific tariffs, but none really help the user to work out the benefits of electricity flexibility.

5.3 Monitoring

Tools are available to monitor electricity use, and most cost at least $100. They include Powerpal, Wattwatchers, Solar Analytics’ Solar Smart Monitor, Mondo’s Ubi and the Efergy Elite etc. They differ regarding whether they can be installed by the household (Powerpal) or need an installer (Wattwatchers, Solar Smart Monitor and the Efergy Elite), which has a significant impact on cost, and the level of detail and analysis they provide. They all allow a comparison of specific tariffs, and to varying extents provide information on the benefits of electricity flexibility. AGL offers a free phone app to households which provides visualisation of time-series consumption data for households with a smart meter.

5.4 Smart meters

The type of electricity meter used by a household determines the types of tariffs available to them, as well as the household’s potential participation in demand response programs.

Currently in Australia three different types of residential electricity meters are used: Types 6, 5 and 4.

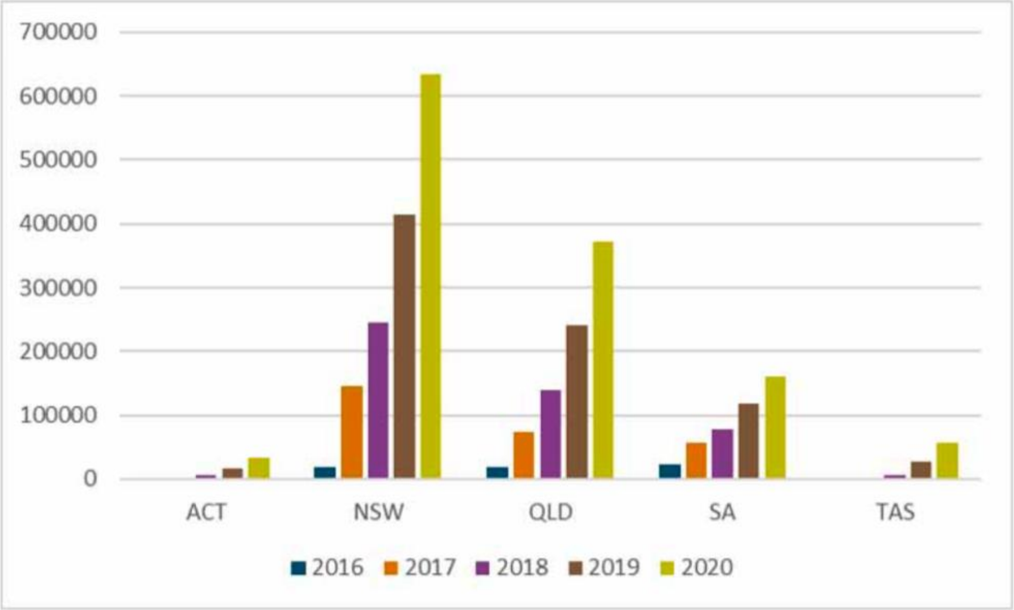
Type 6 – Are accumulation meters and are the most common type of meter and measure only the accumulated electricity use over a given period. As a result, households with these meters can only use flat tariffs. Although these meters can be used for net metered PV systems, they cannot be used where a FiT that is different to the usage tariff is applied.

Type 5 – Are interval meters and so can measure electricity use within periods of each day (half hourly). They have no communications for remote readings. Households with these meters can access time-varying tariffs such as TOU and FiTs, but the meters need to be read manually each billing period. The lack of communications also means that, in the absence of some other monitoring device, households are less able to actively manage their electricity use in real time.

Type 4 – Are ‘smart’ or ‘advanced’ meters and can both measure electricity use within specified periods of each day and be read remotely (as long as there is mobile reception), and so households with these meters can access time-varying tariffs such as TOU and FiTs, as well as demand tariffs which are unavailable for Type 5 meters. Such meters are also capable of remote connection / disconnection, remote on-demand and scheduled meter reading, and remote reconfiguration. The household has the option to deactivate the communications, in which case the meter is Type 4A. Type 4 meters incorporate remotely switchable relays for dynamic smart load control.

Any new or replacement meter in the NEM must be a smart meter. This applies to all new connections, a request by a household, the installation of a solar PV system and the replacement of faulty meter. If the installation is led by the retailer, the household can opt out.

Victoria was the first jurisdiction to roll out smart meters, between 2009 and 2014, and as a result around 98% of small customers have a smart meter (AER, 2020). The uptake in other jurisdictions has been much slower, with only 17.4% of customers outside Victoria having smart meters by June 2020, resulting in 42% of NEM customers having smart meters (AEMC, 2020d). Figure 5-1 shows the uptake of smart meters by small customers in the NEM jurisdictions excluding Vic, and Figure 5-2 shows the uptake as a percentage, where it can be seen that uptake is similar throughout, ranging from 16% to 20%. Figure 5-3 then shows the uptake according to different DNSPs, again excluding Vic, again ranging from 16% to 20%.



Source: AEMO (MSATS data)
Note: Data in this chart shows smart meters for small customers only.

Figure 5-1. Number of smart meters by NEM jurisdiction (excluding Vic) (AEMC, 2020d)

Source: AEMO (MSATS data)
Note: Data in this chart shows smart meters for small customers only.

Figure 5-2. Smart meters as a percentage of small customers in each NEM jurisdiction (excluding VIC) (AEMC, 2020d)

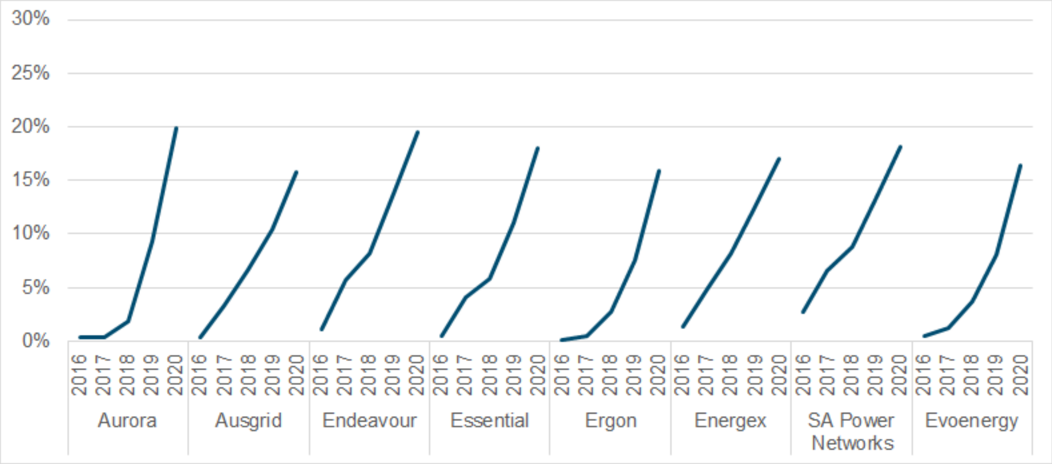


Figure 5-3. Percentage of smart meters per distribution network area (AEMC, 2020d)

In Western Australia, Horizon Power has over 48,000 smart meters across its entire service area. Western power has a smart meter roll out program, with over 100,000 installed across the South West Electricity Network.

Figure 5-4 and Figure 5-5 show the reasons for the installation of smart meters in all NEM jurisdictions apart from Victoria. Slightly over a third were driven by customer requests, most of which would have been due to solar PV installations, and just under a quarter were due to meter repair/replacement. Another quarter were due to new connections to the grid, and the 'new meter deployments' were due to retailer-led roll-outs. The reasons are similar across jurisdictions apart from QLD which has a relatively higher deployment due to meter repair/replacement and Tasmania having a greater proportion due to new meter deployments, which presumably contributes to the state's faster uptake.

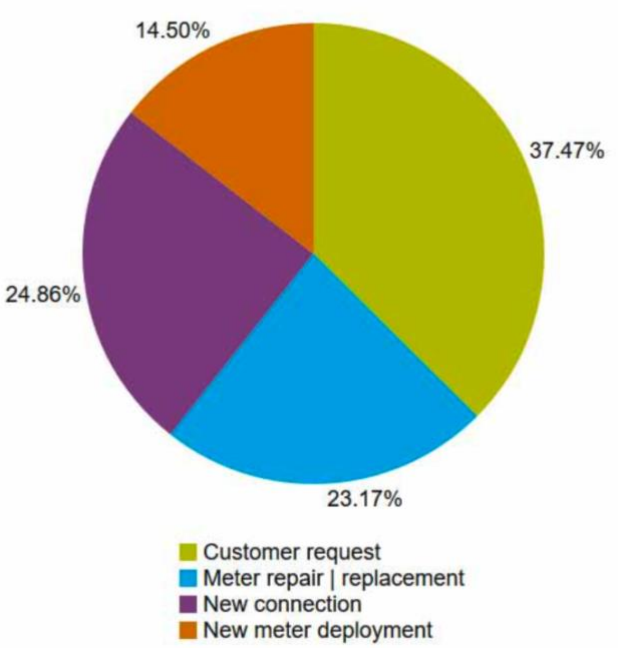


Figure 5-4. Reasons for smart meter uptake (excluding VIC) (AEMC, 2020d)

A review of the regulatory framework for metering services is currently underway by the AEMC (AEMC, 2020c) with an aim of expediting smart meter roll out.

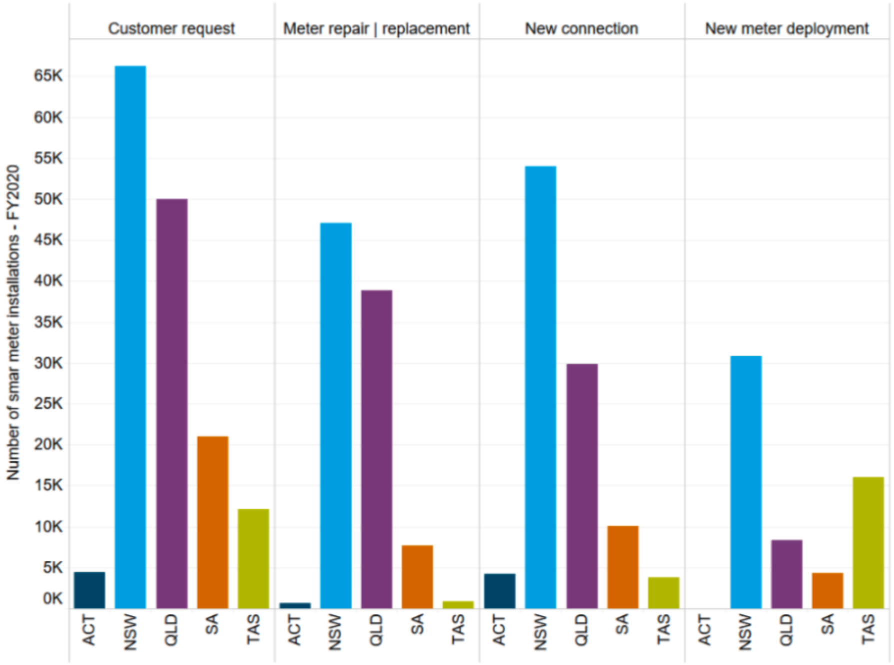


Figure 5-5. Reasons for smart meter installation by jurisdiction (excluding VIC) (AEMC, 2020d)

5.4.1 Smart meters internationally

The AEMC has provided a brief summary of the state of play for the roll-out of smart meters internationally (AEMC, 2020d).

> *"International roll out strategies of smart meters, and the penetration of smart meters differs. For example, in the UK, the rollout is led by the energy suppliers who are responsible for the metering equipment and the in-home display with regulatory oversight and compliance through the Office of Gas and Electricity Markets. Around 31% of consumers in the UK have smart meters in smart mode. In contrast, in New Zealand as at 30 September 2020, 1,649,148 smart meters have been installed into residential homes, which is 89% of all New Zealand residential connections. The roll out does not charge consumers with retailers instead entering into agreements with Meter Equipment Providers who charge them for the use and maintenance of the meter at the property with the retailer absorbing most of these costs. In the EU, where there has been mandatory roll out of smart meters, penetration rates are as high as over 99% in Italy and 98% in Finland."*

5.5 Enabling control technology

Control technology can play an important role in enhancing the capacity of households to provide load shifting, demand reduction or other flexible responses to incentives. It can help overcome restrictions on flexibility due to lifestyle constraints (lack of time, irregular schedules or being out of the home when response is needed), lack of knowledge or understanding, e.g, of tariff periods, or enable households to engage in flexibility with minimal inconvenience.

Development, deployment and integration of these control technologies are therefore likely to be crucial to harnessing the potential flexibility of households. The accompanying spreadsheet 'Tools to support customer decision-making' presents the characteristics of enabling control technologies currently available in the Australian market and we present a brief summary here.

5.5.1 Timers

Most new washing machines and dishwashers have an integral timer allowing delayed start to shift the load to off-peak tariff periods or to increase solar self-consumption. Some clothes dryers also have this functionality but there are safety issues with running them unattended. Low cost ($10 - $30) 'dumb' mechanical or digital timers can be placed at the power point for any appliance. Equivalent switchboard devices for electric hot water, pool pumps or other circuits cost around $40 but require installation by a qualified electrician. Most heat-pump EHW systems, such as *Sanden* or *iStore,* include timing functionality.

5.5.2 Smart plugs

Smart plugs or smart sockets, widely available from around $20, add wi-fi connectivity and a phone app or online dashboard to enable scheduling of device operation. These are easily self-installed, and some models include real-time (or near real-time) monitoring and visualisation of energy consumed through the socket. Most are compatible with some or all the voice-activated smart home technologies, *Apple HomeKit, Amazon Alexa, Google Assistant, Siri, Line Clova, SmartThings,* and *IFTTT.*

5.5.3 Smart relays

Some PV inverter manufacturers, including *Fronius* and *SolarEdge*, use load monitoring and smart relays to activate EHW or other circuits at times of excess solar self-consumption. *Wattwatchers* offer a monitoring and control device which was trialled with a smart EHW control algorithm by *Solar Analytics* (Yildiz et al., 2021), while C*atchPower* has a *Solar Relay* which also allows circuit control as well as DRM control of inverters.

5.5.4 Smart A/C control

Smart thermostats, designed to replace traditional wall-mounted thermostats, are widely available overseas, particularly in the US. They are hard-wired to HVAC systems, so require a qualified installer, and include wi-fi connectivity to enable remote setting of temperature and scheduling, through a phone app or online dashboard. Some include energy monitoring, HVAC diagnostics and compatibility with voice control and smart home systems. However, there are compatibility issues with both ducted A/C and split systems in Australia and, although work-arounds may be possible,[29] well known devices such as *Ecobee* and *Nest* are not available or supported here and others such as *Zen Thermostat* will not control many common A/C systems.[30]

Other smart controllers, such as *Zen Air* or *Sensib*o, use infra-red communications to replace or augment the remote-control unit on any A/C system. They can be easily self-installed - so are relatively low cost - and are compatible with smart home systems and voice control. As well as changing temperature set points and scheduling of A/C operation, they can enable different modes (eco, dry, etc). The *Sensibo Air* can also connect to a motion sensor and so respond to whether the room is occupied.

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[29] https://www.cmservices.net.au/blog/smart_thermostat/

[30] https://zenecosystems.com/home/zenthermostat/compatibility/#Australia

5.5.5 Hot water diverters

For solar households, diverters maximise solar self-consumption by diverting excess solar generation to electric hot water (EHW) systems. Unlike a simple timer, which puts the EHW in a binary 'on' or 'off' state (and may therefore increase grid import if the excess generation is less than the EHW power draw), diverters use pulse width modulation to match the diverted electricity to the available excess generation. They can only be used with resistive, not heat pump, EHW systems. *Paladin, Powerdiverter* and *SunMate* take the water temperature into consideration, while *CatchPower* does not (so will only divert electricity if the EHW thermostat is turned on). Most include an override or boost setting, while more sophisticated models use weather data and forecasting in their control algorithm.

5.5.6 DRED

The nine DRM modes for demand response enabled devices (DREDs) are shown in Table 5-1, as set out in AS4755.3.1 (air conditioners), AS4755.3.2 (pool pumps), AS47553.3 (electric hot water), AS47553.5 (battery energy storage systems) and AS4777.2 (PV inverters).

For loads (A/C, EHW, pool pumps or batteries in charging mode), DRM1 to DRM4 restrict the power consumption to 75%, 50% or 0% of rated power, or increase power consumption. For generators (PV inverters and batteries in discharge mode), DRM5 to DRM8 restrict the power output to 75%, 50% and 0% of rated power, or increase generation. And DRM0 disconnects suitably enabled devices.

Table 5-1 DRED demand response modes

Demand response mode	Description	Applies to
DRM 0	Disconnect, if equipped with a disconnection device	PV, BESS
DRM 1	No load or minimal load	PV, BESS, A/C, EHW, pool pump
DRM 2	Restrict load to no more than 50% of reference value	PV, BESS, A/C, EHW, pool pump
DRM 3	Restrict load to no more than 75% of reference value and provide power quality support if capable	PV, BESS, A/C, EHW
DRM 4	Commence operation or increase load	PV, BESS, EHW, pool pump
DRM 5	No discharge of energy to grid	PV, BESS
DRM 6	Restrict discharge to no greater than 50% of a reference value.	PV, BESS
DRM 7	Restrict discharge to no greater than 75% of a reference value. Provide power quality support if capable	PV, BESS
DRM 8	Commence or increase discharge of energy to the grid	

AS4755 defines the response modes and the hardware interface in the DRED itself, but most DREDs require an additional interface in order to receive DR non-standardised messages sent via wi-fi, 3G/4G, Zigbee, Bluetooth or ripple control. The advanced framework proposed in AS4755.2 includes minimum standards for these communication protocols to enable DR messages to be sent directly to the DRED.

5.6 Suitability for households experiencing vulnerability

The Retailer comparison tools can be suitable for households experiencing vulnerability as long as they have internet access and there are household members who speak English. However, the opportunity for bill savings by switching retailer or tariff is lower for households with low consumption (Tsung et al., 2020). The government websites provide additional information on how to understand energy bills, how to reduce them, and Vic Energy Compare provides information on government rebates that may be available. The Technology assessment and monitoring tools are not really suitable for low-income households because they are unlikely to be able to afford solar/batteries and most monitoring devices cost at least $100.

5.7 In-depth analysis of tools

An extensive analysis of energy tools within the Australian market was conducted. This analysis evaluates tools in accordance with the below research questions.

- *What tariff tools are available for different stages of the customer uptake journey? Are these tools effective in increasing uptake of new tariffs/pricing plans? (Opportunity)*
- *What tariff tools are available to facilitate customers in responding to tariff/market signals? (Opportunity)*
- *How do tariff tools aimed at assisting customers experiencing various types of vulnerability provide benefits to them and the community? What are the outcomes and impact of these tools?*
- *How do tariff tools facilitate customers' energy awareness and knowledge? (Motivation)*
- *How do tariff tools facilitate the ability of customers to make energy decisions about pricing plans? (Ability)*
- *How do tools offered through trusted third parties facilitate customer energy decision making about pricing plans? (Ability)*

Each of the above research questions is informed by two tables which list the identified tools which align with the research questions. These tables can be found in Appendix C and are summarised below.

A description of the first table within each section (*Effectiveness, cost, installation type and owner identification*) is as follows.

This table firstly lists a description of the tool to provide some information about its features, with links being provided beneath the description to provide more information if required. The effectiveness of the tool is then evaluated. This is conducted by attempting to categorise the tools' effectiveness as 'projected' or 'realised' effectiveness. Projected effectiveness usually takes the form of marketing messages claiming that the tool will result in a projected outcome, for example, the expectation that it will save the individual money. Realised effectiveness was derived from, for example, data which quantified energy savings or even customer reviews which report that the tool brought them financial savings and satisfaction through use. An analysis of the penetration rate of app-based tools is then provided. The number of app downloads was sourced from Google Play and added to the number of app ratings sourced from the App Store. Ratings were used as a proxy of app downloads as the App Store does not provide data in regard to the number of downloads of their listed apps. This total was then divided by the number of Australian residential electricity customers, which is cited to be 6,423,649 in 2019-2020 (Australian Energy Regulator, 2020). It is worthwhile noting that some apps are also available outside the Australian market, meaning that the penetration rate provided is inaccurate as the download and ratings totals include international users. Where this is evident, a note has been made within the table. In addition, the cost of the tool and whether professional installation is required is provided. Lastly, we provide a description of the owner of the tool, for example, whether the tool is owned by a commercial entity, non-profit, or by the government.

A description of the second table within each section (*Design type, social support framework and Passive-Interactive-Proactive (PIP) typology categorisation*) is as follows.

This table firstly categorises whether the tool is functional or hedonic in nature. Functional tools are those which are primarily used to achieve a practical or useful outcome (for example, an energy plan comparison website showing an individual an array of available plans). Hedonic tools are those which leverage hedonic elements such as gamification, augmented reality or financial rewards to create more enjoyable experiences. Tools can also blend functional and hedonic elements. Next, tools are categorised in accordance with dimensions comprising the social support framework. The social support framework proposes that there are five support dimensions which act to reduce stress, informational support, instrumental support (also referred to as tangible assistance), network support, esteem support, and emotional support (Cutrona and Russell, 1990, Cutrona and Suhr, 1992). Informational support is provided through the provision of useful information, advice or guidance. Instrumental support (tangible assistance) occurs through the provision of resources to actively help an individual. Network support is provided through the creation of communities and spending time with an individual. Esteem support occurs through the reinforcement of a person's sense of competence or self-esteem. Lastly, emotional support is provided by listening to, encouraging, comforting and understanding the individual (Cutrona and Russell, 1990). This framework is applicable within technologically-mediated environments as evidenced by prior research (Stewart Loane et al., 2014).

Lastly, we then classify each of the tools (where possible) in accordance with the PIP Typology. The PIP Typology proposes that technology can adopt a passive role (requiring cognitive and behavioral human input to operate), to an interactive role (providing personalized output and making some actions on behalf of the human), and finally a proactive role (autonomous decision-making and actions made of behalf of the human, which may be overridden) (Letheren et al., 2019). Some tools are unable to be classified in accordance with the typology as they incorporate human-to-human interaction (e.g., phone calls).

5.7.1 Tariff tools

- *What tariff tools are available for different stages of the customer uptake journey? Are these tools effective in increasing uptake of new tariffs/pricing plans? (Opportunity)*

These tools are described in Tables C-I and C-II in Appendix C.

Key insights:

Effectiveness – Most of the realized effectiveness evidence is anecdotal through customer reviews rather than data-based. Limited data is provided which indicates the realized effectiveness of tools (e.g. Victorian Energy Compare). Most effectiveness claims are projected.

Penetration rate – No meaningful inferences can be made as the vast majority of tools are not apps or are not available on Google Play or the App Store.

Cost – The vast majority of these tools are free to use.

Installation type – The majority of these tools do not require any installation as they are services. Two tools which have app-based components can be self-installed on the user's mobile device.

Owner – Most of the tools are commercial, earning revenue through referrals and commissions from energy retailers who are listed their websites (e.g. Compare the Market). Not-for-profit tools are largely absent, with few government and regulator tools being available on the market.

Design type – All tools were deemed to be functional in nature with the sole purpose of providing useful information to the user.

Support type – Informational support was the most frequently utilized support dimension adopted by tools, followed by tangible assistance. Emotional and network support dimensions were absent.

Level of proactivity – Most tools were interactive in nature, requiring the user to interact with an interface to generate a more personalised outcome (e.g. providing household information).

5.7.2 Tools for response:

- *What tools are available to facilitate customers in responding to tariff/market signals? (Opportunity)*

These tools are described in tables C-III and C-IV in Appendix C.

Key Insights

Effectiveness – There was greater reporting of realised effectiveness, potentially due to the more technologically advanced nature of some of the tools and their ability to collect data.

Penetration rate – Tools with notable penetration rates (i.e. above 5%) were companion apps to smart plugs. However, such apps were downloaded by international customers also, so this penetration rate is potentially inaccurate. App-based tools which are exclusively downloaded in the

Australian market have very low market penetration, as all these tools were downloaded by less than 1% of the Australian residential energy market.

Cost – The cost of these tools varies significantly. Physical tools which require home installation range from $20 for smart plugs to $25,000 for Enphase solar panels and home battery systems. The degree of proactivity which these tools provide seems to inform the cost. Apps and energy programs offered by commercial entities are free to participate in.

Installation type – Some tools installed within the household can be installed by the buyer (e.g. Wattcost or smart thermostats). However, the advanced nature of many of these tools often requires professional installation to be undertaken instead. This installation type is most common for these tools.

Owner – All of the identified tools are sold and owned by a commercial entity.

Design type – The functional design type is the most dominant within the suite of tools. However, some tools do offer a mixture of functional and hedonic design. For example, demand response programs utilise SMS communications to alert the user to upcoming demand response events (functional design) and offer rewards for participation in these events (hedonic design).

Support type – Informational support underpins most of the tools, in addition to the provision of tangible assistance. The provision of tangible assistance is associated with the heightened proactivity of many of the tools listed, as such tools act autonomously in some regard on behalf of the human to provide assistance. Some tools offer esteems support through visualisation of consumption and cost savings. Very few tools offer network support, whereas no tools which were identified offer emotional support.

Level of proactivity – Tools were generally interactive and proactive in nature. Proactive tools were generally tools which were required to be installed in the home, whereas interactive tools were standalone or companion apps. Few tools identified were passive in nature, indicating the tools designed to facilitate customers in responding to tariff and market signals require user interaction or can make decisions on their behalf.

5.7.3 Tools for households experiencing vulnerability

- *How do tools aimed at assisting customers experiencing various types of vulnerability provide benefits to them and the community? What are the outcomes and impact of these tools?*

These tools are described in tables C-V and C-VI in Appendix C.

Key Insights

Effectiveness – The realised effectiveness of tools is generally not specified. Some realised effectiveness can be gleaned from the number of energy customers helped by programs or schemes. Reduce Your Juice was identified as a tool which has had extensive academic exploration of its realised effectiveness. The remainder of tools merely possess projected effectiveness.

Penetration rate – No meaningful inferences can be made as the vast majority of tools are not apps or are not available on Google Play or the App Store.

Cost – All of the tools did not require the individual to pay for them. This is notable particularly as these tools are designed for customers experiencing vulnerability, therefore there are no financial barriers in the way of their adoption.

Installation type – Tools did not require installation as they were predominantly informational resources and services. The sole app-based tool identified requires self-installation on the user's mobile device.

Owner – Owners of identified tools are a mix of government, non-profits and national consumer advocacy bodies. Some tools are offered by commercial entities such as retailers to assist their customers.

Design type – The vast majority of tools identified were functional in design. One tool was identified which had a hedonic design type through its use of gamification.

Support type – All tools provided some form of informational support. Tools also provided tangible assistance, network support, esteem support, and even emotional support (a support type which hasn't been seen within previous tools).

Level of proactivity – No tools which are developed to assist consumers experiencing vulnerability are proactive in nature. Tools were evenly spread between being interactive and passive in nature.

5.7.4 Tools for education and capacity building

- *How do tools facilitate customers' energy awareness and knowledge? (motivation)*

The role of tools in facilitating customers' energy awareness and knowledge is described in tables C-VII and C-VIII in Appendix C.

Key insights

Effectiveness – There were few statements apparent about the realised effectiveness of these tools. Most of the claimed effectiveness was projected in nature.

Penetration rate – Only two app-based tools had identifiable penetration rates, with both having a penetration rate of less than 0.5%.

Cost – All of the identified tools were free of cost.

Installation type – The vast majority of tools did not require installation. One app-based tool was identified which needs the user to self-install it on their mobile device.

Owner – Tool owners are split between commercial entities, government and government regulators, and not-for-profit entities.

Design type – All tools were functional in design.

Support type – All tools provided some form of informational support. Few tools provided tangible assistance and esteem support. No tools provided network support or emotional support.

Level of proactivity – Tools were either interactive or passive in nature. No tools were proactive.

- *How do tariff tools facilitate the ability of customers to make energy decisions about pricing plans? (ability)*

The role of tools in facilitating customers' ability to make energy decisions about pricing plans is described in tables C-IX and C-X in Appendix C.

Key Insights

Effectiveness – Realised effectiveness of some tools was apparent through customer testimonials and data collected on customer interactions with these tools.

Penetration rate – App-based tools identified allowed for comparison between energy retailer offerings. The AGL app had the highest market penetration of 1.79%, followed by Origin at 1.74%, Energy Australia (1.55%) and Aurora+ (TAS only) (0.15%)

Cost – Not only did the costs of the tools deviate, but also the payment types. Retailer apps were generally free, however the Aurora+ app costs $40/year. Physical devices installed within the home cost upwards of $129, although other tools such as Solar Analytics Monitoring operates on a subscription-based payment option in addition to an outright purchase option.

Installation type – App-based tools can be self-installed on the user's mobile device. Some physical devices can also be self-installed within the home, however more advanced home energy management systems require professional installation.

Owner – The vast majority of tools are owned by a commercial entity.

Design type – All the identified tools were functional in design.

Support type – All tools provided some form of informational support and most provided esteem support and tangible assistance. Few tools provided network support and no tools provided emotional support.

Level of proactivity – Few tools were proactive in nature, with the majority being interactive. No tools were passive.

5.7.5 Tools from trusted 3rd parties

- *How do tools offered through trusted third parties facilitate customer energy decision making about pricing plans? (ability)*

Tables C-XI and C-XII in Appendix C describe tools offered through trusted 3rd parties.

Key Insights

Effectiveness – Few tools provide evidence of their realised effectiveness, with the vast majority of tools providing a projected effectiveness through claims or a description of the tool.

Penetration rate – Only two app-based tools had identifiable penetration rates, with both having a penetration rate of less than 0.2%.

Cost – All of the identified tools were free of cost.

Installation type – The vast majority of tools did not require installation. One app-based tool was identified which requires the user to self-install it on their mobile device.

Owner – As third parties were the focus of these tools, there were no commercial entities included within the list of tools. Non-profits, national consumer advocacy bodies and governments and government regulators all had representation.

Design type – Most tools were functional in design. One tool (CHOICE Community) was identified which was a mix of hedonic and functional design types. In addition the provision sharing of information in an online forum (functional) the website rewards users for engagement and positive interactions through badges (hedonic).

Support type – Informational support underpins most of the tools. Few tools provide tangible assistance, esteem support, or network support. No tools provide emotional support.

Level of proactivity – The tools were a mix of interactive and passive. No tools were proactive.

5.7.6 Summary of Insights

- The realised effectiveness of tools is difficult to quantify as this evidence is not commonly provided. If this evidence is provided, it is not consistent across different tools (e.g. lots of tools rely on customer testimonials rather than providing more objective data). Tools generally rely on claims of projected effectiveness. Academic research into these tools is not widespread.
- Market penetration of app-based tools is very low.

- The financial cost associated with tools varies significantly. Generally, tools adopting the form of apps, online services, and informational resources are free to access. Devices requiring installation within the home have costs associated with their purchase, which can range from $20 to $25,000 depending on the scale of energy management provided, technological complexity and proactivity of the tool.
- Most tools are created by energy retailers or other commercial entities.
    - There are fewer tools offered by “trusted” entities such as non-profits, consumer advocacy bodies, government and regulators.
- The vast majority of tools are functional in design. However some tools are integrating hedonic approaches within their design through the provision of gamified elements such as points, badges, and trophies or financial rewards for participation within demand response events.
- Informational support forms the foundation of most energy tools.
- Energy tools generally do not provide more interpersonal support such as network or emotional support.
    - These support types are however present within programs for customers experiencing vulnerability and counselling services
- Energy tools are predominantly interactive to give people control and personalisation. These tools are characterised by apps and online interfaces such as dashboards and interactive webpages (e.g. energy comparison websites).
- Passive tools are generally associated with the provision of informational support (e.g. fact sheets, webpages, guides).
- Proactive tools are predominantly physical devices which are installed within the home which automate household energy use and are paired with interactive tools like apps to allow the user to control these devices to set them to their personal preferences
    - There are barriers to the adoption of proactive tools due to financial costs involved with purchase and also professional installation. This might put the adoption of proactive tools out of the reach of consumers experiencing vulnerability and also renters who cannot obtain permission to install proactive energy devices.
    - It is notable that no proactive devices are offered by more trusted non-commercial entities such as non-profits.

Esteem

Energy plan comparison websites and services: Victorian Energy Compare, Make It Cheaper

Mobile applications or online dashboards/interfaces: Wattcost app, Enphase app, Amber Electric Smartshift app, Aurora+ app, Solar Analytics dashboard, Homebeat Energy Monitor dashboard, WattWatchers dashboard, WattWatchers MyEnergy app, AGL app, Origin app, Energy Australia app, CarbonTrack dashboard/app, Ubi Portal/dashboard, Light Bulb Saver app

Websites or documents: CHOICE Community, Synergy Energy Tool, Energy Rating Calculator, AGL Energy Insights

Programs and Schemes for Customers Experiencing Vulnerability: Reduce Your Juice, Aurora Energy 'Yes' program

Counselling: The Salvation Army Financial Counselling, National Debt Helpline

Emotional

Mobile applications or online dashboards/interfaces: Reduce Your Juice app, Ubi Portal/dashboard

Programs and Schemes for Customers Experiencing Vulnerability: Reduce Your Juice, Aurora Energy 'Yes' program

Counselling: The Salvation Army Financial Counselling, National Debt Helpline

Social Support Framework

Network

Mobile applications or online dashboards/interfaces: Ubi Portal/dashboard

Programs and Schemes for Customers Experiencing Vulnerability: Reduce Your Juice, Aurora Energy 'Yes' program

Events: Energy Consumers Australia – Community Listening Tour

Counselling: The Salvation Army Financial Counselling, National Debt Helpline

Websites: CHOICE Community

PIP typology categorisation:

Passive tool
Interactive tool
Proactive tool
Not applicable

Informational

Physical devices installed within the home: Wattcost hub, Enphase system, Amber Electric Smartshift device, Paladin hot water diverter and controller, PowerDiverter, Sunmate, Catch Power Solar Relay/Green/Blue Solar Diverter, Pooled Energy Intelligent Pool Controller, CarbonTrack Smart Gateway and Home, Ecobee Smart Thermostat, Nest Thermostat, Sensibo Sky WiFi Controller, Sensibo Air, Solar Analytics Solar Smart Monitor, Homebeat Energy Monitor, WattWatchers Auditor 6M, Zen Thermostat, Powerpal, Ubi Energy Management, Efergy Elite Wireless Energy Monitor

Energy plan comparison and services: Compare the Market, iSelect, Canstar Blue, Mozo, Energy Made Easy, Victorian Energy Compare, Connect and Save, Electricity Monster, Electricity & Gas Comparison, Finder.com.au, Electricity Wizard, Make It Cheaper, Bill Hero

Mobile applications or online dashboards/interfaces: Energy IQ, Wattcost app, Enphase app, Aurora+ app, Amber Electric Smartshift app, Origin Spike, AGL Peak Energy Rewards, EnergyAustralia PowerResponse, WattWatchers MyEnergy app, Zen Air app, Reduce Your Juice app, AGL app, Origin app, Energy Australia app, Powerpal app, Pooled Energy Intelligent Pool Controller app, Solar Analytics dashboard, Homebeat Energy Monitor dashboard, CarbonTrack dashboard/app, Ubi Portal/dashboard, Sensibo app, Kasa app (TP-Link smart plug), Meross app, Nexus Home app (Brilliant Lighting smart plug), Light Bulb Saver app, AGL's Alfie chatbot

Programs and Schemes for Customers Experiencing Vulnerability: Reduce Your Juice, Aurora Energy 'Yes' program, NSW Government Energy Accounts Payments Assistance Scheme

Demand response programs: AGL's Peak Energy Rewards 'Managed for You' program, EnergyAustralia's PowerResponse program, Powershop's Curb Your Power program, Zen Ecosystems' Help the Grid program

Counselling: The Salvation Army Financial Counselling, National Debt Helpline

Websites or documents: Energy Australia Energy Tracker, Renew Solar and Battery Advice Calculator, CHOICE Community, PowerWater, Synergy Energy Tool, Energy Rating Database, Energy Rating Calculator, Solar & Battery Calculator, Solar PV Maps and Tools (SunSpoT, PV Postcode Data tool, Live Solar PV tool, PV Performance by Climate Region, Australian Photovoltaic installations map, Market Analysis Charts, Solar Animation Video), AGL Assist Toolkit, AGL 'Here to Help' tool, Energy Consumers Australia – Find Help/PowerCall, Hardship factsheets (AER), CHOICE info resources, ACOSS webpage, QCOSS fact sheets, AGL Energy Insights, Household guides by www.energy.gov.au , CHOICE – Best electricity providers, Energy Consumers Australia – Consumer resources

Instrumental

Physical devices installed within the home: Wattcost hub, Enphase system, Amber Electric Smartshift device, Paladin hot water diverter and controller, PowerDiverter, Sunmate, Catch Power Solar Relay/Green/Blue Solar Diverter, Pooled Energy Intelligent Pool Controller, CarbonTrack Smart Gateway and Home, Ecobee Smart Thermostat, Nest Thermostat, Sensibo Sky WiFi Controller, Sensibo Air , WattWatchers Auditor 6M, Zen Thermostat, Sanden Eco Plus heat pump, iStore hot water system, smartplugs (TP-Link HS100/110, Meross Smart Wi-Fi socket, Brilliant Lighting Smart WiFi plug), Ubi Energy Management, Zen Thermostat

Energy plan comparison websites and services: Compare the Market, iSelect, Canstar Blue, Mozo, Energy Made Easy, Victorian Energy Compare, Connect and Save, Electricity Monster, Electricity & Gas Comparison, Finder.com.au, Electricity Wizard, Make It Cheaper, Bill Hero

Mobile applications or online dashboards/interfaces: Energy IQ, Wattcost app, Enphase app, Aurora+ app, Amber Electric Smartshift app, Origin Spike, AGL Peak Energy Rewards, EnergyAustralia PowerResponse, WattWatchers MyEnergy app, Zen Air app, AGL app, Origin app, Energy Australia app, Pooled Energy Intelligent Pool Controller app, CarbonTrack dashboard/app, Ubi Portal/dashboard, Sensibo app, Light Bulb Saver app, AGL's Alfie chatbot

Programs and Schemes for Customers Experiencing Vulnerability: Reduce Your Juice, Aurora Energy 'Yes' program, NSW Government Energy Accounts Payments Assistance Scheme

Demand response programs: AGL's Peak Energy Rewards 'Managed for You' program, EnergyAustralia's PowerResponse program, Powershop's Curb Your Power program, Zen Ecosystems' Help the Grid program

Websites or documents: PowerWater, Synergy Energy Tool

Counselling: The Salvation Army Financial Counselling, National Debt Helpline

Figure 5-6 Overall Categorisation of tools using Social Support Framework and PIP Typology

5.7.7 Novel tools within the academic literature

A search was undertaken to identify novel tools which have been evaluated by the academic/industry literature but may not be present within the Australian energy market. These tools may be in use or are conceptual in nature (i.e. have not been deployed). This search was not intended to be a comprehensive assessment of the international market but provide some examples of tools which are not yet present within the Australian energy market.

What tariff tools are available for different stages of the customer uptake journey? Are these tools effective in increasing uptake of new tariffs/pricing plans?

Novel tools which assist customer uptake of new tariffs/pricing plans are described in Table C-XIII in Appendix C.

- **Personalized electricity tariff recommender systems** – Tools which utilise customer electricity consumption profiles through advanced metering infrastructure and infers preference of each household user on a tariff plan. Tariff recommendations are then made based on this information.
- **Energy data centralisation sharing services** – Tools such as Midata allowing suppliers to share energy data with third party intermediaries such as price comparison websites. This makes comparing tariffs quicker and easier and enables more accurate comparisons.
- **Communications interventions** – Tools such as Cheaper Marketing Offer Letters which took the form of a personalised letter highlighting the potential savings from switching and signposting cheaper energy deals.

What tools are available to facilitate customers in responding to tariff/market signals?

Novel tools which facilitate customer response to price signals are described in Table C-XIV in Appendix C.

- **Gamified approaches** – Tools can aggregate smart meter data within communities to allow cities to compete to become more energy efficient, Tools can incentivise load shifting through personalised usage targets provided to customers. Adherence is rewarded with coupons which can be entered into lotteries to win gift cards.
- **Integration of artificial intelligence** – Artificial Neural Networks used within potential tools to create algorithms which find low tariff opportunities to encourage customers to participate in demand management programs
- **Blockchain** – Tools may soon integrate blockchain facilitated P2P energy sharing –decentralized energy trading systems which use blockchain technology, multi-signatures, and anonymous encrypted messaging streams, enabling peers to anonymously negotiate energy prices and securely perform trading transactions

How do tariff tools aimed at assisting customers experiencing various types of vulnerability provide benefits to them and the community? What are the outcomes and impact of these tools?

Novel tools which assist customers experiencing vulnerability are described in Table C-XV in Appendix C.

- **Biased load manager home energy management systems –** Home energy management systems designed to create more efficient load dispatches to low-income consumers to reduce energy costs.
- **Persuasive smart energy management systems** – Energy management systems which incorporate the peculiarities of a developing economy (i.e. blackouts or network instability) for low/medium income earners and integrate their budget constraints.
- **Peer-to-peer energy trading** – Community-based P2P energy trading schemes which prioritise vulnerable energy consumers in P2P energy transactions.

How do tools facilitate customers’ energy awareness and knowledge?

Novel tools which facilitate customers’ energy awareness and knowledge are described in Table C-XVI in Appendix C.

- **Augmented reality** – Tools which allow consumers to view electrical consumption of their domestic electrical loads within an augmented reality environment to inform awareness of the amount of energy being currently used and whether to switch the device off.

- **Integration of artificial intelligence** – Tools can use Deep Learning and Recurrent Neural Networks to forecast household energy usage and motivate behavioural change by bringing this data to the consumer's attention
- **Self-service calculators using construction and topographical data** – Tools which allow the input construction data (building density and information about heating/cooling systems), in addition to topographical data (urban/rural location, altitude, number of residents) with other inputs to generate potential cost savings.
- **Advanced, adaptive smart home systems** – Tools which use smart home sensors to generate adaptive recommendations based on household energy behaviour measured through IoT appliances and smart plugs, bringing awareness to potential efficiencies. These tools proactively control appliances to limit their consumption based on consumers' past behavioural data.
- **Gamified approaches** – Tools which monitor energy household use and incentivise both measurable energy savings and responses to system recommendations through points, achievements, and rewards

How do tariff tools facilitate the ability of customers to make energy decisions about pricing plans?

Novel tools which facilitate the ability of customers to make energy decisions about pricing plans are described in Table C-XVII in Appendix C.

- **Advanced, adaptive smart home systems** – Tools which use smart home sensors to generate adaptive recommendations based on household energy behaviour measured through IoT appliances and smart plugs, bringing awareness to potential efficiencies. These tools proactively control appliances to limit their consumption based on consumers' past behavioural data.
- **Energy data centralisation sharing services** – Tools such as Midata, offered by the UK's energy regulator, which allows suppliers to share energy data with third party intermediaries such as price comparison websites. This makes comparing tariffs quicker and easier and enables more accurate comparisons.

How do tools offered through trusted third parties facilitate customer energy decision making about pricing plans?

Novel tools which are offered through trusted third parties facilitate customer energy decision making are described in Table C-XVIII in Appendix C.

- **Communications interventions –** Tools such as Cheaper Marketing Offer Letters which took the form of a personalised letter using branding from an energy regulator which highlighted the potential savings from switching and signposting up to six cheaper energy deals.
- **Energy data centralisation sharing services** – Tools such as Midata, offered by the UK's energy regulator, which allows suppliers to share energy data with third party intermediaries such as price comparison websites. This makes comparing tariffs quicker and easier and enables more accurate comparisons.

Key Insights

1. Real-world effectiveness difficult to quantify beyond controlled experimental results or simulations. Many tools identified are conceptual or are used in a simulated environment within the academic literature.
2. Few novel tools developed to assist consumer uptake of energy plans
3. Novel tools particularly targeting behavioural demand response and energy management behaviour of consumers
4. Artificial intelligence/ big data / IoT devices playing significant underpinning role
5. Hedonic approaches such as augmented reality and gamification also prominent as novel energy tools

6 State of research and barrier analysis

Realisation of residential energy flexibility relies on:

1. utilities and others making tariff and incentive products available to households;
2. households taking up those products (switching to the tariff, participating in the scheme, etc.)
3. and households responding to the incentives (shifting loads to off-peak periods, reducing peak demand, etc.)

There are multiple influencing factors that can facilitate or impede provision of incentives, user uptake and reducing response. They can be broadly categorised into regulatory and market considerations, metering and control technologies, social, cultural and behavioural issues, informational and communication issues. Residential energy flexibility can also deliver net system benefits, and this section also discusses the extent to which current research and industry development activities effectively assess these benefits.

6.1 Regulatory considerations

The regulatory environment within which DER operates is a rapidly moving feast. The focus of this section is on potential regulatory barriers to making tariff and incentive products available to households. It does not cover the regulatory barriers related to, for example, aggregators enabling households to provide network support or participate in spot or FCAS markets, including the 'trader-services model' recently proposed by the AEMC. Likewise, it does not extend to more general barriers to the uptake and operation of DER resources, such as the AEMC Rule Determination on minimum technical standards for DER and the South Australian Smarter Homes initiative, the use of Dynamic Operating Envelopes or more efficient forecasting and scheduling of DER.

These are already the focus of a significant number of workplans underway through both the Post 2025 and AEMC market design processes[31]; and many are expected to be covered in the RACE for 2030 Projects H3 'Using Home Energy Technologies for Grid Support' and N4 'Distribution System Operator and Beyond: Optimising planning and regulation for DM & DER'.[32] Given the ongoing and constantly changing nature of the regulatory environment within which DER operates, it is likely that RACE2030 will need to frequently (monthly or quarterly) reassess this environment for how it impacts on the need for and relevance of particular research projects.

6.1.1 Electricity networks

Distribution Network Service Providers (DNSPs)[33] in the NEM operate as regulated monopolies.[34] Network operators in Western Australia and the Northern Territory are regulated under different regimes, which are much more permissive than in the NEM, especially Horizon Power in WA which operates as a vertically integrated entity (includes generation, networks and retail). The most relevant aspects here are:

1. Limitations placed on DNSPs participating in competitive markets

Where DNSPs are regulated monopolies, they are not allowed to participate in competitive markets, which would for example include any related to the provision of electricity flexibility services. However, this should place little or no restrictions on households engaging in electricity flexibility because i) third parties can do this and ii) many DNSPs have developed ring-fenced arms (such as Yurika (for Energy Queensland) and Mondo (for Ausnet Services)) that are able to access competitive markets. Moreover, removing this

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[31] More information is available here https://esb-post2025-market-design.aemc.gov.au and https://www.aemc.gov.au/our-work/market-reviews-and-advice

[32] For a recent review of these issues (that are constantly evolving) see the ESB's 'Post-2025 Market Design Directions Paper, Jan 2021, as well as https://esb-post2025-market-design.aemc.gov.au.

[33] Transmission Network Service Providers (TNSPs) do not interface with residential end-users and so are not covered here.

[34] It is worth noting that although monopolies are defined as not facing competition, DNSPs do in fact face competition from DER for the provision of network services.

limitation to allow DNSPs to directly participate in these markets without ring-fencing could create a market distortion.

2. Limitations placed on changes during a Tariff Structure Statement (TSS) period

DNSPs prepare TSSs that essentially define the structure of their network tariffs, the process for assigning different households to the different tariffs, an indicative pricing schedule over the regulatory period and an assessment of their impacts on households (Clause 6.18.1A). These generally cover periods up to five years. Each year the DNSPs also prepare Pricing Proposals (PPs) where they essentially publish the prices they will apply to the different tariffs for that year and explain how this affects their projected revenue and customer bills. DNSPs are regulated under revenue caps, which means that they have to design their tariffs in each PP in such a way that they hit their revenue targets each year. Excess revenue is paid back through lower tariffs in the following year, and vice versa. The TSSs and PPs must be compliant with the National Electricity Rules (NER) and are assessed by the Australian Energy Regulator (AER).

Although it can be very difficult to introduce new tariffs once a TSS has been approved by the AER, it is possible under Clauses 6.18.1B and 6.18.1C. This is relevant when the DNSP may wish to introduce tariffs with different designs to enable the uptake and operation of electricity flexibility (for example novel types of cost-reflective tariffs or tariffs that enable local trading). Clause 6.18.1B allows a DNSP to change its TSS no later than nine months before the start of a regulatory year of the regulatory control period to which the TSS applies – as long as this can be justified to the satisfaction of the AER. Clause 6.18.1C allows a tariff structure to be changed no later than four months before the start of a regulatory year as long as the DNSP's revenue from the relevant tariff each year is no greater than 0.5% of its annual revenue, and as long as the DNSP's revenue from the relevant tariff, as well as from all other relevant tariffs, each year is no greater than 1% of its annual revenue. Such tariffs are termed 'subthreshold tariffs' and have been included in two current Pricing Proposals. Evoenergy has proposed a residential battery tariff that includes a fixed daily charge, TOU consumption charges, a seasonal peak demand import charge, and seasonal export charge and a critical peak export rebate. They have also proposed a large-scale battery tariff although this is only for commercial customers. Essential Energy has proposed a range of tariffs that include peak time rebate components, export charges and critical peak pricing.

In its recent 'APIA for DER' rule determination[35] the AEMC increased the individual threshold from 0.5 per cent to 1 per cent of the DNSP's annual revenue requirement, and the cumulative threshold from 1.0 per cent to 5 per cent of the DNSP's annual revenue requirement. These increased thresholds should allow greater flexibility for network operators to develop innovative tariffs.

3. Limitations to the Pricing Proposal

Although the TSS sets out an indicative pricing schedule over the regulatory period, there will inevitably be changes to these prices in the Pricing Proposals. This could include local use of system charges (LUOS) where households are charged lower network charges where the source of the electricity is nearby – as is being considered for community batteries. Clause 6.18.2(b)(5) of the NER requires that a pricing proposal set out the nature of any variation or adjustment to the tariff that could occur during the course of the regulatory year and the basis on which it could occur. Should a change to the structure of the tariff will be required, this would have to occur through Clauses 6.18.1B or 6.18.1C as above.

4. Limitations on applying distribution use of system charges (DUOS) charges/rewards to exports

Clause 6.1.4 of the NER currently states that "A Distribution Network Service Provider must not charge a Distribution Network User distribution use of system charges for the export of electricity generated by the user into the distribution network". The AEMC's recent 'APIA for DER' rule determination[35] makes a number of recommendations, including that a DNSP can charge for solar exports. The AEMC also recommends that DNSPs should pay tariffs for exports to the extent that they provide network benefits. The AER will be charged with the development of a methodology for, and to regularly calculate, the customer export

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[35] AEMC, *Access, pricing and incentive arrangements for distributed energy resources, Draft rule determination*, 25 March 2021

curtailment values (CECVs). These are intended to help guide the efficient levels of network expenditure for the provision of export services and serve as an input into network planning, investment and incentive arrangements for export services.

The AEMC also stated that DNSPs may need to consider the extent to which the costs related to the export service are recovered solely from DER exporters. Some of the costs associated with the export service, such as that associated with the network's intrinsic capacity to host exports, are likely to be recovered from all network users. Whether such tariffs are implemented, and the nature of that implementation, will be up to each DNSP. Being tariffs they will need to go through the standard TSS process, including a transition strategy and a more rigorous public consultation process, and so the final nature of such tariffs, and their impacts on households, is unknown at this stage. It is worth noting that DNSPs are currently trialling or implementing technical solutions to high solar penetration and so it is possible that DNSPs will choose to undertake these sorts of measures instead.[36] Another complication is of course the extent to which retailers pass on any export charges/rewards, and how they interact with existing FiTs.

However, assuming that DNSPs implement such tariffs as outlined by the AEMC, and retailers pass them through, the final outcome on households is still difficult to determine. It is likely that export tariffs will encourage the installation of BTM batteries by PV-owners who can afford them – although according to the AEMC modelling, this incentive is small compared to that already in place. Assuming a battery is installed, this would of course come at a cost but would also enable more active participation in electricity flexibility mechanisms including being paid for solar exports during peak periods, which could provide revenue. The installation of more batteries would have two opposing effects on other households: i) it would also decrease revenue for retailers and DNSPs – where the latter are regulated under a revenue cap and so any decreased revenue will be passed back to all households in the form of higher tariffs in the following year, and ii) batteries actively operated to provide electricity flexibility, and even when operated in load-following mode, can reduce demand during network peaks and high spot price periods, which can then also reduce costs for all households.

Notwithstanding the two opposing impacts described above, PV-owners who cannot afford batteries will have options to shift load into the middle of the day, but otherwise may have higher electricity bills where they pay the export tariff. Households who do not have solar should have lower bills because the DNSPs' revenue cap regulation will mean that any increased revenue from export tariffs (that isn't spent on upgrading the network to cope with increased exports) will be passed back to all customers in the form of lower tariffs in the following year. They will also continue to benefit from the downward pressure that solar PV places on wholesale spot prices and network costs.

Also note that should clause 6.18.4(a)(3) be removed (see point below) export tariffs may only be applied in certain areas (with high PV penetration and predominantly residential loads), and even possibly at different rates. This would result in different levels of impact for different households who otherwise may have essentially identical loads and exports.

5. Limitations placed on applying different tariffs to different customers

Clause 6.18.4(a)(2) of the NER states that "retail customers with a similar connection and usage profile should be treated on an equal basis" and clause 6.18.4(a)(3) states that "retail customers with micro-generation facilities should be treated no less favourably than retail customers without such facilities but with a similar load profile" and clause 6.18.4(a)(4) states that a "Distribution Network Service Provider's decision to assign a customer to a particular tariff class, or to re-assign a customer from one tariff class to another should be subject to an effective system of assessment and review". Another recommendation of the AEMC's recent 'APIA for DER' rule determination[35] is that clause 6.18.4(a)(3) is removed. Although this is intended to enable PV households to participate in additional markets, it could have significant consequences reaching well beyond solar export tariffs because it applies to all tariffs. Thus, for example, it

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[36] For example, Powercor is balancing and decreasing the voltage at particular zone substations, and SAPN are implementing flexible export limits that can be varied dynamically according to local conditions at different times.

could mean that households with PV systems could be assigned to special TOU or demand charge tariffs not applied to other households. Consideration is also needed regarding whether tariffs should be designed to support value optimisation for different DERs, for example, when households have both home BESS and EVs. However, there are dangers in removing this technology agnosticism because, given that tariffs are designed to reflect the cost a household imposes on the electricity system, it shouldn't matter what technologies they use to do this. All that matters is the resultant impact they have on the electricity system. Of course, retailers may use such tariffs for customer acquisition, for example to attract households with EVs who may perceive they are receiving a special deal. Another possible reason for technology-specific tariffs is that owners of technologies such as batteries and EVs may be happier to deal with a more complex tariff, whereas households without such technologies may be less 'engaged' and so find such a tariff to be too complex and so move to a different retailer.

6. Tariffs must be reasonably capable of being understood by households

Clause 6.18.5(i) states the structure of each tariff must be reasonably capable of being understood by retail customers that are assigned to that tariff, having regard to: (1) the type and nature of those retail customers; and (2) the information provided to, and the consultation undertaken with, those retail customers. Yet another finding of the AEMC's recent 'APIA for DER' rule determination[35] is that this clause is a barrier to DNSPs developing innovative pricing options targeting retailers and energy intermediaries (rather than households). The AEMC considers that pricing structures could be specifically designed for retailers and/or energy intermediaries to then re-package in innovative ways to meet demand from customers in specific segments or with specific characteristics. This could include "prices for devices" where complex network tariffs are passed through by retailers, targeted at enabling technologies that can provide an automated response without the need for customer understanding. Thus, the relevant clause has been amended require DNSP tariffs to be understandable by either retail customers or retailers or Market Small Generation Aggregators.

6.1.2 Electricity retailers

DMO and VDO

Electricity retailers operating in the National Electricity Market (NEM) operate under the National Electricity Rules, including the National Energy Retail Law, National Energy Retail Regulations and the National Energy Retail Rules (electricity retailers in Victoria have to comply with the Victorian Energy Retail Code). Retailers in WA operate under the Code of Conduct for the Supply of Electricity to Small Use Customers. These generally focus on the protection of consumer rights (including the provisions of a Default Market Offer (DMO) under the Electricity Retail Code) and ensuring competition in order to place downward pressure on electricity prices. The Electricity Retail Code states that retail customers in South Australia, NSW and south-east QLD must be provided with a DMO limited by price caps set by the Australian Energy Regulator to help keep household electricity bills down. Similar rules apply in Victoria under the Victorian Default Offer (VDO).

The ACCC notes that the median price paid by both standing offer customers and market offer customers decreased after introduction of the DMO and VDO (ACCC, 2020b). There are opposing views on the impact of such default offers on innovation. As discussed in Section 3.1.2.3, non-price competition in NSW is expanding and some suggest that this may be because the DMO has flattened the variation between market offers, in which case retailers must be more innovative to find different ways to compete. An alternative view is that the default offers may stifle innovation because they don't allow for bundled products. Such a product could include non-price benefits such as offers from other industries (for example, banking or telecommunications). Such an innovative offer may breach the price cap, which doesn't take into account the other benefits, and households may therefore be discouraged or prevented from considering a potential beneficial offer. This highlights the need for the providers of bundled products to make it clear why they provide value despite potentially having higher electricity rates, especially where a household must be notified if they breach the price cap, as is required under the VDO. Another option to address this would be through carve outs under the DMO/VDO and regulated standard offers for innovative products. A similar effect may occur in the ACT and Tasmania where ActewAGL and Aurora provide regulated standard offer prices, and in Ergon's area where prices are regulated. The AER recent determination on DMOs[37] expects significant reductions, and it will be interesting to see how this affects innovation in the market.

There is currently no NEM-wide obligation on retailers to notify households if they would benefit from a different offer although, in Victoria, the Essential Services Commission mandates retailers to notify customers if they are paying $22 above the VDO and offer the customer the (flat) VDO or a more beneficial tariff if they have one. This makes TOU tariffs less attractive and may be holding back penetration of CRTs in then state, despite its high smart meter penetration. However, notification of preferable tariff arrangements is added to electricity bills and often goes unnoticed, particularly by direct-debit customers. An obligation on retailers to be proactive in ensuring households are on the most advantageous offer would increase switching between tariffs (though would not increase – and might even reduce - switching between retailers).

Multiple Trading Relationships

Multiple Trading Relationships (MTRs) allow an end-user to engage with multiple aggregators or retailers. This would, for example, allow an end-user to engage with one or more aggregators to sell DER services (such as network support, participation in spot and FCAS markets) while remaining with their chosen electricity retailer. This should increase competition between aggregators and so result in better outcomes for end-users who wish to participate in these markets. A secondary benefit should be that additional participation in these markets should reduce costs for all end-users. However, MTRs currently require a separate connection point for each retailer/aggregator, which would increase costs, and would mean that the PV system would have to be gross metered and so none of the PV electricity could be used on-site. A proposed rule change request to allow MTR without the need for separate connection points was rejected by the AEMC in 2016. In their P2025 Market Designs Directions Paper, the AEMC flagged that the implementation of their proposed trader-services model may require MTR reforms, although the nature of these reforms was not clarified.

NERL and ACL

The more innovative offers (such as the bundled products discussed above) may span both the National Energy Retail Law (NERL) and the Australian Consumer Law (ACL). The NERL is more proscriptive than the ACL regarding consumer protections, and products that span both jurisdictions may be too difficult to deal with. As a result, it may be easier for retailers to take the safe path of conventional offers and so avoid any issues. A related issue is that bundled offers might avoid the consumer protection framework of the NERL and so, for example, someone who buys a phone plan with free/cheap electricity may find they have no protection against disconnection etc.

6.2 Market considerations

6.2.1 Tariff assignment

How network tariffs are assigned, and then how they are passed through to households in their retail tariffs, are both relevant to the uptake of more cost-reflective tariffs. As discussed in Section 3.1.1.3, most new customers are assigned to cost-reflective network tariffs (either TOU, transitional demand or demand), and are also assigned to such tariffs if their meter is replaced for any reason. They can then opt out to a different tariff if they choose, in some cases having the option to move only to another cost-reflective tariff (Ausgrid and Evoenergy) and in some cases to a flat tariff. In all cases where the cost-reflective tariff is not the default, households have the option to opt in. In Victoria, all retailers must offer a flat tariff and customers on a TOU tariff can choose to switch to that flat tariff.

A systematic review of CRTs and DR trials and programs Parrish et al. (2019) found that participation rates are typically low in opt-in schemes, with just over half of the schemes analysed securing participation from 10% or less of the target population, while recruitment rates in opt-out schemes were found to be consistently high. Nicolson et al. (2018) conducted a meta-analysis of 27 studies of customer demand for

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[37] https://www.aer.gov.au/system/files/AER%20-%20Default%20Market%20Offer%20-%20Price%20determination%202021-22%20Final%20Determination%20-%2027%20April%202021.pdf

TOU tariffs and found uptake between 1% and 43% for opt-in arrangements and between 57% and 100% for opt-out, with real-time pricing less popular than static TOU tariffs, but noted the disparity between customers' stated willingness to switch to TOU and current switching rates. The authors suggested a range of alternatives to opt-out arrangements for incentivising uptake, including small upfront payments, bill protection and automation, and recommend further research to test the impacts of these measures on uptake, as well as exploration of the effects of different messaging strategies and targeting of households with specific technologies such as EHW or EVs.

A problem with allowing households to either opt in to or out of cost-reflective network tariffs is that (assuming it is passed through in the retail tariff) the people who choose to opt in, or who choose not to opt out, are the ones who are likely to benefit the most from such tariffs. These can be divided into those who have the ability to significantly reduce their demand during peak periods (e.g. they have a battery) and those who already have the right sort of load profile. The former will provide benefits for other households, but the latter will just reduce revenue to the networks and so increase costs for other households. Choi et al. (2019) found that voluntary adoption of TOU tariffs is first taken up by households with flat consumption profiles, who, in the first instance, reduce their bills without reducing peak demand. However, if adoption does not extend to households with peakier loads, this leads to increased tariff rates for all customers and results in the TOU-adopting households subsidising peakier, non-adopting households. Thus, low levels of voluntary TOU adoption are less equitable than flat tariffs.

However, while opt-out arrangements result in higher uptake of CRTs, it may also mean lower levels of response to the tariffs. Levels of ongoing response by participants over time have been found to vary widely in meta-analyses (Parrish et al., 2019). In general these are relatively high in programs that are opt-in (Parrish et al., 2019, Faruqui, 2010) and comparably low in those that automatically enrolled participants (Parrish et al., 2019, Torriti and Leach, 2012, Miller et al., 2013, Miller and Senadeera, 2017) reflecting that the smaller cohorts of households who actively choose to take up a tariff or other incentive product are more likely to stay engaged than those larger cohorts who may be successfully recruited to a default scheme but who do not stay engaged over time (Goulden et al., 2018).

Households adopting time-varying tariffs may face increases in electricity bills, particularly if they have high demand at the time of network peaks and high wholesale spot prices. The potential size of this increase is, of course, dependent on the specific tariff structure and rate, and on the household's ability and willingness to shift loads in response to the price signal. There is therefore concern that assignment of households to CRTs, particularly if it is mandatory, could result in bill shock.

One approach used by DNSPs to help avoid any bill shock from being moved to cost-reflective tariffs is to use a transitional demand tariff that starts with a very low demand charge rate. Unfortunately, this may provide the household with little incentive to reduce their demand peaks and so they may still suffer bill shock when they finally move to the full demand charge tariff. This type of unintended consequence could exacerbate customer antipathy towards CRTs and smart meters and increase the extent to which mandatory cost-reflective tariffs can act as a barrier to the uptake of smart meters (see Section 6.3.1).

This of course raises the issue of whether retailers actually pass-through cost-reflective network tariffs, and if they do then whether they pass through the same structure. Retailers face a strong incentive to not make their tariffs too cost-reflective because they may lose customers. As discussed in Section 3.1.2.2, even if they do pass them through, they may have quite a different structure, see for example Figure 3-18. The most perfectly designed network tariff will of course be much less effective if it is passed through with a radically different structure or if it not passed through at all. There is very little information on the extent to which this occurs.

6.2.2 Price-responsiveness and cost-reflective retail tariffs

A very large amount of work has been undertaken regarding household response to cost-reflective tariffs. Table D-1 in Appendix D summarises the key literature, including the meta-analyses cited in this section. The reported price responsiveness of households ranges from an *increase* in demand in response to a higher price signal (Currie, 2020) to a price elasticity of -2.25 (Caldwell, 2020), although there may well be reports of greater elasticity. There may also be asymmetry in price elasticity, with consumers responding differently to reduced prices than to increased prices (or not responding at all) (Byrne et al., 2021). A price elasticity of -2.25 means that for every 10% increase in price the demand decreases by 22.5%.

However, of most interest here are the reasons that the reported price elasticities can vary so much:

1. Firstly, is it short-term elasticity or long-term elasticity that is being measured? Short-term elasticity may describe changes that occur over a day, week or even a month (with some papers reporting on immediate changes in response to a CPP signal) whereas long-term changes can be over a year or even 10 years, as equipment and building stock are changed (Andruszkiewicz et al., 2020, Currie, 2020). Longer-term responses may reduce utility revenue more than short-term, but also allow greater certainty regarding required electricity system capacity; whereas short-term responses can be used to avoid crises and have little impact on utility revenue.
2. All the barriers and influences discussed in Sections 6.3 and 6.4, can impact on price responsiveness and inform the concept of *flexibility capital*, which describes a range of factors that can enable or prevent demand flexibility in households. Examples include:
    - Whether the household has significant loads (EHW, A/C, BESS or EVs), and how available they are to respond (as discussed in Section 6.5.3).
    - Whether the household has the enabling control technology to respond, as discussed in Section 6.3.2
    - Socio-demographics such as household income, although research findings disagree on the impact of these on response (Section 6.6).
    - A range of other household characteristics, including number, age, gender, ethnicity, income, education of occupants, dwelling type and size and ownership of smart technologies or rooftop solar (see Section 6.5.2).
    - External factors including the state of the economy, season or climatic conditions (see Section 6.5.7).
3. The design of the tariff: Two of the most relevant design aspects are the size of the peak rate compared to the off peak rate (Faruqui et al., 2017, Batalla-Bejerano et al., 2020) and the time period over which the peak rate applies, with shorter time periods more likely to elicit a response. Another important consideration is whether the price signal applies as a penalty to increased demand or as a reward to decreased demand, where Prasanna et al. (2018) found that a penalty-based price signal was more effective, which they thought may be explained by loss aversion: People show greater sensitivity to losses than to gains and so go to greater lengths to avoid them.
4. Timing is important as discussed in Section 6.4.3
5. How the price signal interacts with everyday routines, either temporarily or permanently, and the social dynamics that drive them, as discussed in Section 6.5.6.
6. Whether the tariff is assigned to households on a mandatory or voluntary basis and, if voluntary, whether it is opt-in or opt-out (see Section 6.2.1).
7. The time of day, week and year, as discussed in Section 6.5.6.
8. As well as having loads available, the loads must be in use immediately prior to a price event to be able to respond (see Section 6.5.3).
9. Offers that may be associated with the tariff. If a new tariff offering (or other incentive mechanism) is part of a broader associated demand management programs, and may accompanied by information programs, especially in the form of an app, or even better by some sort of device, the response will be greater.
10. There is also a relationship between price elasticity and cross elasticity, where in this case the latter relates to the price impact of being able to substitute alternatives for electricity, such as gas, oil or

wood. In essence this means that the availability of alternatives (higher cross elasticity) results in greater observed price elasticity (Andruszkiewicz et al., 2020).

Because of all these influences on price responsiveness, it is clear that it will vary greatly between different customers, and so segmentation of customers into different groups may be necessary for effective cost-reflective pricing (Dutta and Mitra, 2017).

6.2.3 Inadequate or uncertain value

The highest ranked barrier to DR by retailers and aggregators in Energy Synapse's stakeholder consultation (Energy Synapse, 2020) was "financial payment not attractive enough". In several studies households have expressed doubts that the financial benefits associated with using technologies such as smart meters to achieve demand flexibility would be sufficient to make their engagement worthwhile (Throndsen and Ryghaug, 2015, Balta-Ozkan et al., 2013, Buchanan et al., 2016), and 'running appliances when electricity is cheaper was perceived as pointless if savings were minimal' (Balta-Ozkan et al., 2013).

In one phase of Ausgrid's hot water load control trial, not using a lot of electricity and not being convinced that they would save much money were, on average, the two biggest reasons for not being interested in switching to off-peak systems (Ausgrid, 2016). Many participants in AGL's Managed By You programme thought "the monetary value of their rewards to be insignificant". This can present a barrier not only to the uptake of and response to those incentives but will also make it difficult for utilities to provide DR incentives they can afford. Ausgrid found that for the small hot water systems component (Project 1) of their hot water control trials, the total program costs including customer engagement and acquisition costs (including marketing materials or customer contact) and the cost of supply and installation of the load control devices were high per kilowatt of demand reduction (Ausgrid, 2016). This can be problematic because the value of achieved flexibility must be large enough to compensate households for the labour involved in taking up the opportunity, for any comfort or convenience sacrificed to provide the flexibility and/or cover the cost of enabling technology.

VPP trials using household batteries address this value issue by stacking value from different markets, with the use of aggregated BESS to provide FCAS services currently providing much of the value: "Revenue is strongly correlated to how many contingency FCAS markets they participate in" (AEMO, 2021a). However, this increases complexity and, more generally, market uncertainty creates risk that must be carried by the utility or passed to customers. The value of BDR used to address network peak demand, or a VPP participating in contingency FCAS markets, is dependent on the occurrence of power system events and there is, of course, uncertainty regarding how frequent and extreme these will be in the future. The ability to participate in potential higher-frequency (e.g. 2 second) FCAS markets or supply synthetic inertia on a millisecond timeframe may increase the future value available to VPPs[38].

Uncertainty in the value of flexibility that can be achieved by a specific household presents a further barrier to both provision and uptake of incentives. The value of achievable flexibility (and therefore the potential available incentives for households) depends not only on the potential revenue streams but on the size of available loads (Section 6.5.3) and generation, as well as on other household characteristics. For utilities, recruitment of participants without knowing this information increases the uncertainty regarding the achievable value per household, while data collection and targeted marketing increases costs. For households, uncertain rewards add to the challenges of making a decision about participation in a DR scheme. As an example, Powershop's Grid Impact VPP generated 'grid credits' for households can vary between $20 and $236 annually.

6.2.4 DR marketing and recruitment costs

Recruiting households to participate in any sort of program targeting some version of flexible response can be time consuming and expensive. Endeavour noted the high cost of marketing and education in its PeakSaver BDR program including the difficulty and necessity of educating households about demand response. They also observed that "distrust in explanations of peak demand and the motivations of the

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[38] https://www.ecogeneration.com.au/trust-us-vpps-are-the-way-of-the-future-sapn-report/

electricity industry is likely to reduce demand response" (Nicholls and Strengers, 2013). Ausgrid found that, even after a household had been contacted and an offer made, "the limited resources available to project manage the trial and manage the individual requirements of some customers' installations may be a contributing factor to slowing down the ongoing customer acquisition process". They also found that another time-limited factor was the need to give "customers time to consider the offer or refer to someone more qualified to provide information and clarify their understanding before proceeding" (Ausgrid, 2016).

Unlike retailers' normal customer acquisition and retention costs (CARC), which can be absorbed into market pricing (because customers are choosing between different tariff offers which all include CARC), recruitment costs for DR schemes can be less easily absorbed because customers are being asked to choose a DR scheme over no DR (which has no acquisition costs).

6.2.5 Market complexity

With 40 retailers active in the NEM (AEMC, 2020a) and thousands of tariffs, households already face difficulties in engaging with the electricity market and there is plenty of evidence from the behavioural sciences that an abundance of choice can lead to poor decision making.

Energy Consumers Australia found that "energy bills and plans consistently confused and overwhelmed consumers, who struggled to understand the breakdown of costs and found comparing providers near impossible" which often caused them to "give up and disengage" (ECA and Forethought, 2019). As well as multiple tariff rates, this customer-facing complexity includes discounts with diverse structures and application (Mountain, 2019), further reducing transparency and understanding, and contributing to reluctance to adopt cost-reflective tariffs (Mayol and Staropoli, 2021). As a result, more than half of households have *never* changed their energy supplier (Australia, 2021).

Poor communication exacerbates the effects of this complexity. Electricity bills are "typically confusing and not useful to help consumers navigate the electricity market" (Bialecki et al., 2018). This contributes to the general distrust of the electricity market – and of retailers in particular - with some households suspicious that the confusion is deliberate, "I find it very convoluted and it is really hard to understand what the best deal is, they confuse you on purpose with usage rates and other things" (electricity customer quoted in ECA and Forethought, 2019). The addition of demand tariffs adds further complexity and makes it harder for customers to understand their bills and requires relatively sophisticated data analysis to unpick the relationship between household behaviours and energy costs, or to compare the total costs of different tariff structures (Mountain, 2019).

Assessment of the diverse opportunities to participate in demand response opportunities or VPPs, or evaluating the costs and benefits of batteries, requires a high level of engagement, and is likely to be beyond many time-poor households with only scant understanding of their energy costs.

6.3 Enabling technologies for metering and control

6.3.1 Smart meters

Cost-reflective and dynamic pricing depends on appropriate metering technology and appropriate access to energy data for households, retailers and 3rd parties. Additionally, energy sharing within local networks (e.g., community batteries or peer to peer trading) depend on the ability to measure local flows.

The slow roll-out of smart meters (SM), with only 17.4% of households outside Victoria having an SM by June 2020 (Section 5.4) is therefore an obvious barrier to increasing uptake of time-varying tariffs. It is important to note that, although necessary, high penetration of smart meters is not sufficient to ensure high uptake of CRTs, as witnessed by Victoria's 19.3% uptake. Low smart meter penetration is also a barrier to other demand response mechanisms including BDR and DLC, as it makes it difficult to measure the achieved demand response. In AGL's Peak Energy Rewards BDR trial, only 2,000 of 4,300 signed-up participants had smart meters, and of the 2,300 SM installations attempted, 800 failed (mostly in apartments) (AGL, 2019).

There is a range of reasons for the slow rollout of SMs. The introduction of a contestable market in metering installation and provision of metering services “was expected to enable greater availability of meters for consumers or market participants to acquire, at the market determined least cost by providing innovation and choice through commercial incentives, placing downward pressure on the price of meters plus associated products and services, and removing barriers and disincentives” (AEMC, 2020d). However, it has introduced additional complexity for customers and has not delivered an efficient system for SM rollout. Responsibility for metering is now shared and installation of an SM requires co-ordination between retailer, metering co-ordinator, metering provider, metering data provider, DNSP and customer. Installation delays are the leading cause of complaints about smart meters, including complaints from customers with registered life support equipment (EWON, 2020). Although complaints have decreased following new rules introduced in February 2019 establishing clear timeframes for installation, 10% of complaints to the ombudsman still relate to meter exchange.

Other customer complaints about smart meters include billing faults and incorrect information or advice, as shown in Figure 6-1.

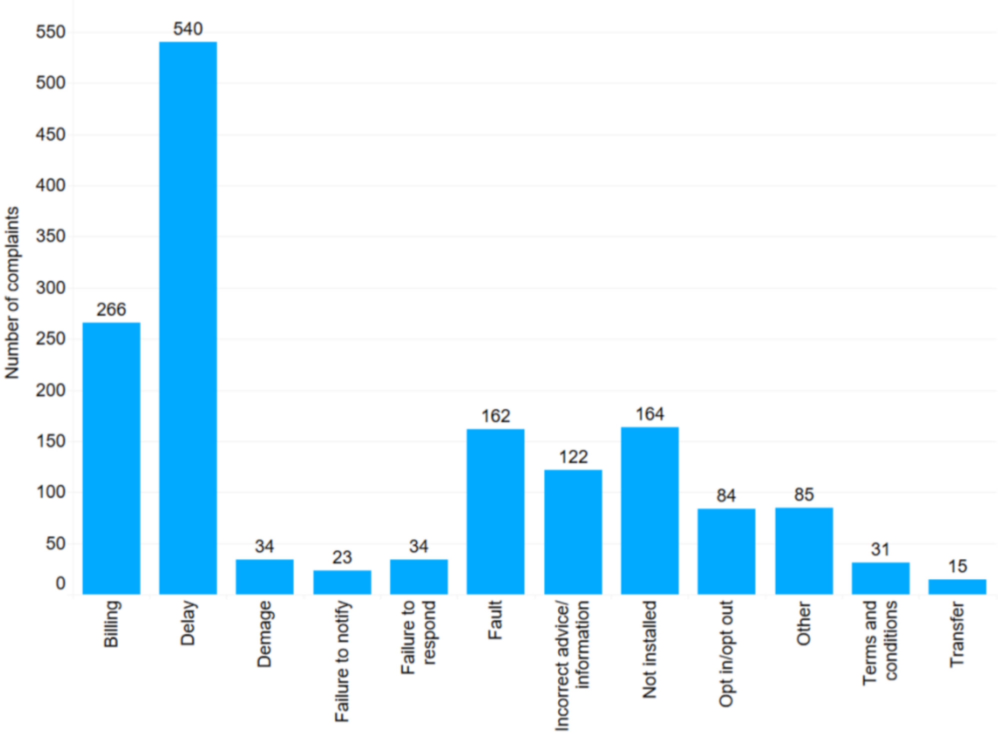

Figure 6-1 Digital meter exchange complaints in NSW 2019-20 (AEMC, 2020d, using data from EWON, 2020)

Retailers are only obliged to arrange for installation of a SM if the existing meter is faulty or if the household installs solar, not in response to a customer request if the existing meter remains fit for purpose and is working accurately (AEMC, 2020d). The frequency of existing meter malfunctions has been lower than expected and retailers may have been deterred from pursuing wider rollouts by the communications obligations imposed on them. Once SM installation has been initiated, barriers faced by meter installers include access difficulties, lack of space on switchboards or in meter cupboards, shared fusing, asbestos switchboards and wiring defects, as well as customer refusal. These can add significant expense to the installation which, if it isn’t met by the retailer or customer, may lead to the installation being abandoned.

While more than one in three SM installations is the result of a customer request, the value proposition of SMs is not clear to many households. 60% of complaints about digital meters are from customers who did not see the expected cost benefits (EWON, 2020). This is not just a question of whether smart meters are installed or not, but also whether the hardware and firmware kept up to date and are sufficiently smart to enable user response.

Other households are deterred from installing an SM by concerns about remote disconnection or by antipathy to time-varying tariffs. So, as well as the limited uptake of smart meters being a barrier to cost-reflective network tariffs being implemented (Australian Energy Regulator, 2020), the converse may also be true. If a customer installs a smart meter, they may be automatically placed into a tariff they don't want to be on. For example, in the Ausgrid network, customers on flat tariffs who request a meter replacement are placed on a demand tariff by default and, if they choose to opt out, they can only revert to a TOU tariff.

For households with smart meters, asymmetry in data access presents a barrier to customer recruitment by 3rd parties and to measurement of demand response. Transfer of metering responsibility away from DNSPs to retailers and metering co-ordinators has increased complexity and created inequities in data access (ACOSS et al., 2021). In particular, incumbent retailers now have access to interval data which allows them to identify households most likely to respond to DR incentives (or even to target households that won't be negatively impacted by CRT), and target marketing of their offers accordingly, while other retailers and 3rd parties do not. Moreover, these retailers are better able than other parties to operate DR schemes as their access to SM data allows measurement of DR, while DNSPs need to collaborate with multiple retailers in order to replace aging load control infrastructure with smart meters[39].

There is a broader question of whether metering regulation could better support innovation in the smart meter rollout, enabling lower cost but technically suitable technology or incentivising more sophisticated technology and value-adding services such as data access and visualisation.

Although it is widely understood that deployment of smart meters is a necessary part of increasing flexibility, there is little quantitative evidence of the value they can unlock. Smart meters have the potential to deliver value to customers (real time data to inform energy management, access to CRTs and demand response schemes, and identification of unsafe neutral connection issues), to retailers (remote meter reading, data giving greater understanding of customer load characteristics and facilitating CRTs and to DNSPs (data on voltage fluctuations and to identify power outages and safety issues, management of controlled loads), as well as to third party aggregators of flexibility services. Understanding the value that can be accessed by different stakeholders can enable appropriate allocation of the costs of SM deployment, help overcome household reticence and "help policymakers to design cost-causal cost-recovery measures that can lead to increased customer support for these measures" (Matisoff et al., 2020). This suggests a research imperative to better understand the value of SMs and how it can benefit a range of stakeholders, as discussed in Section 7.3.3.

6.3.2 Access to control technologies and DER

The capacity of a household to offer flexibility through tariff or other incentive products is affected by access to technologies that can support flexible energy use. The degree to which a household can respond to tariff (or other) signals depends on their access to control technologies, which can range from simple timers or programmable thermostats through to complex home energy management systems, incorporating a battery to provide a totally automated response (Faruqui et al., 2017, Batalla-Bejerano et al., 2020).

This aspect of flexibility capital (see Section 6.5.1) is typically highly inequitable, with ownership of smart home technologies tending to depend on ownership of the home (Balta-Ozkan et al., 2013). Tenants are typically precluded from installing DER such as rooftop solar, batteries and EV charging due to the nature of the rental contract, while the options to purchase DER may be limited for residents - owners and tenants alike - of some kinds of homes, such as apartments. Particular demographic cohorts, such as older, disabled or less technology-literate people, could also face obstacles in accessing and deriving benefit from DER. There is therefore potential for this barrier to be reinforced by the expansion of flexibility markets, further deepening the inequality between those currently with and without access to DER (Murtagh et al., 2014).

Automation is especially effective in enhancing a price response because it avoids the need for manual responses, enables a very quick response and avoids excessive responses (Dutta and Mitra, 2017, Bailly, 2018). In Australia, *Amber Electric* report significant demand reduction, without any control technology, from their customers in response to wholesale price spikes, but their current customer base is skewed towards

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[39] https://bit.ly/3g2OulO

highly engaged early adopters, and the company is expecting control and optimisation technology to become part of its primary product offering as it scales.

Carmichael et al. (2021) highlight the importance and interdependence of CRTs, smart meters, storage (including EVs) and automation (the "Demand response technology Cluster" as shown in Figure 6-2) in increasing residential DR, as well as the need for smarter comparison tools, data portability and simplified switching to support uptake of these technologies. "Promoting awareness that smart meters, smart tariffs, and storage and automation technologies enable greater benefits when combined could increase consumer engagement across all these technologies and services. Each component can act as an enabler and or driver for adoption of other components, e.g., smart meters enable smart tariff adoption and EVs and EV-tariffs could drive smart meter adoption."

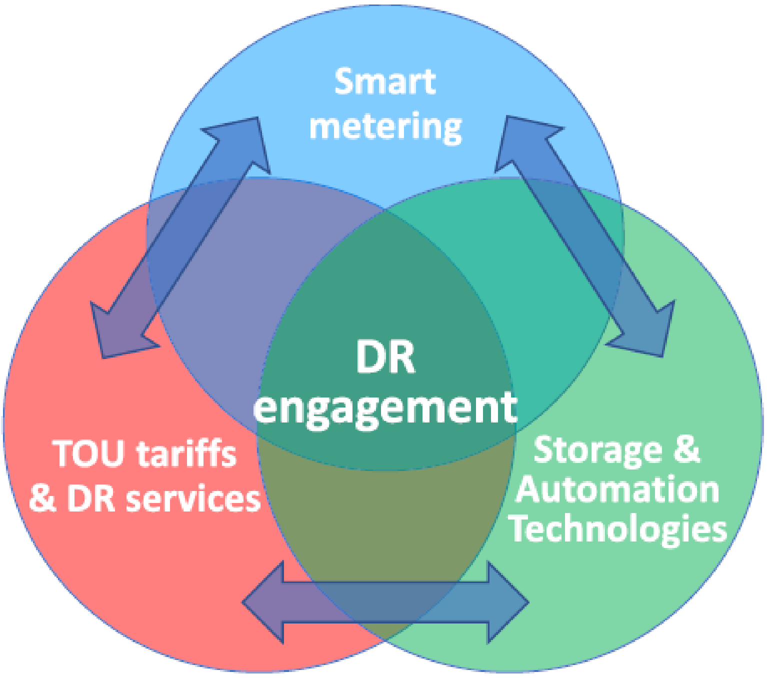

Figure 6-2 The "Demand Response Technology Cluster" (Carmichael, Gross, Hanna et al. 2021)

6.3.3 Compatibility and interoperability

Barriers relating to interoperability of control technologies affect the ability to provide incentives as well as households' uptake of and ability to respond to incentives.

AS4755 demand response capability is being used successfully for DLC of air conditioners in Queensland through EQL's *PeakSaver* programme. The COAG Energy Council agreed to extend this capability through the mandating of AS4755 compatibility for all air conditioners, resistive electric hot water systems, pool pump control units and EV charge controllers[40]. While the OPBR advised that greater justification for a mandatory standard was required, a move to mandating the standard is being led by South Australia. Findings from DLC trials suggest that there are unresolved issues with the implementation of this standard, as well as significant limitations to the capability of DRM-enabled devices (Section 6.3.4).

However, AS4755 compatibility is not the same as compliance. AGL's Peak Energy Rewards DLC trial excluded air-conditioners that were not compatible, but found during installation that "many models required supplementary hardware units to be added, in addition to the DRED, in order to access the demand management functionality" (AGL, 2018). It was also found that the standard was only partially implemented for some models and that "the response of air conditioners to the standard control commands varied, with different air conditioners responding to the commands in different ways. Individual end-to-end testing was required for each installation, and in some cases re-mapping of the control commands was necessary to

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[40] https://www.energyrating.gov.au/news/smart-demand-response-decision-ris-approved

force the installation to behave according to the standard." The incompatibility of aircon units with AS4755 was described as the main impediment to successful recruitment and caused a significant proportion of households who had registered interest to be excluded (AGL, 2019).

SwitchDin have provided a summary of the challenges of communicating with and controlling PV and battery inverters (Kassouf, 2020). Sunspec Modbus is a common communications protocol based on the Modbus series protocol (developed initially for industrial automation) which is intended to promote interoperability between inverters and aggregators or DER management system (Obi et al., 2020). Sunspec Modbus is used by most inverters in the Australian market, although some manufacturers use proprietary systems, while NMI meters commonly use DNP3 protocol. However, implementation of these protocols varies and may include proprietary elements. Different inverters also offer different control functionality, such as providing export limits at the inverter terminals or at the grid connection point, or no control at all, or only through onboard optimisation algorithms, and functionality and protocols may vary with different firmware versions. Additionally, levels of transparency over, and access to, control protocols vary between different manufacturers, with some only allowing access to preferred partners, and sending repeated signals can cause damage for some inverters.

The successful introduction in South Australia of mandated remote export control without requirements for any specific control or communications protocol may suggest there is no need for standardisation. Conversely, compliance with international rather than local standards could serve to reduce costs of compliant appliances.

IEEE 2030.5 for DR in Smart Grids is the standard implementation of the Smart Energy Profile, originally developed by the Zigbee Alliance and the HomePlug Power Alliance, designed to enable communication between appliances, BESS, HEMS and metering devices. The standard includes security protocols, a set of functions for DR, load control, metering, etc. (Obi et al., 2020). The DER Integration API Technical Working Group is localising IEEE 2030.5 for the Australian market (Weise, 2020) and the IEEE 2030.5 API is likely to be incorporated into AS4755, without affecting the DRM requirements.

While IEEE 2030.5 is primarily designed for direct control of devices, OpenADR relies on a gateway device, Smart HEMS, or aggregator to translate flexibility requirements from DNSP or other utility into specific device behaviours. Open ADR was developed for DR but has been adapted to include control of inverters, VPPs and EV charging infrastructure (OpenADR Alliance, 2020). Other relevant international standards include IEC 15067 for smart HEMS and IEC 15118 for EVs,

More generally, standardised communication protocols and control functionality would provide greater opportunities for integration of appliances with Smart HEMS, including voice assistants such as Amazon's *Alexa* and *Google Assistant* which already have the ability to monitor smart meter data and alert users of energy usage.[41] However, there are also data privacy and security concerns associated with greater integration of devices, as discussed in section 6.5.5.3.

6.3.4 Technical functionality and performance

As well as the interoperability and implementation issues outlined above, DLC trials have discovered several shortcomings of the AS4755 DRED control protocol. The most significant limitation is that the standard is limited to one-way communication with devices, with no facility to confirm that the appliance has received the signal or implemented DR. In DLC of air-conditioning, for example, sending a DRM signal to limit power consumption to 50% of maximum will have no impact on demand if the appliance is switched off or operating at less than 50% power. Separate energy monitoring is therefore needed to confirm whether the appliance responded, but even with this, AGL's *Managed for You* program found that "it was frequently difficult to verify which mode an air conditioner was actually using from looking at the measured consumption data" (AGL, 2019). Given the challenges of accessing and analysing smart meter data (Sections 6.3.1 and 6.3.6), this creates challenges both for calculating total achieved DR and for determining appropriate levels for household rewards.

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[41] https://www.agl.com.au/smarthome

A related issue with AS4755 is the limited functionality included in the protocol. Demand response modes in the standard are limited to restricting either load or grid export to zero or 50% or 75% of a reference value. The lack of granularity in these DRM, combined with differences of implementation make it difficult to predict the impact of DRM signals on appliances.

Another issue raised by the AGL DLC trial was that the absence of a local override facility in AS4755 DRED control. “Unfortunately, the air-conditioner control mechanism specified in AS4755 does not allow any opt-out or override capability at the customer’s air conditioner. This is a significant shortcoming of the current standard when it comes to air conditioning control” (AGL, 2019). User research consistently reports households’ preference for the ability to opt out of a specific DR event, “to temporarily remove themselves from the program, for example for special occasions, for health reasons or if they no longer wished to participate … Unfortunately, the air-conditioner control mechanism specified in AS4755 does not allow any opt-out or override capability at the customer’s air conditioner” (AGL, 2019). Offering the ability to opt out for health reasons goes beyond satisfying user preferences to utility’s duty of care for customers experiencing vulnerability.

Conversely, making it easy for households to opt-out of a specific event can undermine the DR programme. ZenEcosystems’ *ZenAir* DLC trial used a *SmartAir* infrared (IR) device to control users’ air-conditioning temperature settings, reducing the temperature for a pre-cooling period prior to an event and then increasing it for the event duration. Although the functionality of the existing IR controller was replicated by the *SmartAir* device and associated app, households were allowed to keep the original device in order to give them the option of overriding the DLC and opt-out of DR events. The low – or possibly negative DR - achieved by the scheme was attributed, in part, to use of the original controller to change A/C settings, overriding the DLC without detection by the smart controller (Zen Ecosystems, 2018).

While COAG are set to decide whether AS4755 will be mandated in its current form, the standard itself is under review[42] and is likely to incorporate aspects of IEEE 2030.5 (as described above), but it is not clear whether it will include opt-out or feedback functionality. There is concern that the standard is based on an outdated approach to DR (Kuiper and Blume, 2021), as well as being specific to Australia and wholesale adoption of an international standard such as IEE 2030.5, which has been used successfully in Australian trials, may be a preferable option (Kuiper and Gill, 2021).

6.3.5 Installation

As well as barriers presented by the performance and interoperability of enabling technologies, there are additional challenges presented by the installation process itself which can lead to increased costs and/or render households unable to participate in DR programmes. These are similar to the physical and technical issues relating to smart meter installation (Section 6.3.1), including co-ordination difficulties. For example, in Ausgrid’s DLC hot water control trial, of the 64 customers who responded to the offer and registered their interest in participation in the small hot water system component (Project 1), the installation was cancelled in 31% of cases; and in the subsidised controlled load connections component (Project 2), only 104 of 282 registered participants went ahead with installation. For Project 1, “the main reasons for cancelled installations was the difficulty experienced by the installer in contacting the customer (12%), jobs cancelled by the customer (9%) and customers ineligible for the trial as they were not the property owner (6%)”, while for Project 2, “one of the key reasons for cancelling was that customers were not prepared to pay the quoted amount for additional works/ upgrades required for non-standard and more complex installations” (Ausgrid, 2016).

While some technical issues (such as households with gas hot-water or the wrong-sized water tank for Ausgrid’s Hot Water trial, or non-AS4755 air-conditioning systems for AGL’s A/C trial) could be avoided with improved information gathering before installation, others (such as the need for switchboard replacement) are only discoverable on-site. Other technical issues can be caused by installers themselves. Energy Australia’s Mass Market DLC programme found issues with installations of smart isolation switches and

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[42] https://aemo.com.au/initiatives/major-programs/nem-distributed-energy-resources-der-program/standards-and-connections/as-4755-demand-response-standard

circuit-level control devices, including mislabelled circuits and inaccurate monitoring (Energy Australia, 2020). “No two consumer switchboards are the same resulting in the installer encountering a different safety, analysis, design and physical challenge each time they install a device” (Energy Australia, 2019).

Because of their greater complexity, most installations in the Bruny Island Battery Trial, involving solar PV, battery and Reposit battery management system, had faults, including missing or misplaced labels, switches without adequate protection from unintended operation, wiring issues or loose terminals, which required repeat visits for rectification, leading to increased costs and delays in the trial. Poor experiences with the installation process affected households’ attitudes to the technology and to the DR programme overall. One of the key findings of the trial was the key role played by installers, not only in ensuring appropriate and safe installation of technology, but as a source of information for households. However, “generally the installers handed the system over to the customer in a way that left householders lacking knowledge of their systems” (Jones et al., 2019).

Indeed, as they are often the only point of face-to-face contact for households, installers are a key source of information about DR schemes for households, and a source of information about customer characteristics for utilities. In Ausgrid’s Hot Water DLC trial, it was sometimes only when an installer visited the household that inappropriate equipment was discovered, or that households found out details of the scheme, such as the requirement to move to time-based pricing, that led them to withdraw from the programme (Ausgrid, 2016).

These installation challenges point to the need for greater consideration of installer recruitment and training in planning of DR initiatives – which could have significant cost implications. Energy Queensland, recognising the important role of installers in their PeakSmart A/C DLC programme as a source of information (knowing which room a DRED A/C unit is installed in is important to understanding its DR potential), as a communication channel to households and as a route to market, introduced an incentive scheme for installers.

However, in some situations, the expectations placed on installers may be too great. In the Bruny Island trial, “it was assumed that installers would provide technical design support, sales, supply, install and follow up support for householders. However, we observed that installers in the most part do not have the capacity to fulfil all these roles. No other stakeholders (other than installers) are currently available in the marketplace to fill knowledge support and problem resolution roles. Installers’ likely lack of capacity for these extensive roles leaves a fairly large gap in support for householders.” (Watson et al., 2019).

6.3.6 Measurement of baseline and demand response

Measurement of DR is necessary in order to assess its market value and to reward households for their flexibility. In general, DR cannot be measured directly since any change in demand is caused by a combination of the response and changes to the other factors that drive residential electricity use, such as temperature, occupancy, behaviour, etc. A range of approaches is therefore used to estimate DR delivered through mechanisms such as DLC, BDR, etc. However, there are limits to the accuracy of these methods.

This is particularly challenging for BDR, where the response to a given signal is unknown and dependent on user behaviour, but it is also not straightforward for DLC. The impact of remotely switching an A/C unit off, limiting it to 50% (DRM2) or 75% (DRM3) power through DRED control, or increasing the temperature setting of a smart thermostat is dependent on whether the A/C unit is switched on, it’s initial temperature setting, the air temperature of the room it is in and the thermal performance of the house. As AGL’s *Peak Energy Rewards* reported, “Air conditioners can only be controlled if they are turned on in the first place. In practice only around 20% of units in the trial were turned on at the time of the two events, both of which were held on weekday afternoons when grid supply issues are likely to occur” (AGL, 2019). Similarly, neither switching an EHW system off to reduce demand or switching it on to soak up excess solar generation will have any impact if the water temperature is at or above the setpoint of the tank thermostat.

All DR mechanisms need a method for calculating or estimating the total DR achieved by multiple households, but it is not always necessary to identify the response of individual households. An example is Energy Queensland’s PeakSmart DLC of air-conditioners, which incentivises households with a discounted A/C system. While EQ needs to understand the total DR available through the scheme, this can be achieved through a stochastic method, multiplying the known number of controlled A/C systems by the average response of a small sample of participant households with monitoring installed. This aggregated estimate is limited by assumptions about how representative the monitored households are of the 120,000 participants (e.g. location of A/C unit, type of dwelling, household occupancy and behaviours), but it is not necessary to know whether a specific household delivered any demand reduction.

Conversely, if households are rewarded for participation in particular events, or for the level of their response, more specific data are needed to enable fair rewards and generate participant trust. In particular, self-reported participation in BDR events does not always align with delivered DR. For example, in AGL's Peak Energy Rewards program, 30% of self-reporting event participants did not decrease – or even increased – their demand (AGL, 2019).

Where smart meters are installed and their data accessible, they can be used to assess DR, but the low penetration of smart meters outside Victoria (Section 6.3.1) presents a barrier for all potential DR aggregators; and where smart meters are installed, access to the data is limited to the household's existing retailer and DNSP (Section 6.4.1). Moreover, the 30-minute granularity of smart meter data, and DRED, can be limiting: "The standard measures the target consumption reduction of an air conditioner as an average over half an hour. At times, the instantaneous demand will be much higher than this. As a result, a group of controlled air conditioners in a specific network area can still generate high demand peaks on the local network. From a wholesale market perspective, the benefit of a half-hour average demand reduction following the implementation of the five-minute market is questionable." (AGL, 2019)

Moreover, estimation of DR relies on developing a counterfactual baseline load profile, using historic load profiles, which is "especially challenging for the residential sector" (Energy Synapse, 2020). This is because of the sensitivity of household loads to ambient temperature, their intermittency and their dependence on occupant behaviour. Baseline estimation is particularly difficult for solar households, particularly if using net load, rather than total generation and consumption (or circuit level consumption), and there is no simple correlation between net daytime load and temperature.

The commonly used CAISO '10 of 10' method uses an average load profile of the 10 days prior to the event, with an adjustment of up to 20% depending on actual consumption on the morning of the event. This has limitations for loads that depend on temperature or vary between different days of the week. High load immediately before an event can also lead to false negative if the baseline is based on average consumption. AEMO and ARENA adapted this method, restricting qualifying days to those with similar average temperature and increasing the maximum adjustment limit to 40%, thereby increasing the accuracy and precision of baseline estimates for non-solar households, but not to a useful level (ARENA, 2019).

Other variations on the method include changing the period of qualifying days and using the hour immediately before the event for anchoring (United Energy). Zen Ecosystems used a constructed baseline by drawing a straight line between demand an hour before the event and demand an hour after. AGL developed a method using "deep learning" algorithms, including generating a regression of net load against temperature, de-biasing against the previous week's load and anchoring to consumption on the event day. This gave more accurate, individual baseline predictions (and associated household DR targets) but took time, and therefore increased the advanced notice needed for events. AGL's latest report on their residential BDR scheme (AGL, 2019) reported some continuing participant dissatisfaction with baseline inaccuracy causing them disadvantage.

6.3.7 Technology costs

Regardless of whether the cost of enabling technology is paid by the household, the utility or the aggregator, the cost of supply and installation reduces the proportion of the DR value available to incentivise households and intermediaries. In general, retrofitting control or monitoring technologies is significantly more expensive than installation in the factory or in conjunction with other technologies. For example, in Ausgrid's early *CoolSaver* trial, "the marketing approach and acquisition model had a high cost due to the need to retrofit to existing air conditioners", the next phase leveraged "the initial purchase and installation of new compliant air conditioners and so lower the cost of customer acquisition and participation" (Ausgrid, 2015). Similarly, after initial retrofitting trials, Energy Queensland restricted their *PeakSmart* programme to new air-conditioning installations, while Solar Analytics monitoring is sold through solar installers to avoid the need for an additional truck roll.

Where installation requires a qualified tradesperson, labour costs are likely to make up a significant part of the cost and, for this reason, a number of more recent DLC trials are using plug-and-play devices that can be installed by households, such as the Sensibo and ZenAir infrared air-conditioning controllers, rather than electrician-installed DRM devices.

Additionally, technology installation may trigger other costs, such as switchboard upgrades. While this is often the case for solar installation, the household benefits are usually sufficient to compensate, with only a small reduction in payback period, but where the benefits are lower, or the cost of additional work is disproportionate to the cost of the installed technology, this may prevent installation. For example, in the subsidised controlled load connections component (Project 2) of Ausgrid's hot water trials, "scoping visits by an electrician were conducted for all 79 sites and it was identified that while the stand alone cost of installing a new meter could be subsidised, the costs of the additional works required to achieve switchboard compliance at the majority of sites was too expensive. This meant that nearly all sites that did not already have controlled load equipment in place were deemed too expensive and above a reasonable ($500) level of subsidy" (Ausgrid, 2016).

High technology and installation costs are a particular barrier for renters, due to high turnover and split incentives between landlord and tenant, and apartment owners, due to the challenge of securing strata body approval for expenditure.

The high current cost of home BESS is one of the key reasons for low penetrations (compared to PV), with typical payback periods for BESS installed to augment existing PV far in excess of the battery lifetimes, with most existing BESS installed for non-financial reasons including increased autonomy and security of energy supply (ITP Renewables, 2020). High future penetration of BESS therefore relies on significant cost reductions, delivered through massive upscaling of production (largely in response to the growing global EV market) and a learning rate (cost reduction for every doubling of production) of 18% (Bloch et al., 2019).

6.4 Information and communication

6.4.1 Data access

Issues relating to data access create barriers to the provision of incentives, and to household take-up of, and response to, incentives. Smart meter data has potential value to households and to utilities. Although the value of this data is uncertain and dependent on household behaviour, creating difficulties in appropriate allocation of the costs of smart metering (Matisoff et al., 2020).

Its value to households includes supporting decision-making about choice of retailer and tariff structure, buying DER, including PV and BESS, and appliances, and upgrading building energy efficiency (Energy Consumers Australia, 2020b). Although customers with smart meters have the right to access the data from their retailer or DNSP, there is currently no standardised procedure and the data is not provided in a format readily understood by households. Moreover, for many of these use cases, the customer will need to pass the data onto - or authorise access to - a 3rd party such as a comparison website or solar assessment tool. The procedures for authorising 3rd party access also vary between utilities and the data is not supplied in a standard format. A potential additional use case for timeseries meter data is to provide feedback to enable households to assess the impact of their flexibility behaviours. However, to inform behaviour modification, this requires (near) real-time data which is not currently available from smart meters, and so requires installation of secondary metering.

For utilities, including retailers, aggregators, etc., access to smart meter data can assist both with customer acquisition and with assessment and reward of flexibility.

When recruiting participants for DR schemes or marketing tariffs, it is useful to identify customers with specific load profiles in order to target those most likely to benefit from, or respond to, the incentive. Both DLC and BDR schemes require access to energy load data to generate baseline load forecasts and to measure actual load, in order to verify or estimate the achieved level of DR. There is no current mechanism for 3rd party DR providers to access smart meter data for multiple customers, even those that have signed up to participate in a DR scheme (Zen Ecosystems, 2018).

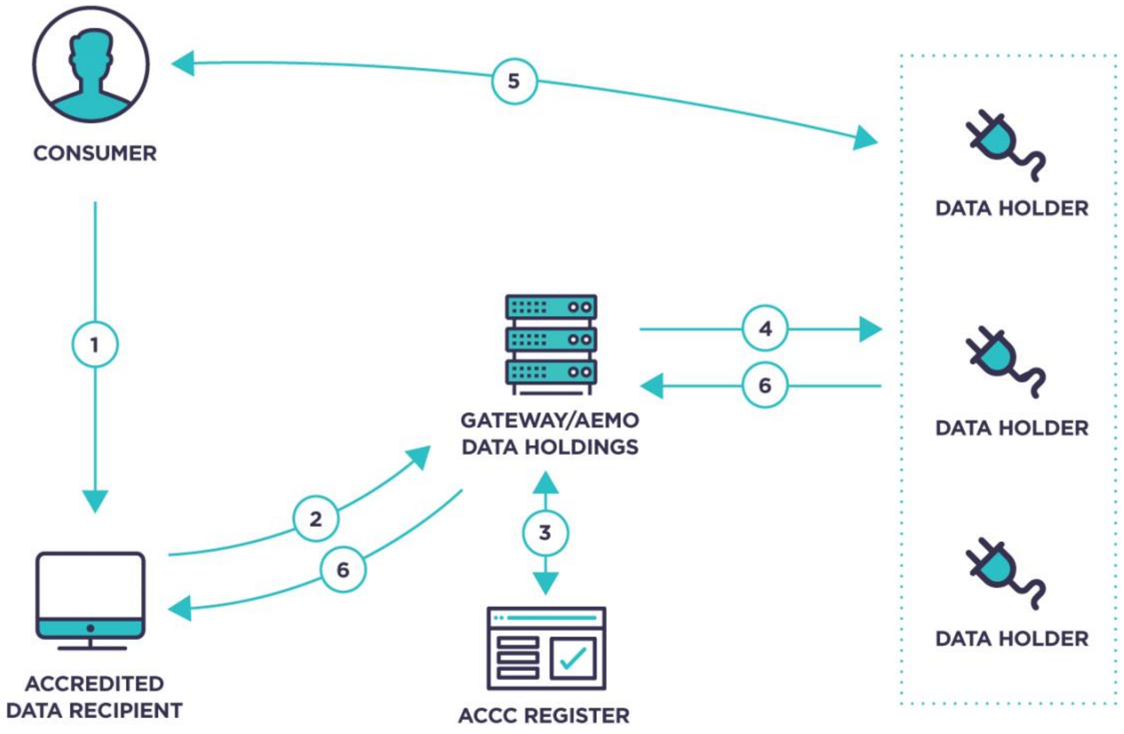
While retailers and DNSPs have access to this data for their own customers, 3rd party providers do not, and this creates an imbalance in the market in favour of incumbent retailers. Contestable metering was introduced to increase competition in the provision of metering, but in shifting responsibility for metering from DNSPs to metering co-ordinators appointed by retailers, ironically, it may have distorted competition in markets for residential flexibility services.

However, note that smart meter data alone may not be sufficient for utilities to identify particular types of household. For example, Ausgrid reported that a lack of information about the type of hot water systems that their customers already have was an impediment in identifying the target audience in their hot water load control trials – in one of their trials, one third of the customers who received the offer were subsequently deemed ineligible as they had gas or solar hot water (Ausgrid, 2016). Energy Australia has likewise noted that the available data is insufficient to profile and access suitable end users for participation in its mass market BDR programme (Energy Australia, 2020).

Additional to these issues, household concerns about data privacy, in particular that the data can be used to identify household behaviours or could be exploited by utilities (see Section 6.5.5.3) contribute to reluctance to install smart meters or to participate in DLC programs or VPPs.

Extension of the Consumer Data Right (CDR) to the energy sector is intended to simplify access to energy data and may help to open up opportunities for 3rd parties.

The ACCC favours a “gateway model” for managing data access and storage, under which data is held by multiple data holders (including retailers, AEMO, AER, DELWP), with AEMO playing the role of gatekeeper (ACCC, 2019). While retailers will retain customer and billing information, metering data will be held by AEMO, along with NMI data and details of DER resources (on the DER register). When a household authorises a third party (‘accredited data recipient’) to access their energy data, AEMO identifies the data holder and shares the data as shown in Figure 6-3.



1. The consumer consents to an ADR obtaining their data.
2. The ADR contacts the gateway, seeking to access the consumer's data.
3. The gateway authenticates the ADR using data previously obtained from the ACCC's Register.
4. The gateway identifies which data holder(s) hold the consumer's data and provides transaction details to them.
5. The process of authentication and authorisation occurs in accordance with any requirements in the CDR energy rules. The gateway's role in this process is to be determined.
6. The consumer's data is shared with the ADR via the gateway.

Figure 6-3 High-level transaction flow for energy data access under CDR (ACCC, 2019)

The ACCC is engaged in a stakeholder consultation process regarding their proposed CDR energy rules framework (ACCC, 2020a). Questions raised in submissions include whether there should be a lower level of authentication required for meter data than for personal identifiable information (in order to make it easier for 3rd parties such as aggregators to access energy data) (St Vincent de Paul Society, 2020) and whether retailers should retain the gatekeeping role instead of AEMO (AGL, 2020).

6.4.2 Information and household understanding

The provision of information and households' understanding of available tariffs and other incentive products can pose challenges in achieving uptake and response. Energy Consumers Australia's most recent surveys indicate that 70% of households are confident (7 or higher out of 10) in their ability to make choices about energy products and services, while 60% are confident (answered 7 or higher out of 10 when asked to rate their confidence out of 10) that there is enough easily understood information available for them to make decisions about energy products and services (ECA, 2020). However, consumers have also reported being "consistently confused and overwhelmed" by existing tariff structures and electricity bills, preferring simplicity and ease of management (ECA and Forethought, 2019). Lack of understanding can increase distrust. DR programs to address peak demand also appear to be relatively poorly understood (Strengers, 2010). AGL has observed, for example, that the variable incentives in its Peak Energy Rewards program confused and disengaged participants. Ausgrid found the short offer period may have been a deterrent to participation in its hot water control trials, because survey responses suggested that people needed more time to think about and understand the offer (Ausgrid, 2016).

Van den Broek (2019) identifies 4 types of energy literacy discussed in the literature: energy device literacy (relating to appliances), energy action literacy (relating to the impact of energy-saving behaviours), energy finance literacy and multifaceted energy literacy (encompassing all of the above). In general, studies have found low levels of energy literacy, whichever definition is used, with higher levels amongst those with higher numeracy and education, or with positive environmental attitudes. However, there is little evidence of the impact of energy literacy on energy behaviour, other than energy action literacy. This suggests the importance of specifically increasing households' understanding of how much energy can be saved (or shifted) through changing particular behaviours. This finding is supported by customer views reported by Energy Consumers Australia. "Consumers voiced frustration with their inability to make effective, logical decisions when it came to managing their usage. Solutions which highlight the impact of specific appliances or behaviour on their energy bill were desired to help understand how changes in use translated to changes in their bill. Additional information and tailored consultations to guide energy management were also solutions consumers wanted, in order to understand energy in a more individualised, practical sense." (ECA and Forethought, 2019)

Understanding can also vary within households, which may impede engagement in DR, as found in a trial in the UK in which poor response was attributed to the trial participant not communicating the household participation with the person responsible for household chores (Crawley et al., 2021).

The role of sensory feedback (relating to temperature or other weather conditions, for example) in householders' understanding of their energy use and generation has been explored in the literature (e.g., Martin, 2020) and suggests the need for messaging to build on existing understandings, either as an alternative to digital feedback or in conjunction with it.

Increasing household understanding of how they use (and produce) electricity, and of the electricity market, is important in enabling them to assess incentives and offers and to respond with flexibility. However, the complexity and diversity of some opportunities – such as VPP participation, discussed in Section 4.7 – means that many households lack the time and expertise to compare the costs and benefits of different offers, and may base decisions on other factors such as the type or reputation of the company.

There is a danger that focusing on household understanding puts the onus of responsibility for the energy system on them, rather than on the utilities and institutions that run it. The Opportunity Assessment for E1 Trust Building suggests that "*building energy literacy to improve energy system outcomes is not an effective solution because (i) widespread education campaigns have low efficacy; (ii) it is difficult, if not impossible, to force people to learn things if they are not motivated to do so; and (iii) if the system and processes were simplified, current levels of literacy would be sufficient […so] better designed interfaces with the energy sector are a more pressing need.*" (Russell-Bennett et al., 2021)

There is evidence that DER ownership increases understanding of, and engagement with, household energy use and it is likely that participation in flexibility schemes will similarly increase understanding. An emphasis on education and energy literacy in isolation is unlikely to increase flexibility. However, simplifying the way households interface with the electricity system and providing accessible tools to assist them in making decisions and managing their energy use will increase both their capacity for flexible response and their understanding of their own energy behaviours and the wider energy system.

6.4.3 Communication and recruitment

A commonly reported barrier to recruitment to DR schemes is difficulty in informing prospective participants about the program and communicating the value proposition. For example, recruitment to Zen Ecosystems air-conditioning DLC trial was reported to be difficult due to the challenges of communicating the value proposition and convincing households there would be minimal impact on their comfort (Zen Ecosystems, 2019). Recruitment to new types of incentive products such as VPPs may be more complicated than traditional product sales, as suggested by Simply Energy, because it involves the sale of a technical product and service, rather than a commodity. This can lead to customer confusion and a longer decision-making period.

Identifying effective channels for communication and recruitment is one aspect of this challenge. A variety of strategies are employed for BDR programs; for example, Jemena has trialled a range of means to access potential participants in the PowerChanger program – including via school/community presentations, direct mail, social media, email to Jemena portal users – and has found that social media achieves the best reach, at the lowest cost, but that direct mail is best for community rewards groups.

Recruitment for air-conditioning DLC occurs either via the identification of existing units with DR capability or at the point of sale of new units. In Ausgrid's CoolSaver program, each strategy was employed at different stages. Of 1205 registered potential participants with existing air-conditioning units in 2013/4, 134 had viable units, while recruitment at point of sale was trialled in 2015, and only 11 participants were recruited, short of expectations. Ausgrid points out that promoting DLC-enabled air-conditioner sales through third parties is necessary, while also providing a least-cost solution. The expenses required to achieve the former could undermine this business model, however, for 'it appears that the amount of money such a program can provide to third party facilitators (i.e., retailers and installers) is not sufficient for them to divert from their business as usual activities.' (Ausgrid, 2017). Energy Queensland's *PeakSmart* programme has successfully used point-of-sale recruitment using an upfront discount on air-conditioner purchase.

The language used to describe flexibility schemes is important. Industry terminology (tariffs, kilowatts, network, retailer) is not always understood by non-experts and more 'customer friendly' (price, hours of usage, high energy appliances, bill-provider) may be more effective in communicating with households (Russell-Bennett et al., 2017). A particular example is in the language used to warn participants of potential adverse affects. While there is a need to identify households experiencing vulnerability and exclude from recruitment, particularly for BDR or DLC of air-conditioning, screening is challenging, and safety warnings are necessary but may not be sufficient. For example, "Completely turning off your electricity isn't safe. If you use less than 0.3kWh an hour during the event, you will not be rewarded for any reductions made under that amount" (United Energy's *Summer Saver* BDR scheme). Many households would not understand the meaning of "0.3kWh an hour" and the messaging of "reduce your electricity use – but not beyond a specific value" is confusing.

Timing of messaging around demand response events is important. If the period between notification and the event itself is too short, a response may not be possible, whereas if the period is too long, a consumer may forget or consider the future event to be of little importance. Similarly, if there is a long period between the event and resultant price impact on the household. BDR or CPP events are likely to provide feedback much quicker than a TOU tariff where the impact is in an electricity bill up to 3 months later (Batalla-Bejerano et al., 2020).

Over-communication can also be a barrier. Households feeling bombarded with information are unlikely to engage and may be reluctant to try new opportunities, underlining the importance of quality and focus, rather than the amount or depth of communication.

6.4.4 Digital feedback

Research shows that digital feedback has been effective but the size of the impact varies among studies (Chatzigeorgiou and Andreou, 2021). The impact of HEMS with energy feedback and smart functionality on energy consumption varies widely across a relatively homogeneous (high income, highly educated early technology adopter) households (Nilsson et al., 2018), with low response attributed to lack of interest in HEMS, perceived lack of capacity for demand reduction, 'justifiable' energy use related to comfort trumping environmental concerns, heterogeneity of values between household members and low impact of energy costs on total household expenditure. While the reduction in consumption achievable by providing energy feedback through a dedicated display device, estimated at 3-5% in one meta-analysis (McKerracher and Torriti, 2012), may not be cost-effective, other potential benefits include load-shifting, customer retention, and long-term education and behaviour change. Feedback is a necessary element in household learning about energy use, and real-time feedback, combined with frequent accurate billing is needed for sustained demand reduction (Darby, 2006).

However, there are barriers associated with feedback and how information in communicated via In-Home Displays (IHDs). Some study participants have reported finding IHDs opaque and offering information, such as absolute measures of electricity consumed, kilowatt hours or carbon dioxide emissions that is not useful (Goulden et al., 2014, Hargreaves et al., 2010). Provision of energy or financial data without context, and unrelated to household energy behaviours can fail to engage households, or can even reduce engagement, and there is a need to design feedback devices, platforms and messaging to help households understand the impact of their behaviours and routines on their energy use and costs (Buchanan et al., 2015). Energy, financial and eco-feedback also have to compete with explicit and implicit messaging about utilities as providers of unquestioned demand (Strengers, 2011b).

The perceived complexity of operating a Home Energy Management System may also be seen as an impediment and, for some households in a load-shifting trial observed by Kobus et al. (2013), it resulted in discontinuation of use.

Real-time feedback is commonly found to be more effective than historical feedback (although the meaning of ‘real time’ varies widely. Feedback of appliance-level data disaggregated through non-intrusive appliance monitoring (NILM) methods has not been widely tested (Chatzigeorgiou and Andreou, 2021). ‘Higher involvement interventions’ such as home energy audits and information and education programmes can also achieve energy conservation (Delmas et al., 2013). While some studies have found that monetary feedback is superior to information about energy use, others suggest that it can be counter-productive where it crowds out other motivations or if the financial benefits are small (Delmas et al., 2013), or even results in increased consumption (Buckley, 2020). Gamification appears promising and personal self-set goals for energy conservation has been found successful in a number of trials, but there are conflicting findings regarding the effectiveness of social or peer comparisons (Chatzigeorgiou and Andreou, 2021). Asensio and Delmas (2015) found that environment and health-based messaging (referencing pollution levels, childhood asthma, etc), combined with real-time data feedback motivated greater reductions in electricity use (particularly by households with children), and with greater persistence, than cost-saving information.

Most studies of the impact of feedback on peak clipping and load shifting reported in the literature rely on smart meter data (Batalla-Bejerano et al., 2020). In Australia, AGL’s *Peak Energy Rewards* and United Energy’s *Summer* Saver BDR trials gave near real-time feedback, but most other trials have relied on reporting after the event. Australia’s low smart meter penetration is a major barrier to productive flexibility research as well as to increasing flexibility.

Although the literature contains a lot of feedback studies, there is an identified need for standardisation and increased rigour in the design of trials. In particular, many studies combine a range of feedback strategies making it difficult to draw clear conclusions about the efficacy of each (Chatzigeorgiou and Andreou, 2021). Greater energy savings are reported by studies with small sample sizes and those without control groups or consideration of demographic characteristics (Buckley, 2020).

Importantly, the majority of studies in the literature focus on energy efficiency and conservation, rather than other flexibility outcomes, including load-shifting or export reduction. Batalla-Bejerano et al. (2020) present a systematic review of literature relating to the interaction of smart meter and data feedback with customer energy behaviours. Of 113 articles aimed at understanding demand side response, only 10% addressed peak clipping and 22% load shifting, with the remainder focused on reducing consumption. The three empirical studies on peak clipping and the six on load shifting all showed a positive impact of real-time feedback.

This suggests opportunities for rigorous studies of real-time feedback focused on flexibility responses, rather than energy saving. These are discussed in Section 7.4.3

6.5 Social, cultural and behavioural issues

6.5.1 Flexibility capital

Defined as “the capacity to responsively change patterns of interaction with a system to support the operation of that system”, flexibility capital (FC) is an emerging theme in the social science literature relating to energy flexibility. The FC of a household is determined by a variety of diverse factors including household occupancy, working patterns, building structure, “size of electrical loads, presence or absence of energy storage, culture and religion, life stage, wealth, and so on” (Powells and Fell, 2019). “Having flexibility capital [can entail] both owning technologies and using electrical loads that can be flexibly managed." (Fjellså et al., 2021). Although FC can exist in all types of households, the source it is derived from varies with the income or wealth of the household; in general, more affluent energy users provide FC through ownership of technology (batteries, HEMS, etc.) while less affluent users provide FC through changes to daily routines, at potential cost to their comfort or convenience (Figure 6-4).

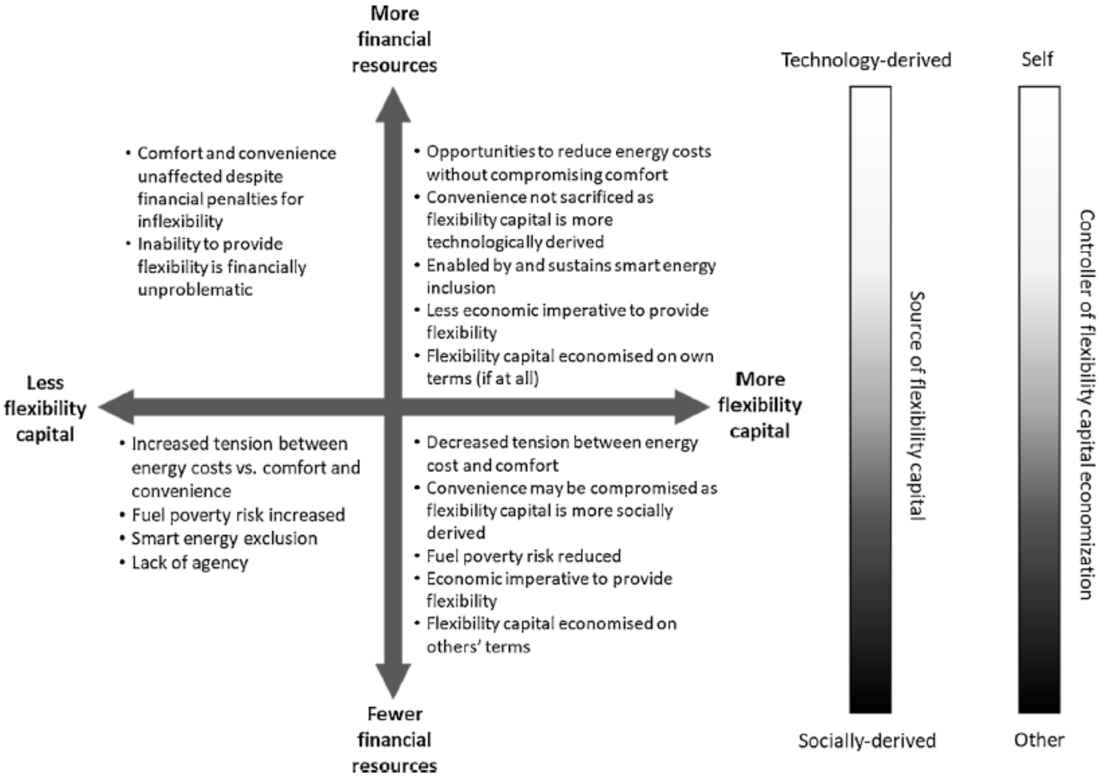


Figure 6-4 Generalized representation of the interaction between flexibility capital and financial resources (affluence) (Powells and Fell, 2019)

Verbong et al. (2013) describe how empirical evidence of the potential of financial stimuli is mixed, and that a variety of variables can influence residential energy consumption, such as daily routines, individual preferences, social relations in a household or the way a technology is embedded in daily practices. Much of the industry discussion around flexibility identifies 'behavioural issues' as a significant barrier to both the uptake and response to tariffs and other incentives. The difficulty of engaging end users is frequently cited, suggesting a perception that energy users have significant untapped resources of FC. While this is true on aggregate, both FC and the daily impact of making it available vary between households and the "work required to deliver flexibility is not evenly and fairly distributed between and within different households" (Fjellså et al., 2021).

Flexibility capital is therefore a useful framing for understanding some of the reasons why households don't always voluntarily take up cost-reflective tariffs or participate in DR schemes as well as why their responses to those tariffs or other incentives is variable.

6.5.2 Household characteristics

A number of studies have looked in detail at the relationship between response to CRTs and household characteristics. For example, Stelmach et al. (2020) reported that price responsiveness was associated with being older, non-white, female and with lower electricity bills. Other factors related to increased price responsiveness included more household members and more smart technologies, and homes with a smaller floor area. An Australian study (Currie, 2020) found that strong responders were less likely to have solar or be home during the day, and more likely to have higher education, a higher income[43], use more electricity, and have more people in the house. They also noted that strong responders made up only 4.1% of households, and that 16.2% were moderate responders, with the remainder having no noticeable response.

6.5.3 Availability of suitable loads

In order to provide flexibility to reduce demand in response to a tariff or other signal, a household must first have either a suitable electrical load of significant size that is being used immediately prior to the price event but is non-essential, or stored energy that can be used to supply their own load and thereby reduce import from, or increase export to, the grid. Prasanna et al. (2018) found that higher consumption households had a higher elasticity because they were more likely to have electric appliances that could be turned down.

Conversely, flexibility to increase demand requires a suitable electrical load of significant size that is not being used but is available, generation that can be curtailed or available storage capacity that can absorb generation or electricity imported from the grid. Secondly, the household must have some means to turn the load on and off, either manually which requires being at home when the DR is needed, or through some form of automation (Section 6.3.2).

The most significant residential loads for supplying flexibility are EHW, HVAC, BESS and EVs. HVAC (space heating and cooling) is temperature-sensitive, while the other significant loads are not, but are subject to lifestyle and social constraints. Without DLC or other enabling technologies, these loads are unlikely to be used to provide flexibility in response to time-varying tariffs. Dishwashing, clothes washing and drying loads are more discretionary than cooking loads, and so likely to be more responsive to tariffs (Caldwell, 2020, Batalla-Bejerano et al., 2020) and are also more commonly used to increase solar self-consumption (Roberts, 2020). However, their impact is relatively small, demonstrating a mismatch between the size of loads and their availability to provide flexibility.

With penetration of BESS and EVs still low, the most likely loads to be used for DLC or BDR in response to a network signal are EHW and HVAC. Many households also don't have an EHW load available to provide flexibility, either because they have gas hot water or their EWH is on a controlled load connection. Most DR schemes use A/C loads, but not all households have large A/C systems. Additionally, the load available for DR is often well below the rated A/C power if, for example, room temperature has stabilised or the unit is operating in an energy saving mode. This can be a barrier to households participating in DR schemes. For example, Energy Queensland's *Peaksmart* air conditioning DLC scheme removed the incentive for aircons of less than 4kW output power because the maximum DR achievable (of the order of 1kW) was insufficient relative to the costs of recruitment, incentivisation, etc. and is now only available for larger aircon systems.

More generally, Jemena's *Power Changers* BDR trial found that DR participants are likely to be lower energy users, while in AGL's *Peak Energy Rewards* BDR programme, the top 20% of participants provided 80% of the DR and while one household achieved a 6.4kW reduction, most managed less than 300W. Participation in DR or electricity flexibility initiatives may be skewed towards more energy-engaged households, including solar households, who are more likely to have installed energy efficient appliances and or be careful with their energy use, and therefore have less available flexibility. While DR schemes with variable incentives are not attractive to these customers, their participation in fixed reward schemes will reduce the value of the achieved DR and therefore available benefits for all participants.

6.5.4 Household preferences and willingness to participate

There are several barriers to the willingness of households to take up tariff and other incentive products. The academic literature observes that energy tends not to be a day-to-day priority for many people and that their engagement is therefore affected by time constraints and competing demands (Rodden et al., 2013) particularly where, for example, ongoing response through load shifting involves planning. "The time and effort needed to seek out, compare offers and choose a plan can seem like it's just not worth the hassle; and

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[43] Note that there is also contradictory evidence on the relationship between flexibility response and household income (Section 6.6)

many consumers fear something will go wrong if they switch" (Bialecki et al., 2018). People may choose to maintain their existing electricity purchase arrangements, and decline to take up alternative offerings, because of "loss and risk aversion, temporal discounting, neglect of opportunity costs, cognitive and choice overload, procrastination and avoidance of inconvenience (around time, effort and 'hassle')" (Stenner et al., 2015). Engagement may be undermined by a perception that action already undertaken, such as to purchase a solar system or efficient appliance, is sufficient to satisfy energy saving objectives. These biases, tensions and constraints can result in what appears to be a disconnect between economic or environmental intentions and daily energy behaviours, or what is referred to as cognitive dissonance (Users TCP and IEA, 2020).

Particularly important to uptake is the perceived value of tariff or incentive products to the household, especially the financial benefits weighed against the expense of time and effort to take up the product, and other considerations. The difficult in realising sufficient value from household flexibility and the uncertainty in this value were discussed in Section 6.2.3. In the context of a perceived lack of value and a bias to the status quo, the recruitment strategy, and in particular whether the program is opt-in (requiring households to actively sign up) or opt-out (automatically enrolling households and giving them the option to exit the program) may be crucial in determining uptake. As discussed in Section 6.2.1, opt-out DR schemes and CRTs consistently achieve higher rates of participation than opt-in, but will also include more households who do not respond flexibly to the signal.

The response of users once in the program may be limited by the same constraints outlined above. Australian and international experience suggests that 'response fatigue' can set in over time (Kim and Shcherbakova, 2011). Studies have shown how households may lose interest in information about their energy use provided through feedback systems and pricing programs (Verkade and Höffken, 2017, Hargreaves et al., 2013, Goulden et al., 2014), at least in part because it is perceived to bear 'little relevance to the ways in which they carry out daily activities' (Strengers, 2011a). AGL's event participation in BDR trials decreased from 63% to 54% of registered participants after 5 events (AGL, 2019); conversely, Energy Australia & Jemena's *Energy Saving reward* program reported no evidence of response fatigue after back-to-back BDR events.

Given the complexity of the market, if the potential cost to households of engagement (in terms of time, inconvenience, required understanding, etc.) and the perceived benefits of simplicity (predictable bills, low risk) are considered remaining on a flat-rate standing retail offer and ejecting participation in flexibility schemes could be seen as a rational approach for households to take.

Levels of ongoing response by participants over time have been found to vary widely in meta-analyses (Parrish et al., 2019). In general these are relatively high in programs that are opt-in (Parrish et al., 2019, Faruqui, 2010) and comparably low in those that automatically enrolled participants (Parrish et al., 2019, Torriti and Leach, 2012, Miller et al., 2013, Miller and Senadeera, 2017) reflecting that the smaller cohorts of households who actively choose to take up a tariff or other incentive product are more likely to stay engaged than those larger cohorts who may be successfully recruited to a default scheme but who do not stay engaged over time (Goulden et al., 2018).

6.5.5 Concerns about impacts

6.5.5.1 Comfort, convenience and safety

There is some indication that people are open to external control of home appliances, provided it does not impact on their comfort (Darby and Pisica, 2013); indeed, automation of electricity demand may be acceptable to the extent that it makes impacts 'invisible' and could enhance comfort and convenience through the use of smart appliances (Shove and Cas, 2018)

However, households' concerns about engaging with incentives to provide demand flexibility are frequently related to an expectation that load shifting and shaving will result in loss of comfort, convenience and safety. Households are particularly concerned about the impacts of changes to energy consumption practices that are perceived as necessary to their thermal comfort, such as heating and cooling of the home, or time dependent, such as lighting, entertainment and cooking (Murtagh et al., 2014, Powells et al., 2014, Buchanan et al., 2016) – particularly the cooking of the evening family meal, which is perceived by some households as the least flexible energy practice (Powells et al., 2014). Studies about user acceptance of managed charging of electric vehicles have also found a concern that the vehicle would not be charged and available for use when it is required (Darby and Pisica, 2013, Bailey and Axsen, 2015, Parsons et al., 2014, Delmonte et al., 2020). There are also concerns that the use of smart appliances to shift loads could be accompanied by risks of flooding, fire or noise, particularly in relation to the use of washing machines when householders are not home or asleep during the night (Balta-Ozkan et al., 2014, Darby and Pisica, 2013), or by effects on food quality and safety in relation to smart refrigerators and freezers (Mert et al., 2008).

Christensen et al. (2018) explored priorities of 956 people for cost, comfort and environmental considerations for a range of energy services, using multiple pairwise decisions to compare criteria (cost, comfort, environment…) and alternative actions (e.g. shift dishwasher use vs shift washing machine use) to derive a hierarchy of importance: "air temperature, money, shower temperature, shower length, having clean clothes, carbon, and finally having clean dishes" which sheds some light on which aspects of comfort and convenience might be traded for financial or even carbon benefits.

6.5.5.2 Loss of control

Given that engagement with time-based tariffs and other incentive products is likely to depend on automation and control technology where the advance notice period of the DR signal is short, household acceptance of these offers is intertwined with their acceptance of such technology (Cappers et al., 2012). Households in Australia and elsewhere have expressed concerns about loss of control through smart appliances, DLC or TOU tariffs (Paetz et al., 2012, Rodden et al., 2013, Darby and Pisica, 2013, Fell et al., 2014, Mert et al., 2008). Reviews of learnings from smart grid projects in Europe have found that users are 'afraid of losing control of devices in their own household and sceptical about new rates and applications' (Giordano et al., 2013). Similarly, AGL reports that recruitment to the 'Managed for You' aircon and EV DLC part of its Peak Energy Rewards trial was 'more challenging as the customer was required to cede control of their device' than in the behavioural DR component of the trial (AGL, 2018). It is important to note here is that concerns about loss of control are likely to vary depending on the appliance in question and other factors such as the occupancy status of the home, such as whether residents are at home, out, asleep or away on holidays (Buchanan et al., 2016).

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

6.5.5.3 Data security and privacy

Concerns about data security and privacy may be a further barrier to household engagement in tariff and other incentive products (Balta-Ozkan et al., 2013, Buchanan et al., 2016, Fell et al., 2014). These are related in particular to the potential for household behavioural patterns, including occupancy status, religious practices and so on, to be identifiable from smart meter data (McKenna et al., 2012). Further security risks relate to deployment of smart plugs, HEMS and other IoT devices. Many commonly available smart plugs and appliances, require internet connection but lack secure authentication protocols, and so may enable malicious access behind a household firewall and compromise household privacy (Shaw-Williams, 2020).

Data privacy is also a primary reservation voiced by households about the automation of their household loads in DLC programs, and in this respect local automation, or householders programming their own smart appliances to respond to TOU tariffs and other signals, may be more appealing to some households because they perceive that less data would be available to utilities (Paetz et al., 2012). There is also evidence that the unwillingness of households to make their energy data available to utilities is not associated with an unwillingness to share it per se, but related directly to a perception that utilities might exploit data (Rodden et al., 2013). Moreover, interconnection of devices with HEMS and other platforms increases the risk of accumulation of multiple types of data, which may cause concern in light of trends towards profiling customers through mining data lakes collected from multiple sources (Manwaring et al., 2021).

6.5.5.4 Distrust

Many of the households' reservations outlined above about engaging with tariff and other incentive products appear to be influenced by a general, existing distrust in energy suppliers. While some households have greater distrust of retailers than DNSPs, others apply it to all energy companies (Roberts, 2020), so the likely impact of market entry of aggregators and third parties on distrust is unclear. This distrust has been found in international studies to impede willingness to participate in DR (Fell et al., 2014, Buchanan et al., 2016, Paetz et al., 2012, Rodden et al., 2013, Balta-Ozkan et al., 2014, Lopes et al., 2016).

This distrust may be related to a suspicion that energy companies act only in their own interests (Fell et al., 2014, Murtagh et al., 2014), that the only beneficiaries of tariffs and other incentive products would be the industry actors (Throndsen and Ryghaug, 2015) that their own interests in reducing electricity bills could not be served by the same initiatives that generate profit for retailers (Buchanan et al., 2016, Fell et al., 2014). Conversely, there has been less opposition to smart metering where it is perceived to be for 'public benefit' rather that for 'commercial purposes' (Naus et al., 2015) and higher participation rates in DR have been recorded where utility-customer relations are good (Stromback et al., 2011). In December 2020, only 38% of Australian households said they are confident the electricity market is working in their interests (ECA, 2020). While this confidence is at an all-time high and has increased from 21% in December 2017, it certainly shows a low level of trust in the market.

6.5.6 Routines and social dynamics

A further limitation on the capacity to provide demand flexibility through tariffs and other incentive products, or flexibility capital as discussed above, is associated with household routines and social dynamics. Providing flexibility can be difficult for households, especially in response to real-time or other variable tariffs, which are perceived to be too unpredictable and require too much effort to adapt to (Paetz et al., 2012, Darby and Pisica, 2013). This is consistent with the international academic literature that observes that energy consumption practices are embedded in temporal and spatial structures that may not be as flexible and adjustable as is sometimes suggested. In other words, 'people are not free to re-arrange the timing of energy demand at will […] daily and weekly schedules are defined by collective social and temporal rhythms, not by individual choice' (Shove and Cas, 2018). Respondents in studies have pointed out their electricity is high at certain times 'for a reason' (Fell et al., 2014) and that is 'not within their control to change' (Murtagh et al., 2014, Rodden et al., 2013).

Studies have found that households' ability and willingness to respond to higher prices changes throughout the day, and even where the tariff is the same throughout the year (many aren't), households' ability and willingness to respond changes throughout the year (Batalla-Bejerano et al., 2020, Caldwell, 2020, Andruszkiewicz et al., 2020). Furthermore, not all households are equally capable of load shifting due to the social dynamics associated with energy consumption practices (Christensen and Friis, 2016). Some households, such as those with children, are found to be particularly inflexible (Nicholls and Strengers, 2015).

Indeed, peak demand times are not just responses to economic signals (Strengers, 2018) but are a product of the compression of multiple social practices into a specific time period (evenings, which occurs more with families with children) or as the intensity of energy associated with a specific practice (air-conditioned cooling). Response to a price signal therefore depends on whether the price signal temporarily disrupts or permanently shifts everyday routines. Thus, households are likely to be more responsive to tariffs like CPPs, which can convey a sense of urgency and importance and, unlike TOU tariffs, do not regularly disrupt routines. This view is supported by the fact that information-only trials of CPP, which do not include a price signal, have resulted in a greater response than a TOU tariff in the same trial.

The imperative to shift loads can make uneven demands on different members of households, particularly ‘flexibility woman’ (Johnson, 2020), given that practices in the home are often shaped at least in part by gender roles (Hargreaves et al., 2010, Ehrnberger et al., 2013) and generate conflicts (Nyborg 2015), an example of the ‘variagated and uneven consumer outcomes’ of flexibility (Calver and Simcock, 2021). For example, in a load shifting trial ‘almost nobody believed that coordination with other household members would work in the long run’ because it constitutes extra work (Paetz et al., 2012). These limits to household demand flexibility and indirect effects of initiatives to incentivise flexibility may therefore pose a barrier to their success if these dynamics are not taken into account in program design (Throndsen and Ryghaug, 2015).

6.5.7 External factors

A household’s ability to respond to incentives (and its likelihood of taking up an incentive offer) is dependent on whether the region being assessed is in recession or enjoying a growth phase, and whether it is a cold climate or warm climate area, and indeed on the season (Currie, 2020) or prevailing weather conditions (Batalla-Bejerano et al., 2020). The impact of Covid-19 on household energy use is a case in point (IEA, 2021).

6.5.8 Implications for automated vs behavioural demand response

The concerns about a loss of control, data security and privacy, and distrust in the energy sector outlined above suggest that users may not accept demand flexibility programs that involve automation of household loads. On the other hand, the limitations that many households face in the provision of flexibility that are associated with lack of flexibility capital and the constraints related to household routines and social dynamics, also discussed in this section, mean that automation may enable households to participate where they would otherwise not be able to, or reduce inconvenience and disruption of manual changes to their energy practices, by ‘tak[ing] over some of the planning activities otherwise left to the householder’ (Verkade and Höffken, 2017, p. 40) and allowing them to ‘set it and forget it’ (Cappers et al., 2012). There is evidence that people may be open to automation (Buchanan et al., 2016, Goulden et al., 2014, Fell et al., 2014, Strengers, 2010) or even prefer it (Friis and Haunstrup Christensen, 2016) – but only provided that it involves minimal changes to their household practices and associated sacrifice of comfort or convenience. The literature also indicates that willingness to give up some control through the automation of household loads is further dependent on a sense of trust in the program provider (Buchanan et al., 2016, Stenner et al., 2017, Paetz et al., 2012, Goulden et al., 2014, Fell et al., 2014, Rodden et al., 2013) and a sense of autonomous, voluntary engagement and choice about the parameters of their participation (Buchanan et al., 2016, Fell, 2016). The granting of a ‘social licence’ to automate household loads may be related to the degree to which households “effectively feel part of new energy systems designed to serve them” (Adams et al., 2021).

6.6 Households experiencing vulnerability

Rather than vulnerable households being a distinct identifiable group, vulnerability can affect anyone, and does affect a large proportion of Australians at some point in their lives because of illness, loss, natural disaster, bereavement or other life events. 1 in 6 Australian women have experienced physical and/or violence by a current or previous partner, 1 in 5 Australians have a disability, 2 in 3 experience some kind of financial stress, 30% have savings of less than a month’s income, 44% have low literacy, and 1 in 5 speak a language other than English at home (Consumer Policy Research Centre, 2020). AGL’s analysis of their 2.4million customer accounts found that energy-related financial hardship is often related to some combination of low income, being aged 30-49 (so-called ‘family formation’ cohort), large household size and higher than average consumption (Nelson et al., 2019, Simshauser and Nelson, 2014).

Households experiencing vulnerability are likely to experience individual states that cause their vulnerability rather than characteristics or demographics that make them vulnerable. Individual states can affect anyone, with changes in health, grief, mood, fear, or motivation likely to impact customers’ vulnerability. External conditions also play a role, and these can be out of the household’s hands.

There is a range of issues that disproportionately affect the ability of households experiencing vulnerability to take up and respond to flexibility incentives. Individual characteristics include low-income, low-education, old age, single-parent, Indigenous. Individual states include poor health, grief, mood, stress, fear, motivation, transitions (e.g. moving between houses, marriage break up). External conditions include discrimination, repression, stigmatization, distribution of resources (e.g. market choice), physical housing (e.g. insulation, heating/cooling requirements), extreme climate, power imbalance in the marketplace (Baker et al., 2016).

Low income households are more likely to be older and to live in apartments or in older, uninsulated houses and more likely to have older wall- or window-mounted A/C, portable A/C and electric or gas room heaters, and less likely to have ducted A/C (Goldsworthy and Poruschi, 2019), but there is a little understanding of the particular energy consumption and load profiles of vulnerable households. AGL identified the heterogeneity of household consumption and income, and particularly that 4% of households have low incomes and electricity consumption significantly above average. They recommended redesign of state concession frameworks to include variable payments related to consumption (Nelson et al., 2019)

Calver and Simcock (2021) explore the academic literature on DR through an energy justice lens, identifying both opportunities and risks in DR including for the sustainability, affordability, availability and intergenerational equity of energy supply. There is a lack of clarity about the impacts of TOU tariffs on households vulnerable to energy poverty. Some studies show benefits for these households in line with those for other customers, while a recent American study of 7,500 households found that all households participating in a TOU tariff trial showed bill increase, with the greatest increases faced by households with elderly and disabled occupants (White and Sintov, 2019). There is little research on the distributional outcomes of different types (structures, periods, rates) of TOU tariffs or other financial incentives and their particular impact on vulnerable households. As a proportion of income, low-income households typically spend twice as much on electricity as high-income households (Simshauser and Nelson, 2014), so even small absolute changes to bills can have a significant impact. There is also a risk that lack of flexibility capital can increase households' vulnerability to energy poverty under DR schemes and cost-reflective tariffs and these impacts should be considered in design of flexibility incentives.

There are conflicting findings on the relationship between household income and responsiveness to CRTs. Prasanna et al. (2018), Pereira Uhr et al. (2019) and Lin and Wang (2020) found that lower income households were more responsive than higher income households (because their electricity bills make a greater proportion of their income, and their housing stock may provide less protection to temperature changes). In contrast, Currie (2020) found greater peak load reduction in response to TasNetworks' *Empowering You* TOU tariff trial (2016 – 2018) from households with high energy use and wealthier households, while Burns and Mountain (2021) found that low-income households do not respond at all to TOU pricing. Reasons for the latter could include: inefficient appliances, higher daytime occupancy, lower shiftable loads and social factors. Further, Schulte (2016) and Moshiri (2015) found that the response to energy price changes was stronger for high-income households, possibly because they had more discretionary appliances that could be turned down or off.

As discussed in Section 6.3.2, financial constraints can affect households' ability to make investments in DER (including PV and BESS) or in monitoring or control technology. Limited or unreliable access to smart phones can also restrict access to monitoring technologies (Nicholls et al., 2017). Moreover, 11.5% of Australians do not have access to the internet at home (Degenhard, 2021), which also has implications for access to enabling technologies. Over time, there may be an ongoing trend for high income households to show greater response, as more of them install enabling technologies, such as batteries.

Living in rented accommodation adds additional barriers to DER, including split incentive issues which might be addressed by changes to tenancy laws, according to Nelson et al. (2019), as does living in an apartment rather than a house (Roberts et al., 2019). Only about 12% of NSW households in receipt of energy rebates have rooftop solar, compared to around 21% of all households (APVI, 2020). The penetration of smart meters is also lower in apartments than houses, restricting access to cost-reflective tariffs and demand response schemes, while apartments typically have smaller water tanks, reducing their shiftable loads.

Some low-income households have low energy use and are therefore less likely to benefit from switching retailers and tariffs than those with higher energy use. Security deposits requested by retailers for customers with no or poor credit history present an additional barrier to switching (Queensland Council of Social Service et al., 2016). Low energy users are also less able to respond to flexibility incentives.

Conversely, some households have large and/or non-negotiable loads, because of poor thermal performance of housing, lack of capital to invest in energy-efficient appliances, or constraints of routine or social dynamics (Section 6.5.6), which result in high electricity bills and increased household vulnerability. Elderly or unwell household members may restrict flexibility of A/C use, or flexible response by such households may endanger household members. Although it is clear that there is heterogeneity of load profiles across households experiencing vulnerability (Trotta et al., 2020), the characteristics of these profiles in the Australian context are not well understood.

The complexity of electricity market structures and pricing, and information asymmetries can also disproportionately affect households experiencing vulnerability, and can even trigger or exacerbate that vulnerability (Consumer Policy Research Centre, 2020). The perception that cost-reflective tariffs disproportionately affect low-income households has implications beyond those households in creating political barriers to CRT implementation (Matisoff et al., 2020).

Given access and suitable information, low-income households may be more likely to use smart home technologies. However, these technologies can increase energy use and bills if their use is driven wholly by comfort and convenience (Nicholls et al., 2017).

Calver and Simcock (2021) identified the need for greater understanding of the barriers faced by low-income and other households in accessing and using enabling technologies, and how these could be overcome, as well as of the impact of increased flexibility household well-being of different types of households and ability to use necessary energy services when required, particularly focusing on comparing impacts across different householder types with varying energy needs.

6.7 Delivering net system benefits

As shown in Figure 1-1, the ‘End Results’ of electricity flexibility responses can be divided into changes to income for electricity utilities (including aggregators), impacts on household bills, broader system impacts and non-financial impacts. Although the focus of this part of the Opportunity Assessment is on how tariffs and other incentives deliver net system benefits, this section first briefly discusses the extent to which the other impacts are being addressed by current research and industry development activities.

The impacts of different tariffs on the **income of TNSPs, DNSPs, retailers and aggregators** are currently assessed as part of their standard tariff development processes (the Tariff Structure Statements (TSSs) and Pricing Proposals); and are not relevant for aggregators. The impact of different tariffs on **household bills** is also assessed to some extent through the TSS and Pricing Proposals processes but is limited by the lack of data that represents the diversity of customer loads.

The impacts of other flexibility incentives are incorporated to different degrees into these same processes, but generally only to the extent that they have an obvious and significant impact on household load/generation profiles. These sorts of data, that not only take into consideration the possible impacts of different tariffs and other incentives, but also how they interact, are in short supply, and are possibly non-existent. Although electricity DNSPs and retailers may have limited access to such data, it is not available to other stakeholders, including aggregators, government regulators, community groups and research institutions. Such data are of course required to obtain a proper understanding of the impacts of tariffs and other incentives, and are therefore critical to optimising their development.

This unavailability of household data is a significant gap in current research that needs to be addressed, see Section (see Section 7.6.1). As discussed below, there also is a need to develop sophisticated modelling approaches that can take into account the complex interactions between different tariffs/incentives and household behaviour.

The **non-financial impacts** of different tariffs and other incentives include increased renewable generation, reduced greenhouse gas emissions and broader social benefits such as employment creation, reduced particulate pollution, reduced environmental impacts (for example from open cut coal mines), etc.

For each of these impacts there are well established assessment approaches. Apart from energy reliability for households, they are based on changes to the relative use of renewable energy and fossil fuel-based generation. It is through such changes, as well as changes to load and distributed generation profiles, that tariffs and other incentives also deliver net system benefits. More specifically, the net system benefits are the result of changes to spot prices, changes to network peaks, changes to solar export peaks and changes to the shape of the system-level load profile (specifically minimum system-level demand and ramp rate).

6.7.1 Types of system benefits

This section discusses the degree to which current research and industry development activities

i) assess how well tariffs and other incentives result in net system benefits, and

ii) focus on the optimisation of their ability to deliver these benefits.

The system benefits that could potentially be provided by tariffs and other incentives influencing household electricity flexibility are:

i) reduced spot prices,

ii) a smoother system-level load profile,

iii) reduced demand during network peaks, and

iv) voltage regulation.

Any assessment of the ability of tariffs and other incentives to deliver these system benefits ultimately depends on the approaches used to determine how they affect the household load/generation profile. Of course, voltage regulation can also occur through direct technical control (such as the use of Volt-Watt or Volt-VAR inverter modes), however such technical control is not the focus of this OA. The exceptions to this are VPPs that target frequency control by providing FCAS services, and these are discussed in Section 4.7.

Assessing how changes to the household load/generation profile result in system-level impacts is very complex but, surprisingly often, is only performed at a very superficial level. For example, a single load profile may be used to represent the diversity of all household loads (AECOM, 2019, AEMO, 2021b) or a single day may be used to represent all the days of the year. Apart from the extreme diversity to be found in household load profiles, both between households and even throughout the year for a single household, additional variation occurs when solar PV, electric vehicles and the various demand response options are added. This is further complicated when technologies such as BTM batteries are used because they respond to the resultant mixture of altered load profile and solar PV generation – and create an entirely new profile. Given the future-focus of RACE for 2030, and in fact any planning exercise, extrapolating from current demand profiles to future profiles is critical.

AEMO's Integrated System Plan most likely uses the most advanced methodology to generate future load/generation profiles in Australia. It uses a capacity expansion model to develop scenarios of the network and generation capacity required to meet demand over time. This is based on regional and subregional topologies, where SA, Tas and Vic all have a single sub-region, Qld has three and NSW has four. The electricity demand for each subregion is made up of three components: Underlying demand excluding large industrial loads (meaning all residential and commercial loads combined), DER forecasts, and large industrial loads. These are aggregated into a single demand profile for the sub-region (AEMO, 2021b). To create the residential forecasts, AEMO applies a growth model that includes estimates for the impacts of electric appliance uptake, energy efficiency savings, changes in retail prices, climate change impacts, gas-to-electricity switching, and what they call 'the rooftop PV rebound effect'[44]. However, the outputs of all this are simple annual consumption values. A single half hourly demand profile is then generated for each year for

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[44] This assumes that electricity use by PV households will increase by 20% of the total PV generation because the PV electricity is cheaper. Confusingly, they also assume a general price elasticity of zero for reductions in retail tariffs (meaning lower retail tariffs do not increase electricity use). Also, anecdotally there are reports of households oversizing PV systems to meet future loads such as EVs, which creates a 'reverse rebound effect' where higher loads increase PV generation (rather than PV generation increasing loads).

each region (i.e. State/Territory) by applying these values to a single reference year to ensure that the new profiles hit specified targets for maximum summer demand, maximum winter demand, minimum demand and annual energy use. Price elasticity is included only for weather-sensitive loads with a value of -0.1 for price increase (i.e., for a 10% increase in price, demand will decrease by 1%), and a value of zero for price decrease. The impacts of electric vehicles, solar PV (using a single generation profile with increasing contributions from west-facing PV over time) and batteries are then added to this load profile. The battery operation is based on a mix of load-following[45] and optimisation in response to a TOU tariff, resulting in an increase in electricity use due to losses (AEMO, 2020b).

Although this approach is most likely the most sophisticated in Australia to-date, and is understandable given that the ISP is focused on large-scale generation, it does highlight some limitations that could present opportunities for RACE projects. In summary, it:

1. uses a single residential load profile for each region,
2. allows for only very limited interactions between different technologies,
3. does not appear to allow for any net generation at the distribution level,
4. does not allow for the impacts of particular tariffs or incentives (apart from the impact of a TOU tariff on batteries which seems to have little effect),
5. assumes either no price elasticity or very limited unidirectional elasticity for weather-dependent loads.

Thus, even at the aggregated level, it likely underestimates the impacts of synergistic interactions between technologies and tariffs, especially given the limited price elasticity that has been assumed. Such responses could include step-changes to the uptake of particular technologies such as batteries, which as above, would result in an entirely new profile. Of course, this sort of modelling is not useful when analysing impacts at the LV level (and is not intended to be) but given the potentially significant impacts of DER at the LV level, similar effort should be applied to modelling at this level.

Although the My Energy Marketplace dataset will provide valuable data, there is still a need for real data on the variation of price elasticity with different aspects of household flexibility capital, such as income, access to technology and social and behavioural constraints, and on the relationship between tariffs, technology uptake and elasticity. There is also a need for modelling of the synergistic impact of DER on aggregated load profiles and the implications for tariff design and system impacts. These are discussed further in Section 7.6.3.

6.7.2 Impacts on spot prices

In brief, there don’t appear to be any research or industry development projects that specifically evaluate the efficiency and effectiveness of tariff and incentive products to reduce spot prices. The following summarises the main approaches being used to assess the impact on spot prices of changes to demand seen at the wholesale level.

Changes to the amount of load seen by the wholesale generation market can change the realised spot price through what is known as the merit order effect. In its simplest form, this occurs because, for example, a reduction in demand moves the realised dispatch price down the bid price stack. Where it moves from one price band to a lower one, the dispatch price will be reduced (Antweiler and Muesgens, 2021). However, calculating the actual impact on spot prices is very difficult because changes to the load profile don’t just move bids up and down the dispatch order, they change how generators ultimately decide to bid (and so alter the dispatch stack itself), and over the longer term may change the generation and transmission capacity that is built. The main approaches used to assess the impact of the merit order effect are listed below, some of which may be combined to achieve a more accurate outcome.

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[45] Load-following means that the battery will soak up excess solar generation that would otherwise be exported to the grid and, until it is empty, will use this to avoid electricity being drawn from the grid.

1. **Regression analysis** uses historical price and generation data to estimate the change in spot price (the dependent variable) over a given period, driven by a particular variable being assessed - such as changes to demand or additional renewable energy generation (the independent variables) (Csereklyei et al., 2019, Sirin and Yilmaz, 2020). Because this method is based on analysis of historical data, it can't be used to assess the impact of future events, such as changes to the shapes of demand profiles driven by DER. A variation on this approach is the use of a supply curve model that uses the historically available generators and their marginal generation cost based on estimated averaged marginal fuel costs (the merit order) to estimate the impact of changes to various parameters on the final dispatch price (Mills et al., 2021).
2. **Operational or dispatch models** use historical load and price data and simulate generator dispatch based on the short run marginal cost of generation that is assumed to be available. These can be divided into economic dispatch models (based on SRMC) and unit commitment models (which include economic optimisation of individual plant i.e. when they should be turned on and off). These are both types of optimisation model (operation of the system at least-cost), but there are also agent-based models where particular plant will bid into the market / operate in order to maximise their own profit (so instead of bidding according to their SRMC they would use some sort of strategy-based bidding). Unlike Nempy (below) these approaches don't use the actual dispatch stacks for each dispatch period, only what the model thinks they should have been if all generators were available and were bidding according to economically rational bidding behaviour. Thus, they do not take into account other influences (such as market speculation, generator outages, ramp rate constraints, interconnector constraints, FCAS requirements etc.) that would affect generator operation. They also do not consider the longer-term impacts of changes to demand on generator and transmission line construction.
3. **Nempy**[46] has recently been developed at UNSW and reverse engineers the NEMDE[47] (that AEMO uses to solve the dispatch stack/order for every 5 min period). This can be used to work out how the spot price moves up/down the dispatch order assuming that the inputs of each bid stack interval (the influences listed above) are fixed. Although this takes into account the generators that were actually available in each dispatch period and the other influences on the operation, it doesn't allow for the fact that the different levels of demand may change how generators bid, nor the longer-term impacts of changes to demand on generator and transmission line construction.
4. **Capacity expansion models** will, under a given set of assumptions, determine not only the generation that should be dispatched, but the new generation and transmission capacity that should be built, and the generation that should be retired, to meet demand at least-cost over a set time period (e.g., out to 2050). They undertake these calculations based on a fixed demand profile over a full year, and one of the outputs is the marginal spot price for each dispatch interval (e.g., 1 hour). Thus, changes to the underlying load profile will change what is built, how it is operated, how much generation needs to be dispatched in each interval, and therefore the marginal spot price. This approach assumes a perfectly efficient market and does not take into account the influences listed above. It solves for the lowest cost outcome in a more abstracted generalised way and is suitable for long term trends in dispatch and build capacity and so provides a lower bound on costs. In contrast, the dispatch models will provide the real-time dynamic market that is reflected in the bid stack, providing more of an equilibrium outcome that takes account of the other influences, and so result in a higher spot price. AEMO's Integrated System Plan modelling is performed using a capacity expansion approach, and such models are also used by Monash University (Melbourne/Monash University Energy Integration Lab; MUREIL)[48], the Victoria Energy Policy Centre (National Energy Market, Capacity Expansion and Energy Dispatch)[49], the University of Qld

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[46] By Nick Gorman, SPREE, available at https://github.com/UNSW-CEEM/nempy
[47] National Electricity Market Dispatch Engine
[48] https://www.energy-transition-hub.org/project/multi-model-energy-transition-scenarios-towards-zero-emissions
[49] https://www.vepc.org.au

(Australian National Electricity Market model; ANEM)[50] and ITP Renewables (OpenCEM)[51]. They are slightly different to each other and each has its pros and cons, but all may be suitable for assessing the impact of changes to system-level demand on spot prices.

5. **PLEXOS**[52] is commercially available software platform that can be used to simulate the NEM. It includes a capacity expansion component but then also applies an operational model to derive spot prices. It is the most accurate and detailed of all the models but is not favoured by research organisations because it is not open source and so has limited potential for modification/refinement and collaboration.

Of course, there are variations on all these approaches, which are more or less favoured depending on the modeler's expertise, including the use of Nash-Cournot equilibrium (which uses a parabolic curve instead of a linear curve for dispatch), bi-level models (which have top level optimisation where everyone sets bids and then a bottom level optimisation that solves an optimal dispatch, and so introduces a gaming component), as well as least squares regression analysis, econometric regression analysis, equilibrium models, empirical dispatch, deterministic, etc.

In terms of options for RACE 2030 research projects, it is likely that some combination of capacity expansion models and dispatch models should be used to assess the short, medium and longer-term impacts of changes to load profiles on spot prices. Short-term assessments can use the existing and committed build and should be consistent with the aggregated forecasts used for network impacts discussed in Section 6.7.4. The medium to longer-term assessments would require the use of a capacity expansion model, the outputs of which would be inputs into dispatch models. The medium-term assessments (out to 5 years) should also be consistent with the aggregated forecasts used for network impacts. Capacity expansion and unit commitment models are mixed integer linear programs (which don't produce spot prices so readily), whereas economic dispatch models use a linear program which provides spot prices (also called marginal and shadow prices) for the supply of electricity within given constraints, when supply equals demand, which is how NEMDE works. All these approaches have problems with detailed network constraints, which will depend on the configuration of the network, and the UQ ANEM model could be used for that although, being more complex, it takes longer to run. There is also a need to develop validation techniques for all these models.

6.7.3 Changes to minimum demand and ramp-rates in the system-level load profile

Again, there don't appear to be any research or industry development projects that specifically evaluate the efficiency and effectiveness of tariff and incentive products to increase minimum demand or to reduce ramp rates in the system-level load profile. As shown in Figure 6-5, increasing levels of solar generation in particular, and of wind to a lesser degree, are changing the shape of the system-level load profile, creating the infamous 'duck curve'. The reduction in minimum demand reduces the amount of synchronous generation that is available to provide inertia (which helps to maintain frequency) and system strength (which helps to maintain voltage), and act as operating reserve (required to maintain system security). The increasing ramp rate means that generators find it more difficult to change their output rapidly enough to meet demand (AEMO, 2020c). AEMO regularly assesses the level of minimum demand, and there is a significant amount of work being undertaken under the P2025 workplans to develop approaches for assessing the consequences and financial impacts of reduced minimum demand and increasing ramp rate (AEMC, 2021). The increasing ramp rate means that generators find it more difficult to change their output rapidly enough and so meet demand (AEMO, 2020c). As these methods are developed, they should be used in RACE projects to investigate the impacts that tariffs and other incentives have on minimum demand and ramp rates through changes to system-level load profiles.

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[50] https://economics.uq.edu.au/research/research-centres-and-groups/energy-economics-and-management-group/models
[51] http://www.opencem.org.au
[52] https://energyexemplar.com/solutions/plexos/

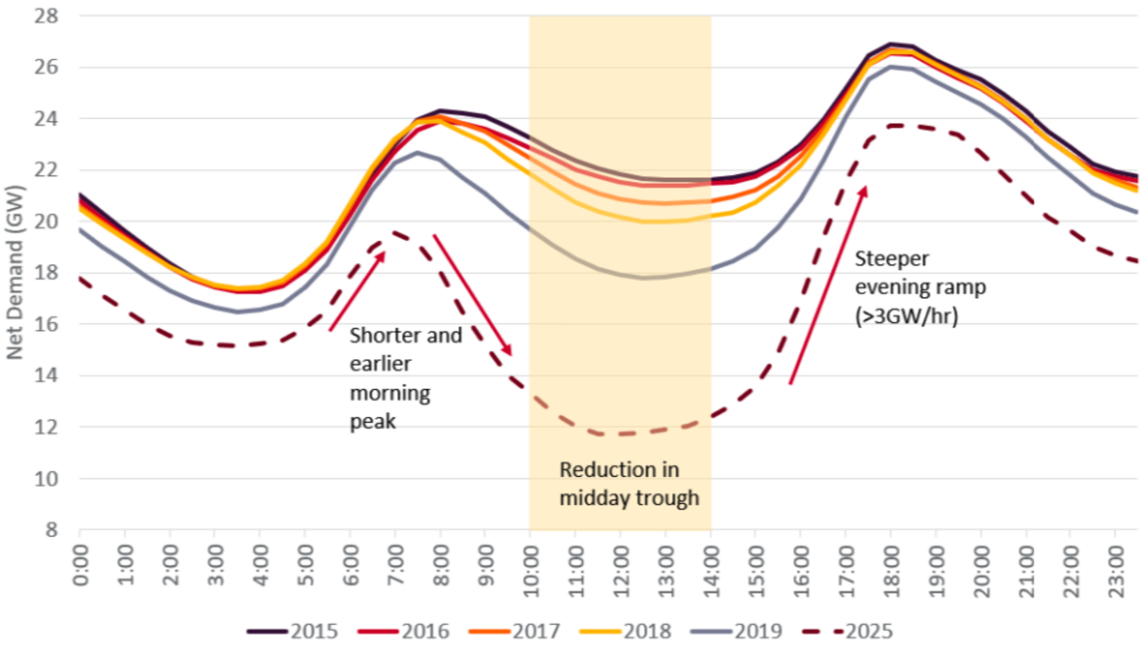

Figure 6-5. NEM average winter net demand curves, actual 2015-19 and projected in 2025 under Draft 2020 Central generation build (AEMO, 2020c)

6.7.4 Impacts on demand during network peaks

There appear to be very few research or industry development projects that specifically evaluate the efficiency and effectiveness of tariff and incentive products to reduce demand during network peaks. In 2015 ISF/UTS undertook an ARENA-funded project that assessed the feasibility of local network charges and Local Generation Network Credits designed to encourage distributed generation to support the network, which led to an unsuccessful Rule Change proposal (Rutovitz et al., 2016). More recently there has been an emerging interest in the use of community batteries to soak up excess residential solar which is then fed back to the grid in the evenings to provide network support. Although these trials include tariff design, the focus is on the impacts on customers using the battery, including the use of local use of system charges, not on how these tariffs may affect the provision of network support. A report by ANU assessed the impact of different tariffs being applied to the community battery itself but didn't quantify the impacts on network costs (Shaw et al., 2020). Ultimately, it is likely that such batteries are best placed to provide network support through direct control rather than through tariffs.

As discussed above, the impact of tariff and other incentives on network augmentation costs is driven by their impact on the load profile, specifically the periods of peak demand as seen by the network. The most sophisticated methods used to determine the impacts of load profile changes on network asset costs are used by the DNSPs as part of their Distribution Annual Planning Reports (DAPRs).[53] Although these are applied only over the five-year regulatory period, modified versions of their approach could be applied to longer time horizons. The key difference here, compared to assessing the impacts of changes to load profiles on spot prices, is that network impacts are site-specific. They are assessed by DNSPs at the distribution feeder level, the zone substation level and the sub-transmission substation level (and for Ausgrid, at the transmission level). This makes any assessment of the impacts of household electricity flexibility, which itself occurs to different degrees in different parts of the LV network, much more complex.

DNSPs use LRMC approaches to correlate the design and pricing of tariffs with the capital expenditure (capex) of the network. These approaches can also be used to assess the financial impacts of changes to the sizes of demand peaks (driven by tariffs or other incentives). There are several ways to calculate LRMC.

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[53] For example, see pages 12-20 of Ausgrid's 'Distribution and Transmission Annual Planning Report' December 2020.

These include Average Incremental Cost (AIC), Turvey Incremental Cost (TIC) and Long Run Incremental Cost (LRIC). The AIC approach is the most common method used by DNSPs and essentially involves averaging the present value of the augmentation costs (both capital[54] and marginal operational) to meet the peak loads (assuming a given probability of exceedance) over a given timeframe then dividing these by the incremental load. The main disadvantage of this approach is that it doesn't allocate an increment in demand with the resultant change in cost, which can be very relevant when looking at the impact of changes to demand profiles in particular years because network costs can be very lumpy. The TIC approach is similar to the AIC approach except that the present value of the augmentation costs is calculated for both the base case and an incremental but permanent change. The LRMC is calculated by dividing the increase in costs by the increment in demand. Because this approach focuses on the cost implications of a small increment in demand it is more likely to capture the lumpy investment profile (although only if the demand increment spans that change in investment). The LRIC approach is similar to the AIC approach and is used in the UK but can be complex and costly to perform.

There is a need to develop a common approach to assessing these sorts of impacts at each of the three levels (distribution feeder, zone substation and sub-transmission substation) that is consistent with the approaches used by DNSPs.

6.7.5 Impacts on voltage

Tariffs and incentive products impact voltage by changing the load seen by the network and through solar exports (higher loads decrease voltage and solar/battery exports increase it).[55] Although a significant amount of work is being undertaken on the impacts of changes to loads and exports on network voltage, and how to ameliorate these impacts, there is little focus on how this is influenced by tariffs and incentive products.

The main current area of interest is the impact of solar exports on voltage in the distribution network, and this provides a useful case study for these types of impacts. PV export peaks occur when the ratio of PV export to load at any particular time is greatest, which in Australia occurs in Spring. They are very location-specific, occurring in locations with high solar penetration and with residential load profiles (which are generally lower during solar generation hours).

DNSPs are required to maintain the voltage on the low voltage network according to limits set by Australian standards, which are a preferred range of 230V +6%/-2% or 225-244V, and acceptable range of +10%/-6% or 216-253V. A recent report by UNSW for the Energy Security Board used data from Solar Analytics devices to measure the voltage at 12,617 locations throughout the NEM (Heslop et al., 2020). The findings for SAPN's network illustrate the diversity of voltage impacts. Around 22% of the sites were found to experience over voltage (>253V) at least 2% of the time and around 21% of the sites experienced voltage >255V. Around 2% of the sites were experiencing regular over voltage events with voltages being over 253, 255 and 258 levels for 35%, 13% and 4% of the time respectively.

There are many ways the voltage impacts of PV exports (or loads) can be managed, and so any assessment of the effectiveness of tariff and/or incentive design to reduce them should be compared to these alternatives. This is highlighted by the fact that the UNSW report found that voltages were generally in the range 240V-245V throughout the day (including overnight), most likely because of the need to avoid voltages below 216V during periods of peak demand (driven by cooling loads such as air conditioning), and the historic 240V standard in Australia. As a result, it was very easy for PV to push voltages up to the 253V limit even though the median increase driven by PV was only 2V to 5V (Heslop et al., 2020). Thus, efforts to reduce the impacts of PV on voltage should include ensuring the networks are at least operating within the preferred range (225-244V).

As a rule, technical issues are best addressed through technical solutions, although they may have equity impacts and so price-based solutions such as tariffs could have a role to play. In their recent

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[54] This includes expenditure related to augmentation (augex), replacement (repex) and connections (connex).

[55] As mentioned above, voltage regulation can also occur through direct technical control (such as the use of Volt-Watt or Volt-VAR inverter modes to control voltage), however such technical control is not the focus of this OA.

Distribution Annual Planning Reports, nearly all the 13 DNSPs in the NEM report issues with power quality and specifically voltage fluctuations in areas with high penetrations of distributed solar PV, and have identified and in some cases implemented possible options for voltage management, including the following:[56]

- Managing distribution transformer tap settings and rebalancing across phases are relatively low-cost options, but are only applicable where voltages are generally high and no or very limited low voltage excursions are experienced, or where phase imbalance exists;
- Network augmentation options can reduce the impedance from the distribution transformer and narrow the voltage range, but are more expensive;
- More advanced voltage management via various types of power electronics equipment can dynamically manage voltages at the transformer or other locations on the network;
- Requiring advanced PV inverter functionality can take advantage of inverter capabilities to better manage voltages through Volt-Var and Volt-Watt responses[57], and perhaps ‘external’ control signals; and
- Load management, including controlled load shifting and tariffs to incentivise loads to shift to solar times, can help address both low and high voltages at peak ‘net’ load and ‘peak’ solar times.

Therefore, there is a need to obtain a better understanding of existing voltage issues and the relative effectiveness and efficiency of different options for resolving them, including the impact of different tariffs and incentives on voltage in the field. This is discussed further in Section 7.7.4.

6.8 Summary of barriers

The regulatory barriers (Table 6-1) affect the ability of DNSPs, retailers and 3rd parties to make tariffs or incentives available to households. Barriers to household engagement (Table 6-3) can affect both the uptake of tariffs and other incentive products and the response to those incentives. The market and other barriers listed in Table 6-2 can affect making incentives available as well as the uptake and household response.

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[56] Paraphrased from Heslop et al., (2020)

[57] Indeed, recently adopted aspects of the AS4777 standard for small PV inverters in Australia require proportional reduction in real power output (Volt-Watt mode) or reactive power absorption (Volt-VAR mode) capabilities. The latter is preferable in that less real power is lost but absorbing reactive power will increase losses in the network and may have only a limited capability to reduce voltages in many areas of the distribution network. These modes are now being required by a growing proportion of Australian DNSPs.

6.8.1 Regulatory barriers

Table 6-1 Regulatory barriers

Barrier	Type of incentive affected
Limitations on market participation of DNSPs	DNSP providing non-tariff DR mechanisms
Limitations on changes to tariff structure during 5-year TSS period	Innovative network tariffs
Limitations to tariff changes within 1-year pricing proposal period	Innovative network tariffs
Absence of NUOS charges/payments for export	Export NUOS charges
Limitation on applying different tariffs to different customers	Specific NUOS tariffs for DER owners; locational pricing
Requirement that tariffs be reasonably capable of being understood	NUOS tariffs targeting retailers and intermediaries
DMO and VDO may affect innovation	Innovative retail tariffs
Overlap of NERL and ACL complexities and lack of protection	Bundled retail tariffs

6.8.2 Market, technology and information barriers

Table 6-2 Market, technology, and information barriers

Barrier	Affects making incentives available	Affects take-up of incentives	Affects response to incentives	Energy management behaviour (in response to tariff or self-consumption)	**B**attery **M**anagement **S**ystem	**H**ome **E**nergy **M**anagement **S**ystem	**D**irect **L**oad **C**ontrol	**C**ontrolled **L**oad	**B**ehavioural **D**emand **R**esponse	**V**irtual **P**ower **P**lant
Lack of benefit to retailers and DNSPs from household response to CRTs			Yes	✓	✓	✓				
Low penetration of smart meters	Yes	Yes	Yes	✓			✓	✓	✓	✓
Interoperability of enabling technologies	Yes	Yes	Yes			✓	✓			✓
Limited functionality of enabling technologies	Yes	Yes	Yes				✓	✓		✓
Installation issues	Yes	Yes			✓	✓	✓	✓		✓
Measurement of baseline and response	Yes	Yes	Yes	✓			✓	✓	✓	✓
Technology costs	Yes	Yes			✓	✓	✓	✓		✓
Data access	Yes	Yes	Yes	✓	✓	✓	✓		✓	✓
Information and user understanding		Yes	Yes	✓	✓	✓	✓		✓	✓
Communication with end users	Yes	Yes	Yes	✓			✓		✓	✓
Tariff assignment	Yes	Yes		✓	✓	✓				
Marketing and recruitment costs	Yes						✓		✓	✓
Inadequate value of flexibility	Yes	Yes	Yes	✓			✓	✓	✓	✓
Uncertain value of flexibility	Yes	Yes	Yes	✓			✓	✓	✓	✓
Market complexity		Yes	Yes	✓	✓	✓	✓			✓
Lack of recognition of costs and benefits of local network use and generation	Yes			✓	✓	✓				✓
Lack of understanding of interaction between home and public EV charging behaviours	Yes			✓	✓	✓				

6.8.3 Social, cultural and behavioural barriers

Table 6-3 Social, cultural and behavioural barriers

Barrier	Affects take-up of incentives	Affects response to incentives	Energy management behaviour (in response to tariff or self-consumption)	**B**attery **M**anagement **S**ystem	**H**ome **E**nergy **M**anagement **S**ystem	**D**irect **L**oad **C**ontrol	**C**ontrolled **L**oad	**B**ehavioural **D**emand **R**esponse	**V**irtual **P**ower **P**lant
Lack of suitable loads to shift	Yes	Yes	✓		✓	✓	✓	✓	
Inequitable access to DER	Yes	Yes		✓					✓
Reluctance to participate	Yes	Yes	✓	✓	✓	✓	✓	✓	✓
Concerns about comfort, convenience and safety	Yes	Yes	✓		✓	✓	✓	✓	
Concerns about loss of autonomy	Yes	Yes			✓	✓	✓		✓
Concerns about privacy	Yes							✓	✓
Distrust	Yes					✓	✓	✓	✓
Routines and social dynamics	Yes	Yes	✓		✓	✓	✓	✓	
Concerns about bill shock	Yes		✓						

6.8.4 Barriers relating to system impacts

Table 6-4 System benefits barriers

Barrier	Affects making incentives available	Affects take-up of incentives	Affects response to incentives	Energy management behaviour (in response to tariff or self-consumption)	**B**attery **M**anagement **S**ystem	**H**ome **E**nergy **M**anagement **S**ystem	**D**irect **L**oad **C**ontrol	**C**ontrolled **L**oad	**B**ehavioural **D**emand **R**esponse	**V**irtual **P**ower **P**lant
Lack of understanding of how tariffs/incentives, technologies and behaviour synergistically interact at the individual household level	✓		✓	✓	✓	✓	✓	✓	✓	✓
Lack of understanding of the impacts of electricity flexibility at the system level	✓		✓	✓	✓	✓	✓	✓	✓	✓

7 Gaps in existing research and industry development

This section builds on the previous sections as well as feedback from stakeholders by summarising the various barriers that have been identified and discussing the extent to which they and related issues are being addressed by current research and industry development activities. It is subdivided into:

1. Regulatory aspects
2. Market considerations
3. Enabling technologies
4. Information and communications
5. Social, cultural and behavioural aspects
6. Net system impacts

Section 8 then identifies priority research areas, an impact framework and project opportunities.

7.1 Regulatory aspects

As discussed in Section 6.1, this OA focuses on the regulatory barriers to tariff and incentive products being made available to households. It does not cover the regulatory barriers related to the technical aspects of DER and demand response. These are already the focus of a significant number of workplans underway through both the Post 2025 and AEMC market design processes; and many are expected to be covered in the RACE for 2030 Projects H3 'Using Home Energy Technologies for Grid Support' and N4 'Distribution System Operator and Beyond: Optimising planning and regulation for DM & DER'. In this context, there is a need to better understand the degree to which the following inhibit the deployment of innovative tariffs and incentives as well as household uptake and response to them.

1. Do Clauses 6.18.1B and 6.18.1C need to be modified to make it easier for DNSPs to make tariff changes during the TSS regulatory period and so more rapidly deploy innovative tariffs? This would involve structured interviews of as many DNSPs as possible, as well as other stakeholders including consumer advocates. (see Section 6.1.1)
2. An assessment of the impacts of changes to Clause 6.1.4 that allows charges to be applied to solar exports etc. Similar question if Clause 6.18.4(a)(2) is removed. (see Section 6.1.1)
3. An assessment of the degree to which Clause 6.18.5(i), which states the structure of each tariff must be reasonably capable of being understood by retail customers that are assigned to that tariff, inhibits the deployment of innovative tariffs. This is currently a focus of the AEMC and so most likely does not require additional research (see Section 6.1.1)
4. An assessment of the degree to which the DMO and VDO stifle tariff innovation, and if this is the case then the identification of ways to overcome any restrictions. This would involve structured interviews with as many retailers as possible, both large and small, and other industry stakeholders including consumer advocates (see Section 6.1.2).
5. An assessment of the degree to which the NERL and ACL stifle tariff innovation or result in households being outside the consumer protection framework. This could also involve structured interviews of as many retailers as possible, both large and small and other industry stakeholders including consumer advocates (see Section 6.1.2)

7.2 Market considerations

7.2.1 Approaches to encourage uptake of cost-reflective tariffs

As discussed in Section 6.2.1, the uptake and response to CRTs can be influenced by whether they are opt-in or opt-out. This includes the established gap between customers' stated willingness to participate in

CRTs and the actual uptake, and the findings that opt-out programmes result in higher uptake than opt-in. Although voluntary (and especially opt-in) uptake is associated with higher flexibility response than mandatory, is it because the household has a small peak load already (so essentially just results in reduced revenue for networks and so places upwards pressure on tariffs) or is it because they can significantly reduce their peaks with the right incentive (which should reduce costs for other customers)? Does mandating CRTs and smart meters undermine trust in the energy system and household engagement? There is an opportunity to explore these questions by augmenting opt-in tariff trials with analysis of ‘before and after’ household energy data (requiring installation of smart meters or other monitoring devices in advance of the tariff introduction) and in-depth interviews to explore household behaviour change.

There is also an opportunity to trial alternative approaches to incentivising uptake of and response to (non-mandated) CRTs: including upfront payments, deployment targeted at households with specific loads, and provision or subsidy of enabling technologies, with payments structured to avoid disadvantaging non-participants.

7.2.2 Price responsiveness

As discussed in Section 6.2.2, there is a very large range in the levels of household price responsiveness, which is caused by a variety of factors. There is a need to obtain a better understanding of how these factors may affect household responsiveness to different price signals, not only tariffs but also other financial incentives such as those discussed in Section 3.2.1. This should include both short-term and long-term responsiveness, as well as how incentives affect the price responsiveness of take-up and operation of enabling technologies (including a timer, diverter, battery etc), separated into different customer sub-groups.

7.2.3 Tariff pass-through

The two greatest cost components of tariffs that retailers face are the network component and the spot price component. The more these are passed through to customers the more cost-reflective their tariffs will be. Thus, there is a need to assess: i) how well retailers pass through network tariff for each customer, the reasons why they do and don’t (including customer expectations and risk management) and ways to encourage them to do so, and ii) the methods retailers use to decouple retail tariffs from their own costs (e.g. financial and physical hedges) and whether this leads to efficient outcomes. Where is the sweet spot between simplicity and low risk for customers and effective price signals?

7.2.4 Tariff design

7.2.4.1 Retailer-facing network tariffs.

Modelling and trials of DNSPs applying network tariffs to the aggregated load of their customers. Working with DNSP and retailers to understand the costs and benefits of different options for retailers to reduce their aggregated peak demand. Include an assessment of the impacts of scale – would this favour large incumbent retailers and so stifle innovation? Would this arrangement be cost-reflective, given that aggregation effects may flatten profiles and so obscure customers’ local network impacts at the feeder level?

7.2.4.2 Transitional tariff structures

The use of transitional CRTs with a very low demand charge – and the potential problems of this approach – are discussed in Section 6.2.1. An alternative is for the retailer to apply a cap (based on the household’s previous tariff or the DMO/VDO) with the guarantee that their bill will not go above this level for the first year, then have gradually increasing caps from then on. This then incentivises the retailer to help the household reduce its demand peaks, and to identify households that really can’t reduce their peaks.

It would be useful to run comparative trials of these alternative transitional tariffs with existing (low demand charge) transitional tariffs (with trial participants allocated randomly to one or the other) and measure the achieved flexibility or peak demand reduction.

7.2.4.3 Design of embedded network tariffs

As discussed in Section 3.1.3, there is very little available information on embedded network (EN) tariffs. It is also difficult for an embedded network operator (ENO) to apply CRTs because customers may go on-market and ENO has only a limited number of customers. There is a need to develop, model (using real world EN data) and test innovative EN tariffs for use in ENs with shared and household DER, to optimise outcomes for the households/customers on the EN as well as optimising system-level outcomes. Tariffs need to be designed to incentivise EN participation as well as load-shifting behaviours that improve outcomes for all EN customers, and would likely require transitional arrangements (similar to those described in Section 7.2.4), combined with education and/or automation to enable households to benefit from CRTs and thereby ensure customer retention.

7.2.4.4 Understanding the impacts of use and generation on the local network

P2P, community batteries and similar desirable local balancing schemes require a network tariff discount to work (e.g. local use of system charges, LUOS). But often the thinking around this is disconnected from real network cost drivers. (e.g. LUOS charges are generally considered to be a reduction in kWh rates but to deliver network benefits they need to reduce peak demand into a feeder, not just volume). Application of LUOS would also require a real-time monitoring to track the electricity that is generated and used locally, and costs reconciliation between all involved households. In addition, export to the grid may impose network costs or be beneficial, and so these impacts in local network charges/payments should be accounted for as well. Thus, there is a need to understand these drivers better and develop tariff structures that move beyond LUOS and align network costs/benefits with consumer costs/benefits, as well as identify the situations where local network charges/payments are practical.

7.2.4.5 Impact of different pricing models on EV charging behaviour

An international review of different kinds of electricity tariffs and pricing models (for at home and public charging) in jurisdictions with higher penetration of EVs to understand their impact on charging behaviours. This could include a review of: the impact of different types of tariffs/models on the use of public charging infrastructure; what types of tariffs/models are better for EV owners with different levels of access to at-home charging, different transport needs and different EV usage profiles; how do different tariffs/model affect the operational interaction between EV charging and other devices such as batteries; the impact of charging models that allow EV owners to charge anywhere (including at other people’s homes) with the cost reverted back to their own bill; etc.

7.2.5 Variable value of market-based incentives

Financial incentives based on market values are very variable. There is a need to determine how the value of the incentive is affected by the incentive type, demographic characteristics, household load profile and technologies, and what this variability means in terms of the types of households best suited to such incentives, and how their variability can be minimised.

7.2.6 Non-financial incentives

While the non-financial incentives described in Section 3.2.2 have been used in a number of trials, there is little definitive evidence of their effectiveness or otherwise in increasing either uptake of products or flexible response to signals. There is a need to analyse field data from previous trials and to design new *controlled* trials comparing the effectiveness of messaging appealing to these different motivations. Importantly, the various incentives should be tested individually and in combination with financial rewards, and the outcomes analysed across different customer segments.

For example, working with a retailer, install metering for some of their customers trial messaging requesting customers reduce their peak demand to benefit all customers. Data analysis needs to be combined with user interviews, etc to understand what behaviour change is taking place in households and this needs to be a long-term trial to understand the persistence of any behaviour change.

7.2.7 Household appetite for multiple trading relationships and contractual complexity

The ESB is considering multiple trading relationships for a customer to allow DER to be controlled by an aggregator, while preserving the primary retailer relationship. This creates the opportunity for example to control DER for local network support without needing a pass-through of CRT by the retailer. To what extent will customers want the complexity of two relationships or will the retailer-takes-all status quo remain? (Note that this may well be a research focus of the RACE for 2030 Projects H3 'Using Home Energy Technologies for Grid Support' and N4 'Distribution System Operator and Beyond: Optimising planning and regulation for DM & DER'.)

A related issue is the potential for increased complexity in contracts between households and retailers, aggregators or other third parties. Although households currently choose between retail electricity contracts based on cost, future contracts may include multiple additional variables including capacity, control of technologies, override, energy security (through reserved storage capacity), opt-out clauses, and level of risk. To what extent will households be willing and able to navigate this level of complexity, and how might innovative business models such as subscription pricing support them in managing this complexity?

7.3 Enabling technologies

7.3.1 Comparison and assessment tools

Evaluate the short-term and long-term effectiveness and behavioural impact of tools for retailer comparison and technology assessment to provide evidence of their value, through longitudinal field studies. This requires the establishment of a framework and set of criteria to define effectiveness. Review existing industry and academic research into household preferences for comparison tools and develop a 'How to' guide to highlight best design practice for communicating key data while avoiding information overload.

7.3.2 Monitoring and control tools

Analysis of monitoring and control tools from a household perspective to understand their value to households, their suitability for different households (including those experiencing vulnerability) and different household members, their behavioural impact and effectiveness, through longitudinal field studies. This requires the establishment of a framework and set of criteria to define effectiveness, which accounts for behavioural and technical barriers.

7.3.3 Smart meters and data access

As discussed in Section 6.3.1, the low penetration of smart meters (SMs) is a significant barrier to implementation of CRTs and other flexibility products. Moreover, incentivising retailers and third parties to implement voluntary rollout schemes for SM deployment requires an understanding of the value that can be unlocked by SMs. This understanding could also increase customer support for SM deployment, and/or identify the costs and benefits of a government subsidised rollout.

There is a need for:

i) comprehensive analysis of the value of SMs and the distribution of costs and benefits between different stakeholders – DNSPs, retailers, aggregators and households;

ii) qualitative research based on in-depth interviews with retailers to understand the reasons they don't implement SM rollouts;

iii) qualitative research to understand what benefits (and problems) households see in SM deployment

iv) international review of arrangements for management of metering infrastructure and data, including the option of returning SMs (or appointment of metering co-ordinator) to DNSPs;

v) review of potential mechanisms to improve households' ease of access to their own SM data (also included in Section 7.4.1);

vi) development of business models to support SM rollout.

7.3.4 Installation issues

There is a need for greater understanding of the multifaceted role of installers of enabling technologies (monitoring, solar, batteries, HEMS, etc.) in facilitating household flexibility. As well as dealing with diverse household technical arrangements, installers are often the first or only point of contact for households and have the potential to play a part in education and flexibility advocacy. In-depth interviews with installers could improve understanding of their motivations, knowledge and methods, to inform policy, regulation and implementation plans for new products and services. It would also help to identify the information and training needs of installers themselves.

Focus groups with installers, managers and participants of flexibility trials could provide an opportunity to thrash out the issues from multiple viewpoints. The householders' viewpoint here is important in discovering how the installation process is perceived by prospective customers. e.g., how is information at point of sale presented? Is it understood? Is it meeting customer needs/answering their key questions? How do they verify/compare information? How do they define satisfaction after sale?

7.4 Information and communication

7.4.1 Data access

While some of the data issues discussed in Section 6.4.1 would be addressed by accelerated smart meter rollout, there is work to be done in leveling the playing field for access to customers' energy data. This includes standardising a human-readable data format, establishing a neutral gatekeeper role (whether AEMO or the DNSP) and a simplified procedure for customers access their own data and to allow access for specific organisations or for specific purposes (including research). While ARENA's *Shield* and *My Energy Market Place* projects are developing platforms for sharing data from multiple sources, and there is an ongoing consultation around the Consumer Data Right (CDR), there is still work to do in balancing household privacy concerns with the potential customer benefits of data sharing. This may not present a direct research opportunity for RACE 2030 but data access is of central importance, both to ongoing research and to ensuring equitable market access for innovative retailers, aggregators and third parties.

7.4.2 Common standard for tariff / price information for smart appliances

Development of a simple common data standard (that can be accessed by smart appliances) that retailers could use to publish tariff and price signals via the internet. If there were and it was widely used, would that facilitate an ecosystem of smart appliances that could self-configure to run at least cost times rather than rely on active controls, or simple measures like delayed start functions in dishwashers etc?

7.4.3 Real-time feedback

The research into the impact of feedback to households on their energy consumption, and its omission, described in Section 6.4.4, is largely focused on reducing consumption rather than load-shifting or providing flexibility. There is a need for further trials of real-time feedback aimed at flexibility.

The trials should

- have control groups of households with similar characteristics;
- include A/B testing of different messaging approaches including combining energy consumption data with financial information and environmental / health impacts; and
- have a long-term study period to assess the persistence of behaviour change.

These trials could also

  - combine real-time (or near-real-time) energy data with household temperature and humidity data to enable households to relate changes in energy use to environmental comfort allowing households to make informed trade-offs between energy/cost and comfort

  - compare impact of household-level data with information about which appliances use electricity including how much and when – either through appliance-level metering or machine learning disaggregation algorithms
  - incorporate longitudinal social science research – a series of in-depth user interviews – to understand the impact of the data feedback on broader energy understandings

7.4.4 Community energy models and trusted 3rd parties

i) Some communities are motivated to develop community owned renewable generation, community-scale batteries, parallel grids, and even their own retailers. What are their motivations, and can such models be leveraged to support the use of CRT's or provide alternative pathways to provide flexibility? For example, Enova Energy send messages to their customer base requesting they reduce demand during peak network events, with no direct incentive but to help reduce costs for all Enova customers. How effective is this and can it be scaled?

ii) Is there a broader role for a range of community groups, trusted third parties including NGOs in providing trusted, unbiased information about tariffs, DER, flexibility opportunities, etc. to households to support decision making?

iii) What is the role of partnerships between retailers and NGOs to deliver better resources and experience to customers experiencing vulnerability? Some retailers fund NGOs to do audits, energy education or link to financial counselling (some as part of their hardship provision, some as social responsibility, and some as they're social enterprises and that's their aim). How effective are these? How is their effectiveness monitored and evaluated? Is there a role for community energy organisations in looking at social needs - e.g. supporting social housing and rental programs, community-scale batteries etc.

7.5 Social, cultural and behavioural aspects

7.5.1 Household energy understandings

There is a need for more research into how households understand their own electricity consumption, including at the appliance level (what uses how much and when), as well as system issues such as peak demand, and how both are affected by behavioural decisions. How are these understandings impacted by education and, more importantly, by experiential learning through:

- historic and real-time energy feedback,
- participation in DR schemes and trials, and
- ownership of solar and batteries?

Also, how do these understandings vary between household members and how do learnings diffuse through households? In particular, what are effective mechanisms and messaging for converting energy-based understandings (relating to energy efficiency and total electricity consumption) to power-based understandings (relating to the temporal distribution of electricity use)?

It is important not to see education and literacy programmes as the solution to the complexity and confusion of the electricity market, as it puts the responsibility on households to understand, rather than on utilities to make their products transparent and comprehensible. Nevertheless, diffusion of increased energy understanding – through experience of engagement with DER, flexibility provision, etc. – is a desired outcome that may help embed behaviour change, longer-term uptake of DER and flexibility provision.

7.5.2 Disadvantage and vulnerability experienced by some households

i) There is a need for characterisation of the diverse load profiles of households experiencing vulnerability and analysis of how this impacts their capacity for flexibility. AGL's analysis looks at total consumption as well as income, household size, etc, but what types of time varying load profiles do vulnerable households have? There is obvious heterogeneity – including some very high consumption - but can they be usefully segmented? e.g., low, flat consumption (& low flexibility potential); peaky, highly temperature dependent; or consistently high. Analysis of the impacts of CRTs and other flexibility incentives on the bills of these households.

ii) There is a need to understand how support can be better targeted at these types of households. How can government *DER* subsidies be most appropriately targeted towards currently excluded households? How can government *hardship* subsidies be better designed to reduce hardship, provide network benefits *and* increase access to DER for longer term benefit? Using appropriate household data, an assessment of the impact of different existing and potential government subsidies on bills – including of vulnerable households – and on the network. Comparison of incentives (e.g. current NSW Empowering Homes interest-free battery loan vs battery subsidy vs solar for social housing vs energy rebates) for different types of households – i.e. how should these schemes be better targeted to maximise customer benefits *and* network benefits?

iii) There are particular barriers faced by renters (split incentives) and by low-income households (access to capital) that prevent them from deploying DER (including solar, batteries, EVs) and enabling control technologies, and therefore prevent them accessing potential medium and long-term financial benefits. There is a need to understand how these barriers may be overcome in different jurisdictions, including through government incentives and innovative business models.

More generally, given the specific barriers to flexibility faced by households experiencing vulnerability, all analysis of the impacts of CRTs and other flexibility incentives should include assessment of bill impacts for households unable to participate or to respond for whatever reason.

7.5.3 Cost trade-offs

While household concerns about loss of comfort, convenience, autonomy, privacy and control can be barriers to uptake of flexibility opportunities and enabling technologies, high uptake of EHW controlled load and PeakSmart DLC of A/C suggest that some households are prepared to trade these other benefits for financial gain. There is a need to better understand the trade-offs between these factors and bill savings (and other benefits including environmental and social benefits), how they vary across different loads and devices and between different types of household. In particular, to what extent is vulnerability increased by households trading comfort (or health) for savings?

7.5.4 Device-specific household flexibility potential and preferences

Households' constraints to taking up and responding to flexibility incentives are specific to particular loads and appliances, as well as depending on different aspects of flexibility capital including social and lifestyle issues, availability of enabling technology and preferences. Some households will prefer a simple flat or capacity tariff (even if they pay a premium for the simplicity), while for others, particular loads (EHW, EV, BESS) will have different levels of availability to provide a flexible response to price signals.

There is a need to understand this segmentation of households and loads, through in-depth qualitative and quantitative user research. This would involve identifying the segments with respect to different loads and appliances, assessing their size and relating them to different pricing structures and enabling tools.

7.5.5 Appetite / preference for direct load control

In a world with high levels of controllable DER (generation and loads), there is a trade-off to be considered between sophisticated, confusing cost-reflective tariffs and very simple tariffs with external DLC. The former provides a price signal that links to overall positive system outcomes and can allow customers to self-control or engage aggregators to control for them - max choice, min simplicity. The latter allows for very simple energy plans (e.g. flat fee) but would rely on retailers controlling DER to ensure they can manage costs appropriately. It would be interesting to understand how households would view these two extremes and to find the right balance.

7.6 Household-level impacts and modelling

7.6.1 Household data

As discussed in Section 6.7.1, there is a lack of publicly available high-resolution household load data that can be used to:

i) Undertake a static assessment of the impacts of different tariffs.

ii) Correlate different demographics with different load profiles and with tariff and technology uptake, as well as the responses to tariffs and technologies.

iii) Overlay the impacts of technologies that won't necessarily change the underlying load profile (such as solar and batteries).

iv) Determine how price elasticity varies with different aspects of household flexibility capital, such as income, access to technology and social and behavioural constraints.

v) Undertake all these assessments over a reasonable time period such as three years.

vi) Etc.

Such data need to have the following characteristics. They should:

- be at most half hourly,
- be over at least a full year, although over three years is much better because that allows an assessment of the impact of different technologies and tariffs over time,
- be geographically diverse, so they can capture different demographics, alternative energy supplies and climates,
- include demographic data related to income, household composition, technology uptake, tariffs, etc.

The privacy issues, particularly given the linkage between load and demographic data, require a trusted party (e.g. a university?) to collect, aggregate and anonymise the dataset.

7.6.2 Estimation of baseline load for demand response

There are reasonably good forecasting methods at NEM-level, which are used to schedule generation, but there are challenges at the level of individual or small aggregations of customers. The challenges of estimating a baseline load profile, particularly for solar households, and hence calculating measures such as achieved demand response and price responsiveness, is discussed in Section 6.3.6. There is a need for improved modelling using machine learning methods and a large dataset of household loads to understand the relationship between net household load and a range of factors including temperature, time of day, day of week, and household characteristics including DER ownership, type and operation. This needs an initial deep-dive industry consultation to understand what has been tried to date and the issues encountered.

7.6.3 Sophisticated household-level modelling

As discussed in Section 6.7.1, there is a need to develop sophisticated modelling approaches that take into account the complex interactions between different tariffs/incentives, technologies and behaviour at the individual household level. In order to help with forward planning, this should be performed at high levels of uptake of various devices. As well as evaluating impacts at the household level, the outcomes can also be aggregated to evaluate impacts/outcomes at the LV level and further aggregated to assess system-level impacts. Such models could usefully inform the design of trials to obtain real data. Such models could help determine:

i) The net (synergistic) impact of PV, EV, load shifting, batteries, etc on household load profiles

ii) The impacts of innovative tariffs (that could include peak time rebates, spot price tariffs and solar export charges/rewards) and incentives and what this means for their design

iii) How to target policies/tariffs/incentives to encourage the uptake and operation of different technologies by different types of households

iv) How different tariffs/incentives affect the need for and level of trading between households on the LV distribution network, for example through the use of tariffs that reward export at certain times.

v) The relative costs/benefits of tariffs that encourage export at appropriate times (and so focus on generation) versus the use of LOUS charges (that must be tracked to the point of end use).

vi) What this all means for impacts at the system level (spot prices, minimum demand and ramp rates, network peaks and solar exports) through changes to aggregated load profiles

vii) What these system-level impacts mean for the need for orchestration through for example VPPs

viii) How to co-optimise the household-level and system-level benefits for different types of households

ix) The best ways to optimise system benefits from DER (which should result in bill reductions for everyone)

7.7 Net system impacts

7.7.1 Spot price impacts

As discussed in Section 6.7.2, there is a need to develop methodologies to assess the short, medium and longer-term impacts on spot prices of changes to load profiles driven by electricity flexibility. They will likely use some combination of capacity expansion models and dispatch models; and should be consistent with the aggregated forecasts used for network impacts. There is also a need to develop validation techniques for these models.

7.7.2 Minimum demand and ramp rate impacts

As discussed in Section 6.7.3, there is a significant amount of work being undertaken under the P2025 workplans to develop approaches to assess the consequences and financial impacts of changes to the minimum system-level demand and increasing ramp rates. As these methods are developed, they should be integrated with RACE projects that investigate the impacts that tariffs and other incentives have on the system-level load profiles.

7.7.3 Impacts on network peaks and solar exports

As discussed in Section 6.7.4, there is a need to develop common approaches to assessing the ability of household electricity flexibility to reduce demand during network peaks at each of the three levels (distribution feeder, zone substation and subtransmission substation). These approaches should extend to the financial impacts. They should be consistent with the approaches used by DNSPs and should also be consistent with the forecasts for spot prices. If the aim is to assess the network-wide impacts of tariffs and/or incentives, then the AIC approach is likely to be most appropriate. However, if there is interest in assessing the impact at particular locations then the TIC approach is likely to be most appropriate, as long as the incremental change spans the potential construction of significant network assets.

A similar approach could be used to assess the ability of household electricity flexibility to reduce peak solar exports.

Both of these would benefit from including a geographically-based assessment of the future uptake of different technologies in different areas, including understanding the extent to which solar hosting capacity would be increased and curtailment reduced. This would enable local network impacts to be optimised.

7.7.4 Voltage impacts

As discussed in Section 6.7.5, there is a need to:

i) obtain a better understanding of the prevalence of voltage issues on the low voltage network, their locations and their causes,

ii) measure the impact of different tariffs and incentives on voltage in the field, including through their impacts on the uptake and operation of different technologies, and

iii) compare these to the alternatives discussed in Section 6.7.5 in terms of their effectiveness, efficiency and cost.

This work should be integrated with other voltage-related RACE projects, such as those exploring technical solutions to voltage management.

7.7.5 Impact on the value of flexibility

With greater uptake of batteries and control technologies, and therefore increasing flexibility response, some demand profiles will become flatter and the need for further flexibility may decrease. There is a need to understand how this affects the future value of flexibility, and how this will impact incentives, for example, whether and how much the difference between peak and off-peak rates of time-varying tariffs may decrease. Also, how will this affect cost-recovery of households who have invested in batteries or other enabling technologies?

8 Research questions, priority areas and roadmap

8.1 Priority research areas

Based on the research gaps identified in Section 7, 30 research questions have been identified. These have been grouped into the seven priority research areas shown in Table 8-1. These are arranged broadly in the order of the themes discussed in Section 7 (not in order of priority).

Table 8-1 Priority research areas

	Priority Area	Description	Number of RQs
A	Regulation & policy	Understanding the regulatory barriers to provision of flexibility incentives, including metering.	2
B	Data	Provision of and access to data for customers, industry stakeholders and researchers	2
C	Tariff and incentive design	Design and modelling of tariffs and incentives, understanding their influence on household uptake and response, and assessing their efficiency, effectiveness and impact	15
D	Enabling technologies	Reducing the barriers to deployment of monitoring and control technologies for enabling flexibility	8
E	Supporting household decision making	Understanding how and why households take up and respond to different incentives and opportunities, and developing tools and mechanisms to support them	18
F	Household vulnerability	Understanding the impacts of incentives and flexibility mechanisms on household vulnerability, including the diverse contexts described in Section 6.6	8
G	Value of flexibility	Understanding the value and system impacts of different flexibility incentives and mechanisms	6

Table 8-2 maps each of the research questions to the priority research areas, with most research questions mapping to more than one. Suggested approaches for addressing each of the questions are then presented in Section 8.2.

Note that the research priorities and milestones will change over time as new issues develop. It is highly unlikely that a process such as that undertaken here in 2021 would identify all the issues that needed to be addressed out to 2030.

Table 8-2 Research questions mapped to priority areas

RQ#	Research Question	A	B	C	D	E	F	G
RQ1	What impacts do the Default Market Offer (DMO) and Victorian Market Offer (VDO) and the National Energy Retail Law (NERL) and Australian Competition Law (ACL) have on tariff innovation?	A		(C)				
RQ2	What is the value of smart meters to households and to different industry stakeholders, and how can how can this value be leveraged to increase smart meter penetration?	A	B		(D)	(E)		(G)
RQ3	Given the development of datasets such as My Energy Marketplace and the commercially available datasets, what are the gaps in publicly available high-resolution data and how can they be filled?		B					
RQ4	What is the impact of opt-in versus opt-out tariffs on i) household engagement and trust in the electricity system, and ii) household electricity use and load profiles?			C		(E)		
RQ5	To what extent do retailers pass through the costs they are exposed to and why?			C				
RQ6	What are the costs and benefits and other impacts of networks presenting retailers with a network charge based on their aggregated customers?			C				
RQ7	How can embedded network tariffs and other flexibility incentives be designed so that they optimise outcomes for the households on the EN as well as system-level outcomes?			C		(E)		
RQ8	What is the best way to design tariffs so that the benefits of local network use and generation that supports the network (for example with LET/P2P or community batteries) are shared with households?			C		(E)		
RQ9	How do the tariffs/pricing models for at-home and public EV charging interact and affect charging behaviour?			C	(D)	(E)		
RQ10	How can technology installers be better supported (through training, incentives or other means) to help facilitate household flexibility?				D			
RQ11	What types of control technology tools best enable different types of households (including those experiencing vulnerability) to take up and respond to tariffs and other flexibility incentives?				D		(F)	
RQ12	How can (near) real-time data feedback best contribute to enabling household flexibility and long-term behaviour change?				D	(E)	(F)	
RQ13	What is the best way to introduce cost-reflective tariffs?					E		
RQ14	How can the variability of household impacts of market-based incentives (and of the incentives themselves) be minimised and what types of households are best suited to such incentives?			(C)		E		
RQ15	What is the ability of non-financial incentives to increase either uptake of flexibility opportunities and enabling technologies or flexible response to signals?					E		
RQ16	What are the characteristics of tariff comparison and technology assessment tools that best enable different types of households (including those experiencing vulnerability) to assess and make decisions about taking up cost-reflective tariffs and other flexibility opportunities?					E	(F)	
RQ17	What role can community organisations, NGOs and trusted 3rd parties play in supporting households (including those experiencing vulnerability) in decision-making and provision of flexibility?					E		
RQ18	How can we move from a perceived need for customer education to provision (by utilities and aggregators) of accessible opportunities that enable households (including those experiencing vulnerability) to engage in flexibility opportunities, and also increase their understanding through this engagement?					E	(F)	
RQ19	How can the load-specificity of household flexibility be addressed with appropriately targeted incentives and enabling technologies?			(C)	(D)	E		
RQ20	In which conditions are households prepared to trade comfort and convenience, with respect to different energy services, for bill savings (or environmental and social benefits)?				(D)	E	(F)	
RQ21	How do the various approaches to encourage the uptake of non-mandated cost-reflective tariffs compare in effectiveness?			(C)		E		
RQ22	How do the various influences on household behaviour affect price responsiveness?			(C)		E		G
RQ23	What is the household appetite for complexity (e.g., flexibility schemes with multiple contractual variables including cost, capacity, level of control, override, etc.) vs simplicity (e.g., subscription pricing) and for risk vs certainty, and how can innovative business models and contracting address this?			(C)		E		
RQ24	How do the diverse load profiles of households experiencing vulnerability impact their capacity for flexibility? (Priorities G)						F	
RQ25	How can energy rebates and DER subsidies, as well as flexibility incentives, be better designed and targeted to reduce household vulnerability, provide network benefits and improve long-term outcomes for households experiencing vulnerability?			(C)			F	
RQ26	How can more equitable access to DER (including solar, batteries, EVs) and control technologies be achieved, particularly for renters (overcoming the split-incentive) and low-income households (overcoming the barrier of upfront capital costs to unlock lifetime benefits)?				(D)	(E)	F	
RQ27	To calculate accurate baselines used for rewarding demand response there is a need for a thorough understanding of the relationship between net household load (particularly for solar households) and a range of factors including temperature, time of day, day of week, and household characteristics including DER ownership, type and operation.							G
RQ28	What are the impacts of increased DER uptake and household flexibility response on the value of that flexibility and what are the implications for future incentives and cost recovery?							G
RQ29	How do different tariffs/incentives, technologies and behaviour synergistically interact at the individual household level, and how does this translate into LV level and into system-wide impacts and therefore into impacts on other households?			C				G
RQ30	What net system impacts are driven by tariffs and other incentives through electricity flexibility?			(C)				G

8.2 Research questions and potential research approaches

This section details the research questions and suggests approaches for addressing each of them. The priority research areas addressed by the questions are identified, with primary areas in bold. The sub-sections shown in square brackets describe the gaps in existing research that each RQ addresses.

The potential research approaches and projects are indicative rather than prescriptive. Addressing many of these questions will require a combination of different research methods and it is also likely that some research projects will address more than one question.

RQ1: What impacts do the Default Market Offer (DMO) and Victorian Market Offer (VDO) and the National Energy Retail Law (NERL) and Australian Competition Law (ACL) have on tariff innovation? (Priorities **A**, C) [7.1]

1. Undertake structured interviews with as many retailers as possible, both large and small, and other industry stakeholders including consumer advocates. The DMO/VDO interviews may be best separate to the NERL/ACL interviews.
2. Analysis of the range and characteristics of the tariffs available in the market before and after DMO / VOD introduction.

RQ2: What is the value of smart meters to households and to different industry stakeholders, how can this value be leveraged to increase smart meter penetration? (Priorities **A, B**, D, E G) [7.3.3]

1. Undertake a comprehensive analysis of the value of SMs and the distribution of costs and benefits between different stakeholders – DNSPs, retailers, aggregators and households.
2. In-depth interviews with retailers to understand the reasons they don't implement SM rollouts.
3. In-depth interviews and focus groups with households (including in rented and social housing) to understand what benefits (and problems) households see in SM deployment.
4. International review of arrangements for management of metering infrastructure and data, and assessment of who is best place to roll out SMs, including the option of returning SMs (or appointment of metering co-ordinator) to DNSPs.
5. Review of potential mechanisms to improve households' ease of access to their own SM data (also included in Section 7.4.1).
6. Development of beneficiary pays business models to support SM rollout.

RQ3: Given the development of datasets such as My Energy Marketplace and the commercially available datasets, what are the gaps in publicly available high-resolution data and how can they be filled? (Priority **B**) [7.4.1]

1. Through consultation with researchers and other stakeholders develop the characteristics of a suitable database, including type of data, access, cost, privacy aspects, etc
2. Undertake a review of the nature, characteristics and cost of publicly available datasets using the above criteria.
3. Determine the need for, feasibility and characteristics of a researcher database including a sustainable business model to fund its development and ongoing operation.

RQ4: What is the impact of opt-in versus opt-out tariffs on i) household engagement and trust in the electricity system, and ii) household electricity use and load profiles? (Priorities **C,** E) [7.2.1]

1. Augment opt-in/opt-out tariff trials with analysis of 'before and after' household energy data (requiring installation of smart meters or other monitoring devices in advance of the tariff introduction) and in-depth interviews to explore household behaviour change and motivations.

RQ5: To what extent do retailers pass through the costs they are exposed to and why (and to what extent should they)? (Priority **C**) [7.2.3]

1. Where a trial involves any analysis of household tariffs, it should include the degree to which network tariffs and wholesale prices are passed through in retail tariffs, and why retailers do and don't pass them through.

RQ6: What are the costs and benefits and other impacts of networks presenting retailers with a network charge based on their aggregated customers? (Priority **C**) [7.2.4.1]

1. Examine the possible design options through which this could occur, and how retailers are then able to respond to the network charges they face, including using different approaches to incentivising household flexibility. What are the cost impacts for retailers and different types of households, and the consequences for cost-reflective tariff design? Does it have different implications for different sized retailers?

RQ7: How can embedded network tariffs and other flexibility incentives be designed so that they optimise outcomes for the households on the EN as well as system-level outcomes? (Priorities **C**, E) [7.2.4.3]

1. Using real embedded networks and modelling, explore the impacts of different EN tariff and incentive designs on the outcomes for individual households and the ENO, through direct tariff impacts and through flexibility response that changes load profiles and reduces costs across the EN.

RQ8: What is the best way to design tariffs so that the benefits of local network use and generation that supports the network (for example with LET/P2P or community batteries) are shared between households? (Priorities **C,** E) [7.2.4.4]

1. Undertake modelling with different types of tariffs that can be used where only limited use of the network occurs or where generation can be beneficial. Such tariffs should incorporate costs/benefits on the network at different times, as well as the feasibility/difficulty of tracking the associated electricity flows.

RQ9: How do the tariffs/pricing models for at-home and public EV charging interact and affect charging behaviour? (Priorities **C,** D, E) [7.2.4.5]

1. Undertake an international literature review of different kinds of electricity tariffs, incentives and pricing models (for at home and public charging) in jurisdictions with higher penetration of EVs. It should include EV owners with different levels of access to at-home charging, different transport needs and different EV usage profiles, and synergistic interactions between EVs and home batteries; and tracking options that allow ‘anywhere charging’.
2. Trials of tariffs and charging schemes for EVs, including households with different EV use and charging behaviours, with and without smart chargers. Assess the impact of different price signals and other incentives on at home and public charging behaviour, on load profiles and on the network. Include before and after comparison (using charging diaries, interviews and energy data).

RQ10: How can technology installers be better supported (through training, incentives or other means) to help facilitate household flexibility? (Priority **D**) [7.3.4]

1. Interviews with installers of enabling technologies to understand their motivations, knowledge and methods. Interviews with households with DER or other enabling technologies (including DLC, smart HEMS, etc.) to explore how customers view the installation process and how they perceive and understand the information presented to them at different stages of the process.
2. Focus groups with householders, managers of flexibility trials and installers to understand the issues from multiple perspectives.

RQ11: What types of control technology tools best enable different types of households (including those experiencing vulnerability) to take up and respond to tariffs and other flexibility incentives? (Priorities D**,** F) [7.3.2]

1. Review industry and academic literature relating to the impact of control technologies on flexibility, and household preferences for these tools, including functionality and user interface.
2. Desktop analysis and user assessment of existing control technologies tools in the market, assessment of their suitability for different households (including those experiencing vulnerability) and use by different household members, their impact and effectiveness.
3. Undertake long-term, controlled trials of control technologies, assessing changes to load profiles over the short and long term, combined with longitudinal social science research – a series of in-depth user interviews – to understand household perceptions of the tools. The trials should include:

    - control groups of households with similar characteristics;
    - tools responding to tariffs, to solar self-consumption and to other price signals;
    - testing user preferences, including allowing different trade-offs between comfort, convenience and cost;
    - assessing the impact of technical barriers, including communication & interoperability, installation issues, etc.

RQ12: How can (near) real-time data feedback best contribute to enabling household flexibility and to long-term behaviour change? (Priorities D, E, F) [7.4.3]

1. Review industry and academic literature relating to the impact of feedback on energy efficiency, load reduction and behaviour change and household preferences for these tools, including types and resolution of data and user interface.
2. Desktop analysis and user assessment of existing data feedback tools in the market, their suitability for different households (including those experiencing vulnerability) and different household members, their impact and effectiveness.
3. Undertake long-term, controlled trials of data feedback using different tools, assessing changes to load profiles over the short and long term, combined with longitudinal social science research – a series of in-depth user interviews – to understand household response to the feedback and the impact on broader energy understandings.
   The trials should include:
    - control groups of households with similar characteristics
    - data feedback alone and combined with different types of price-signal (TOU, CPR, etc)
    - comparison of different messaging and communication approaches, including financial and environmental information (real time cost or carbon emissions), gamification, private vs public visibility
    - combination of energy data with temp / humidity data to enable informed cost-comfort trade-offs
    - compare impacts of household-level and appliance-level data

RQ13: What is the best way to introduce cost-reflective tariffs? (Priority **E**) [7.2.4.2]

1. Run comparative trials of existing (low demand charge) transitional tariffs with full demand charge tariffs combined with a bill cap; and assess customer satisfaction and the achieved flexibility or peak demand reduction.

RQ14: How can the variability of household impacts of market-based incentives (and of the incentives themselves) be minimised and what types of households are best suited to such incentives? (Priorities **E**, C) [7.2.5]

1. Analyse the different types of market-based incentives in terms of how their variability may be affected by household demographics, load profile and technologies. Identify suitable market segments.
2. Incorporate the findings into trials of tariffs and incentives.

RQ15: What is the ability of non-financial incentives to increase either uptake of flexibility opportunities and enabling technologies or flexible response to signals? (Priority **E**) [7.2.6]

1. Analyse field data from previous trials and to design new *controlled* trials (including longitudinal social science research) comparing the effectiveness of non-financial incentives both individually and in combination with financial rewards, with the outcomes analysed across different customer segments.

RQ16: What are the characteristics of tariff comparison and technology assessment tools that best enable different types of households (including those experiencing vulnerability) to assess and make decisions about taking up cost-reflective tariffs and other flexibility opportunities? (Priorities **E,** F) [7.3.1]

1. Establish frameworks to assess effectiveness of tariff comparison and technology assessment tools.

2. Review existing industry and academic research into household preferences for these tools and conduct desktop assessment of existing tools.
3. User trials of tariff comparison and technology assessment tools, assessment of their suitability for different households and different household members, their impact and effectiveness
4. Develop a ‘How to’ guide to highlight best design practice for tariff comparison and technology assessment tools

RQ17: What role can community organisations, NGOs and trusted 3rd parties play in supporting households (including those experiencing vulnerability) in decision-making and provision of flexibility? (Priority **E**) [7.4.4]

1. Desktop review of the literature relating to community energy organisations, exploring motivations and behavioural drivers, and models of participation.
2. In-depth interviews and focus groups with community energy organisations, NGOs, state and local government, households and other stakeholders, exploring motivations, issues of trust and potential models for supporting flexibility including information provision, partnerships with retailers, advocacy and support for households experiencing vulnerability, effectiveness of existing support, etc.
3. Identification of key roles for trusted 3rd parties and development of business models to support households in providing flexibility

RQ18: How can we move from a perceived need for customer education to provision (by utilities and aggregators) of accessible opportunities that enable households (including those experiencing vulnerability) to engage in flexibility opportunities, and increase their understanding through this engagement? (Priority **E**, F) [7.5.1]

1. Review of industry and academic literature relating to the impact of DER ownership, participation in DR and tariff trials, real-time data feedback on short- and long-term household understanding of energy and its time-dependent value
2. In depth interviews with trial organisers and participants to further understand the relationship between participation and energy management behaviours and understanding
3. Use findings to inform design of trials of tariffs and flexibility incentives

RQ19: How can the load-specificity of household flexibility be addressed with appropriately targeted incentives and enabling technologies? (Priorities **E,** C, D) [7.5.4]

1. Qualitative research, including in-depth interviews and focus groups, as well as a review of existing industry and academic literature, to identify and segment household capabilities and preferences for flexibility with respect to specific loads and devices, including appetite for tariff incentives versus direct load control.
2. Quantitative analysis, including customer surveys and market survey to assess the size of household segments for flexibility specific to particular devices and appliances.
3. Identify appropriate pricing structures and enabling tools for identified segments.

RQ20: In which conditions are households prepared to trade comfort and convenience, with respect to different energy services, for bill savings (or environmental and social benefits)? (Priorities **E**, D, F) [7.5.3]

1. In depth user research to understand households’ acceptance of reduced levels of service (air heating and cooling, hot water heating, EV charging) in exchange for financial or other benefits, and how these preferences vary between and within households and across different appliances. Should include specific assessment of the extent to which households experiencing vulnerability may sacrifice (or be deprived of) comfort or health for bill savings, as well as how factors such as housing quality (thermal properties) and appliance efficiency affect this.
2. Incorporate these different preferences into design of control technologies and appropriate incentives, and conduct field trials.

RQ21: How do the various approaches to encourage the uptake of non-mandated cost-reflective tariffs compare in effectiveness? (Priorities **E**, C) [7.2.1]

1. Augment opt-in/opt-out tariff trials with the impact of options such as: different communications strategies, upfront payments, deployment targeted at households with specific loads, provision or

subsidy of enabling technologies, etc. (with payments structured to avoid disadvantaging non-participants) and compare uptake.

RQ22: How do the various influences on household behaviour affect price responsiveness? This includes direct responses to different types of tariffs and other financial incentives, as well as the take-up and operation of enabling technologies. (Priorities **E, G**, C) [7.2.2]

1. Where trials assess household responses to tariff changes as well as other financial incentives, ensure they include detailed analysis of household demographics and in-depth interviews with households to fully understand the factors affecting their level of response.
2. Trials that assess price-responsiveness should separately assess how this relates to the uptake of different technology types (ranging from timer to diverter to battery, etc.) and to the operation of those technologies. A higher price signal may be required for uptake than for response.

RQ23: What is the household appetite for complexity (e.g., flexibility schemes with multiple contractual variables including cost, capacity, level of control, override, etc.) vs simplicity (e.g., subscription pricing) and for risk vs certainty, and how can innovative business models and contracting address this? (Priorities **E**, C) [7.2.7]

1. Cross-sectional social science research with households and advocates to understand attitudes to complexity vs cost, etc. Potential contractual arrangements co-designed with households and advocates.

RQ24: How do the diverse energy use characteristics of households experiencing vulnerability impact their capacity for flexibility? (Priority **F**) [7.5.2]

1. Collect and characterise load data as well as household demographics from households identified as experiencing vulnerability (including rebate recipients) and combine with qualitative data (interviews, etc) to understand the constraints on flexibility.

RQ25: How can energy rebates and DER subsidies, as well as flexibility incentives, be better designed and targeted to reduce household vulnerability, provide network benefits and improve long-term outcomes for households experiencing vulnerability? (Priorities **F**, C) [7.5.2]

1. Comparative analysis of the bill and network impacts of rebates, subsidies and incentives using data from existing schemes. Including consideration of the context of vulnerability – e.g. lack of rental rights to install equipment, reduced access to smart meters for renters, split incentives, low minimum wage/welfare, low income, saved capital of retirees or others with apparent low income.
2. Modelling of alternative subsidy and rebate structures and their interaction with flexibility incentives
3. Interviews with vulnerable households and advocates to understand appetite for differently structured subsidies and rebates
4. Trials of better targeted subsidies to support households experiencing vulnerability while improving network benefits

RQ26: How can more equitable access to DER (including solar, batteries, EVs) and control technologies be achieved, particularly for renters (overcoming the split-incentive) and low-income households (overcoming the barrier of upfront capital costs to unlock lifetime benefits)? (Priorities **F**, D, E) [7.5.2]

1. International review of business models and jurisdictional incentives for solar, batteries, EVs and control technologies, including assessment of available data on uptake by demographics, tenure, income, etc.
2. In-depth interviews with renters, landlords and low-income households to understand the drivers and barriers to technology uptake and explore the appetite for different business models

RQ27: To calculate accurate baselines used for rewarding demand response there is a need for a thorough understanding of the relationship between net household load (particularly for solar households) and a range of factors including temperature, time of day, day of week, and household characteristics including DER ownership, type and operation. (Priority **G**) [7.6.2]

3. Undertake a deep-dive industry consultation to understand the approaches that have been tried to date and the issues encountered.
4. Develop improved modelling approaches such as machine learning methods using a large dataset of household loads.

RQ28: What are the impacts of increased DER uptake and household flexibility response on the value of that flexibility, especially as the level of flexibility response increases over time, and what are the implications for future incentives and cost recovery? (Priority **G**) [7.7.5]

1. Include in modelling of network impacts future scenarios with high DER penetration and flexibility response. How does this affect the value available for incentives (e.g., reducing the peak/off-peak ratio of TOU pricing) and cost recovery for households who have invested in DER and control technologies?

RQ29: How do different tariffs/incentives, technologies and behaviour synergistically interact at the individual household level, and how does this translate into LV level and into system-wide impacts and therefore into impacts on other households? (Priorities **C, G**) [7.6.3]

1. Determine the net (synergistic) impact of PV, EV, load shifting, batteries, etc on household load profiles.
2. Determine the impacts of innovative tariffs and incentives on this interaction and what this means for their design.
3. Design policies/tariffs/incentives to encourage the uptake and operation of different technologies by different types of households taking into account this interaction and in order to maximise system benefits.
4. Determine how the synergistic impact of different tariffs/incentives affect the need for and level of trading between households on the LV distribution network, for example through the use of tariffs that reward export at certain times.
5. Determine the relative costs/benefits of tariffs that encourage export at appropriate times (and so focus on generation) versus the use of LOUS charges (that must be tracked to the point of end use).
6. Determine how the synergistic impact of different tariffs/incentives affect the need for and viability of orchestration through for example VPPs
7. Determine how to co-optimise the household-level and system-level benefits for different types of households.

RQ30: What net system impacts are driven by tariffs and other incentives through electricity flexibility? (Priorities **G**, C) [7.7]

1. Develop methods to assess the short, medium and longer-term impacts on spot prices of changes to load profiles driven by electricity flexibility – and to determine the resultant cost impacts on other households.
2. Develop methods to assess the ability of household electricity flexibility to reduce demand during network peaks at each of the three levels (distribution feeder, zone substation and subtransmission substation) and to determine the resultant cost impacts on other households, and compare these to alternatives in terms of effectiveness and efficiency.
3. Develop methods to assess the ability and cost of household electricity flexibility to reduce export peaks at the LV level, and compare these to alternatives in terms of effectiveness and efficiency.
4. Develop methods to determine the impact of electricity flexibility on voltage in the distribution network to i) Better understand the prevalence, locations and causes of voltage issues on the low voltage network, ii) measure the impact of tariffs and incentives on voltage in the field, including through on the uptake and operation of different technologies, and iii) compare these to alternatives in terms of effectiveness and efficiency.
5. Use findings to inform design of trials of tariffs and flexibility incentives, taking into consideration the locational nature of network and voltage impacts.

8.2.1 Research recommendations derived from the modelling exercise

The following recommendations are related to the modelling that was undertaken by EPRI that provided a high-level assessment of the financial potential of household-friendly tariffs and incentives that reward electricity flexibility, which is described in the accompanying report ‘Benefit-Cost assessment for adoption of cost-reflective tariffs and incentives in 2030 and 2035’.

8.2.1.1 Characterise (or estimate) the interaction between tariff/incentive design and BTM battery uptake and incorporate into the financial modelling analysis.

This analysis projected that BTM batteries could be a significant portion of overall customer bill benefits resulting from CRT adoption (by earning revenue for exporting electricity to the grid under grid export tariffs). It is expected that BTM battery adoption will be higher if retail tariffs offer home battery owners more opportunity to benefit economically from home battery operations (such as with a wider range of tariff options enabling revenue from grid export, or tariffs offering higher rather than lower feed-in rates). However, this analysis did not investigate or model the interaction between tariff-enabled economic benefits and battery uptake. Further work to characterize this interaction (particularly with empirical data) may enable more accurate assessments of the impact of CRTs/incentives on BTM battery operation and the resulting customer benefits and grid impacts.

8.2.1.2 Estimate value of “filling the belly” and incorporate this into revised analysis of economic impact.

Historically, the challenge for network planning has been reducing peak load, typically in the evening hours. However, as increasing PV generation dramatically decreases net system load during midday hours, some networks identify low midday demand levels as the major challenge. Therefore, cost reflectivity for tariff design may mean increasing midday demand (rather than decreasing evening demand). Determining whether there is value in increasing midday demand, and estimating this value, may enable a more informed approach to cost reflective tariff design in this new paradigm.

8.2.1.3 Investigate and document the impact of enabling technology on price elasticity of electricity consumption.

Enabling technologies can increase the customer’s ability to respond to price incentives. Key examples include home batteries and meters with central dispatch control. Such responsiveness may be quantified by adjustment in observed price elasticity. Improved price elasticity assessments that incorporate customer use of these enabling technologies can, in turn, enable improved assessment of expected impacts of CRT/incentive implementation.

8.2.1.4 Determine likely scenarios for time of residential EV charging and incorporate this into impact assessment for CRT/incentive adoption.

Existing data on household and system load curves is historical and does not incorporate the impact of EV charging. EV charging is expected by many to become a significant component of system load. Home EV charging could significantly impact the load shape of EV-owning households and could significantly impact how load shaping could best alleviate overall system costs for these households.

Research work within the *RACE for 2030* theme N1 (EV-grid integration) can help to inform the load scenarios and other considerations for incorporating EV charging into CRT/incentive design [cite N1 OA]. Conversely, further work within RACE theme H4 may help with the design of future work in theme H4.

8.2.1.5 Explicitly specify load patterns and price responsiveness of diverse household types

Re-analyse with a segmentation of the population, to investigate and apply differing elasticities to different populations of households. In particular, low-income households may have much lower (near-zero) price response.

8.2.1.6 Compile and incorporate updated network augmentation and operating costs from DNSPs.

The avoided augmentation cost values in various estimates and regulatory filings have varied over the past decade. The accuracy of this analysis may be increased by incorporating values from the most recent AER filings (and/or projections to 2030).

8.2.1.7 Segment this analysis by state and territory.

Key parameters that vary widely by state include marginal peak generation mix, network augmentation costs, current and projected home battery adoption, and system net load shape.

8.3 Indicative research methods

While the suggested research approaches outlined above are not prescriptive, they are useful in suggesting likely project duration and cost involved in answering the different questions. In particular, they suggest a categorisation of RQs into those that can be addressed relatively quickly, through literature and market reviews, desktop analysis, modelling and cross-sectional social science research (interviews, focus groups), and those that require market trials of incentives and technologies and/or longitudinal social science research over a longer timeframe.

Of course, some of the RQs might be best addressed through a two-stage process starting with initial desktop analysis and/or stakeholder interviews followed by a longer-term longitudinal market trial. For the purposes of ranking the likely project duration and cost (Section8.5), these have been split into 2 (labelled ***a*** and ***b*** in Table 8-4 and Figure 8-1 below).

For research projects involving industry trials of tariffs or other incentives, or of enabling technologies or communication approaches, it is recommended that the following should be included, as far as possible, in the project design:

- a clear framework and appropriate metrics for assessing project outcomes;
- data describing household characteristics (occupancy, demographics, types of loads and appliances, level of technology, etc.) should be collected to enable appropriate segmentation of households;
- control groups of households with similar characteristics;
- where appropriate, time-series energy data collected (including before the intervention being trialled) to measure flexibility outcomes (reductions in peak demand and solar export); and
- longitudinal, in-depth social science research to understand the complexities of household motivations and behaviours and their relationship to technical outcomes.

For both trials and modelling of tariffs and incentives, it is important that research outputs include the impacts on households that do not participate, or participate but do not respond, as there will always be households like this, including households experiencing vulnerability.

Where particular tariffs or incentives may deliver net system benefits, it may be appropriate to use a variation of cost/uptake functions to compare their effectiveness (Dunstan et al., 2012). Cost/uptake functions compare the cost of implementing a particular measure to its uptake. For example, a utility may incur a certain cost ($/kVA/yr) to implement a demand management measure, and as long as this cost is lower than the cost of, say, the equivalent network augmentation, then it should be undertaken. This would need to include householders' response to that measure and so would then implicitly include the household's own 'valuation' of that measure.

The RQs are grouped here according to the likely research methods that might be applied:

RQ's likely to be addressed by literature reviews, cross-sectional interviews and desktop analysis only:

RQ1: DMO/VDO and NERL/ACL

RQ2: Value of smart meters to households and to different industry stakeholders

RQ3: Gaps in publicly available high-resolution data

RQ6: Aggregated NUOS

RQ10: How can technology installers be better supported?

RQ14: How to minimise the variability of household impacts of market-based incentives

RQ17: Role of community organisations, NGOs and trusted 3rd parties

RQ18: Learning impacts of engagement in flexibility

RQ19: Targeting the load-specificity of household flexibility with appropriate incentives and enabling technologies

RQ23: Business models and contracts to address complexity

RQ26: More equitable access to DER and technologies

RQ27: Calculating accurate baselines used for rewarding demand response

RQs likely to be addressed by modelling only:

RQ8: Model local network charges for use and generation

RQ24: Impact of diverse energy characteristics of households experiencing vulnerability on capacity for flexibility

RQ29: Synergistic interaction of tariffs/incentives, technologies and behaviour and system-wide impacts

RQ30: Methods to determine net system impacts driven by tariffs and other incentives

RQ28: Declining value of flexibility with increased uptake

RQs likely to be addressed through trials and/or longitudinal social science:

RQ4: opt-in versus opt-out tariffs

RQ5: To what extent do retailers pass through the costs

RQ13: the best way to introduce cost-reflective tariffs

RQ21: options to encourage the uptake of non-mandated cost-reflective tariffs

RQ22: How influences on household behaviour affect price responsiveness

RQs likely to be addressed through a 2-stage process: a) analysis / modelling / cross-sectional social science, followed by b) a trial combined with longitudinal social science:

RQ7: Embedded network tariffs

RQ9: Tariffs/pricing models for at-home and public EV charging

RQ11: Types of control technology tools that enable take up and response

RQ12: How real-time data feedback contributes to enabling household flexibility

RQ15: Ability of non-financial incentives to increase uptake or flexible response

RQ16: Characteristics of tariff comparison and technology assessment tools

RQ20: Trading comfort and convenience for bill savings

RQ25: Better targeting of energy rebates and DER subsidies, to improve long-term outcomes

Of the RQs likely to be addressed through trials, RQ7 (embedded network tariffs) and RQ9 (tariffs for at-home and public charging) will require their own, dedicated trial, but there is potential to combine other RQs into trials that addresses multiple questions.

8.4 Research questions and barriers

Table 8-3 (see next page) shows which of the barriers identified in Section 6 are addressed by each of the research questions. Note that some RQs are designed to target specific barriers, while others are broader and impact multiple barriers.

Table 8-3 Research questions mapped to identified barriers

	Barrier	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
POLICY & REGULATION	Absence of NUOS charges/payments for export																														
	Limitation on applying different tariffs to different customers																														
	DMO and VDO may affect innovation	■																													
	Overlap of NERL and ACL complexities and lack of protection	■																													
MARKET, TECHNOLOGY & INFORMATION BARRIERS	Lack of benefit to retailers and DNSPs from household response to CRTs					■	■																								
	Low penetration of smart meters		■														■						■								
	Interoperability of enabling technologies											■																			
	Limited functionality of enabling technologies											■					■														
	Installation issues										■	■																			
	Measurement of baseline and response																■											■			
	Technology costs																							■		■					
	Data access			■									■																		
	Information and user understanding												■				■	■	■												
	Communication with end users															■	■	■	■			■									
	Tariff assignment				■		■																								
	Marketing and recruitment costs																														
	Inadequate value of flexibility														■					■									■		
	Uncertain value of flexibility												■		■					■								■	■		
	Market complexity						■										■							■							
	Lack of understanding about EN tariff design							■																							
	Lack of recognition of costs & benefits of local network use & generation								■																						
	Lack of understanding of interaction between home & public EV charging									■																					
SOCIAL, CULTURAL & BEHAVIOURAL BARRIERS	Lack of suitable loads to shift																■			■					■						
	Inequitable access to DER																■			■				■	■	■					
	Reluctance to participate				■							■	■	■		■	■	■	■	■		■									
	Concerns about comfort, convenience and safety												■				■			■	■				■						
	Concerns about loss of autonomy																■			■											
	Concerns about privacy												■				■			■											
	Distrust				■								■	■			■	■		■											
	Routines and social dynamics									■		■	■				■			■			■		■						
	Concerns about bill shock													■																	
SYSTEM IMPACTS	Lack of understanding synergistic interactions at household level																													■	
	Lack of understanding of the impacts at system level																														■

8.5 Research rankings

In order to prioritise the research questions and indicative methods described in Section 8.4, each RQ has been scored according to 3 criteria:

- Is it quick?
- Is it important?
- Is it cheap?

This allows identification of RQs and projects which will provide easy quick wins, as well as those that justify investment of significant time and money to achieve major impacts. For these purposes, where an RQ can be addressed by a 2-stage project (e.g., desktop analysis followed by market trial), it has been split into two (labelled a and b in Table 8-4 and Figure 8-1) and each part scored independently.

The scores were initially allocated by the report authors, based on the barrier analysis above and consultation with stakeholders through a series of workshops. These scores were then shared with the Stakeholder Reference Group and adjusted (sometimes significantly) according to their feedback. These scores are presented in Table 8-4.

Figure 8-1 shows the same information as a plot of *Time and resource needs* versus *Importance*, where the y-axis metric uses the average of 'Quick' and 'Cheap' scores, with the axis reversed (cheap, quick projects have low resource needs).

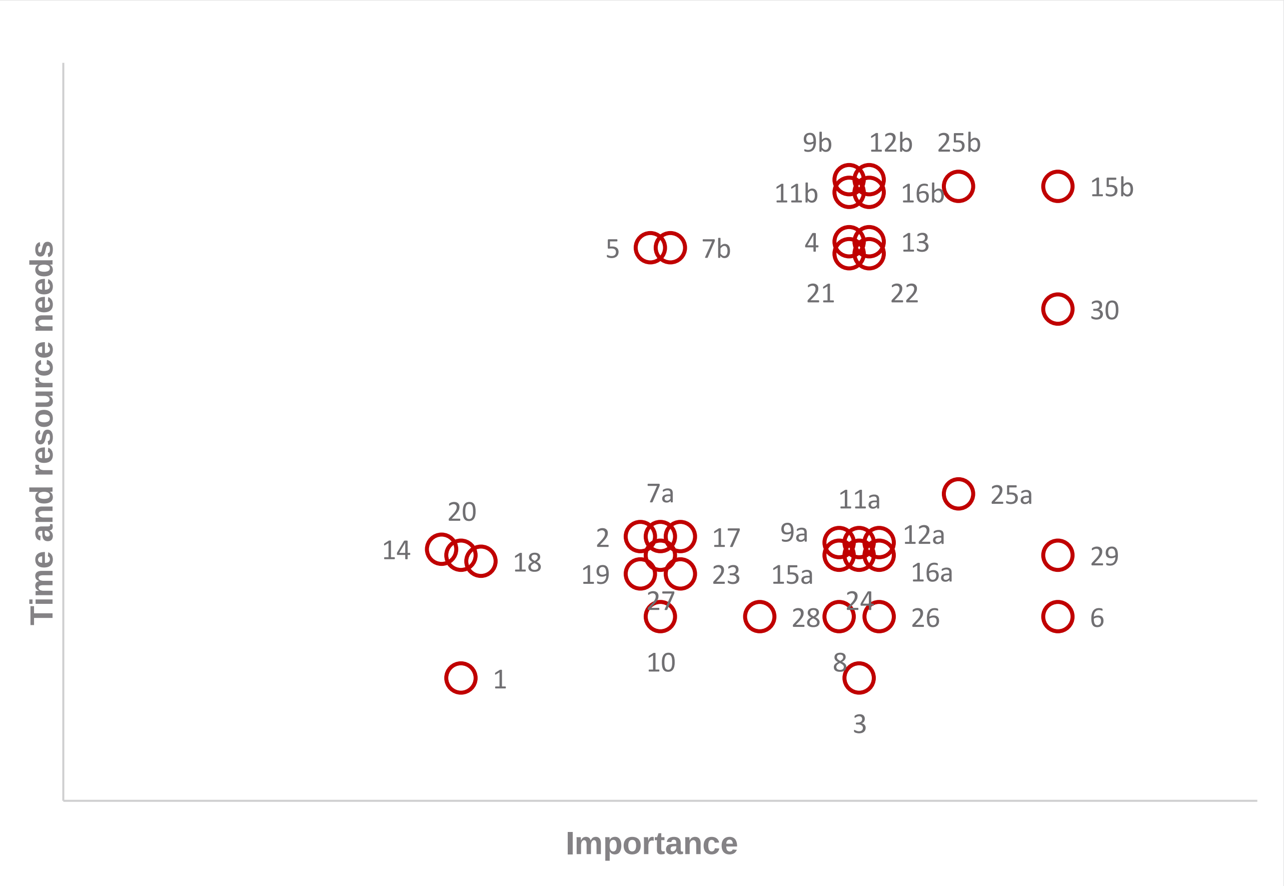

Figure 8-1 RQs ranked by importance and time/cost

The RQs/ projects in the bottom right corner of Figure 8-1might be regarded as 'easy wins', important questions that can be addressed at low cost on a relatively short timescale, while those in the top right corner clearly merit significant long-term investment. However, all the RQs can contribute positive impacts and should be addressed where they align with RACE partner priorities.

Table 8-4 Research questions scored for importance, speed, cheapness

RQ #	Research Question	Quick	Important	Cheap
RQ1	What impacts do the Default Market Offer (DMO) and Victorian Market Offer (VDO) and the National Energy Retail Law (NERL) and Australian Competition Law (ACL) have on tariff innovation?	5	2	5
RQ2	What is the value of smart meters to households and to different industry stakeholders, and how can how can this value be leveraged to increase smart meter penetration?	4	3	4
RQ3	Given the development of datasets such as My Energy Marketplace and the commercially available datasets, what are the gaps in publicly available high-resolution data and how can they be filled?	5	4	5
RQ4	What is the impact of opt-in versus opt-out tariffs on i) household engagement and trust in the electricity system, and ii) household electricity use and load profiles?	1	4	2
RQ5	To what extent do retailers pass through the costs they are exposed to and why?	1	3	2
RQ6	What are the costs and benefits and other impacts of networks presenting retailers with a network charge based on their aggregated customers?	4	5	5
RQ7a	How can embedded network tariffs and other flexibility incentives be designed so that they optimise outcomes for the households on the EN as well as system-level outcomes?	4	3	4
RQ7b		1	3	2
RQ8	What is the best way to design tariffs so that the benefits of local network use and generation that supports the network (for example with LET/P2P or community batteries) are shared with households?	4	4	5
RQ9a	How do the tariffs/pricing models for at-home and public EV charging interact and affect charging behaviour?	4	4	4
RQ9b		1	4	1
RQ10	How can technology installers be better supported (through training, incentives or other means) to help facilitate household flexibility?	4	3	5
RQ11a	What types of control technology tools best enable different types of households (including those experiencing vulnerability) to take up and respond to tariffs and other flexibility incentives?	4	4	4
RQ11b		1	4	1
RQ12a	How can (near) real-time data feedback best contribute to enabling household flexibility and long-term behaviour change?	4	4	4
RQ12b		1	4	1
RQ13	What is the best way to introduce cost-reflective tariffs?	1	4	2
RQ14	How can the variability of household impacts of market-based incentives (and of the incentives themselves) be minimised and what types of households are best suited to such incentives?	4	2	4
RQ15a	What is the ability of non-financial incentives to increase either uptake of flexibility opportunities and enabling technologies or flexible response to signals?	4	4	4
RQ15b		1	5	1
RQ16a	What are the characteristics of tariff comparison and technology assessment tools that best enable different types of households (including those experiencing vulnerability) to assess and make decisions about taking up cost-reflective tariffs and other flexibility opportunities?	4	4	4
RQ16b		1	4	1
RQ17	What role can community organisations, NGOs and trusted 3rd parties play in supporting households (including those experiencing vulnerability) in decision-making and provision of flexibility?	4	3	4
RQ18	How can we move from a perceived need for customer education to provision (by utilities and aggregators) of accessible opportunities that enable households (including those experiencing vulnerability) to engage in flexibility opportunities, and also increase their understanding through this engagement?	4	2	4
RQ19	How can the load-specificity of household flexibility be addressed with appropriately targeted incentives and enabling technologies?	4	3	4
RQ20	In what conditions are households prepared to trade comfort and convenience, with respect to different energy services, for bill savings (or environmental and social benefits)?	4	2	4
RQ21	How do the various approaches to encourage the uptake of non-mandated cost-reflective tariffs compare in effectiveness?	1	4	2
RQ22	How do the various influences on household behaviour affect price responsiveness?	1	4	2
RQ23	What is the household appetite for complexity (e.g. flexibility schemes with multiple contractual variables including cost, capacity, level of control, override, etc.) vs simplicity (e.g. subscription pricing) and how can innovative business models and contracting address this?	4	3	4
RQ24	How do the diverse load profiles of households experiencing vulnerability impact their capacity for flexibility? (Priority G)	4	4	4
RQ25a	How can energy rebates and DER subsidies, as well as flexibility incentives, be better designed and targeted to reduce household vulnerability, provide network benefits and improve long-term outcomes for households experiencing vulnerability?	3	4.5	4
RQ25b		1	4.5	1
RQ26	How can more equitable access to DER (including solar, batteries, EVs) and control technologies be achieved, particularly for renters (overcoming the split-incentive) and low-income households (overcoming the barrier of upfront capital costs to unlock lifetime benefits)?	4	4	5
RQ27	To calculate accurate baselines used for rewarding demand response there is a need for a thorough understanding of the relationship between net household load (particularly for solar households) and a range of factors including temperature, time of day, day of week, and household characteristics including DER ownership, type and operation.	4	3	4
RQ28	What are the impacts of increased DER uptake and household flexibility response on the value of that flexibility and what are the implications for future incentives and cost recovery?	4	3.5	5
RQ29	How do different tariffs/incentives, technologies and behaviour synergistically interact at the individual household level, and how does this translate into LV level and into system-wide impacts and therefore into impacts on other households?	4	5	4
RQ30	What net system impacts are driven by tariffs and other incentives through electricity flexibility?	2	5	2

8.6 Research roadmap and milestones that define the path to impact

	Milestones		
	2023	**2027**	**2030**
A: Regulation / Policy	• Clarification of the impacts of the DMO, VDO, NERL and ACL on tariff innovation (RQ1) • Arrangements for management of metering infrastructure and data developed (RQ2)	• Tariffs and incentive products account for the impacts of the DMO, VDO, NERL and ACL (RQ1)	
B: Data	• Better leverage of the value of smart meters to households to increase their penetration (RQ2) • Gaps in publicly available high-resolution data identified, and researcher database characterised (RQ3)	• Uptake of smart meters by at least 75% of households (RQ2) • Researcher database including a sustainable business model developed and available (RQ3)	• Essentially saturation uptake of smart meters by households (RQ2) • Researcher database expanding and financially viable on an ongoing basis (RQ3)
C: Tariff and incentive design	• Opt-in/opt-out tariffs trials include assessment of engagement/trust and changes to load profiles (RQ4) • An understanding of how well network tariffs are passed through in retail tariffs (RQ5) • The feasibility of networks presenting retailers with a network charge based on their aggregated customers assessed (RQ6) • Optimisation of ways to introduce cost-reflective tariffs (RQ13) • Embedded network tariff design optimised for households and system-wide benefits (RQ7) • Tariff design optimised for local use of the network (RQ8, RQ29) • Optimisation of EV tariffs/pricing models for at-home and public charging (RQ9)	• Retail tariff design now incorporates the impact of whether they are opt-in or opt-out (RQ4), and has been optimised for local use of the network (RQ8, RQ29) • Network tariff design incorporates the degree to which they are passed through in retail tariffs (RQ5, RQ6) • Embedded network tariffs now deployed to optimise households and system-wide benefits (RQ7) • EV charging options have been fully optimised for at-home and public charging (RQ9)	• Network and retail tariffs, as well as other incentives, including in embedded networks, optimised to provide both user and system-level benefits, with resultant benefits for all households (RQ4, RQ5, RQ6, RQ7, RQ8, RQ9)
D: Enabling technologies	• Better understanding of how the different DER and enabling	• Tariffs designed to better target the ability of technologies to drive price response (RQ22)	• DER enabling technologies fully integrated into the NEM, providing

	technologies affect price responsiveness (RQ22) • Understanding of the ability of different types of tools to drive uptake and response to flexibility opportunities (RQ16) • Understand how real-time data feedback contributes to enabling household flexibility and long-term behaviour change (RQ12) • Understand how technology installers can be better supported to help facilitate household flexibility (RQ10)	• A 'How to' guide for tools, and undertake trials of their suitability for different households and different household members, their impact and effectiveness (RQ16) • Longer-term, controlled trials of data feedback on households (RQ12) • Technology installers effectively advocating for household flexibility (RQ10) • Enabling technologies incorporate different household needs and preferences (RQ19, RQ20)	household and system-level benefits (RQ22, RQ16, RQ10)
E: Supporting household decision making	• Approaches to encourage uptake of non-mandated CRT compared (RQ21) • Better understanding of how the various influences on household behaviour affect price responsiveness (RQ22) • How to minimise the variability of household impacts of market-based incentives (RQ14) • A better understanding of the ability of non-financial incentives to increase either uptake of products or flexible response (RQ15) • Identification of key roles for community organisations, NGOs and trusted 3rd parties in supporting households (RQ17) • Understanding the role of experiential learning in increasing household electricity flexibility (RQ18) • A better understanding of household capabilities and preferences for flexibility with respect to specific loads and devices, including appetite for tariff incentives versus direct load control (RQ19) • Understanding of how much households are prepared to trade comfort and convenience for bill savings (or environmental and social benefits (RQ20)	• Voluntary uptake of CRT is greater than 50% (RQ4, RQ21, RQ13, RQ15) • Better incorporation of the various influences on household behaviour into tariffs and other incentives (RQ22, RQ15, RQ20, RQ25) • Minimisation of the variability of household impacts of market-based incentives (RQ14) • Non-financial incentives and messaging fully incorporated into flexibility schemes (RQ15) • Community organisations, NGOs and trusted 3rd parties actively engaged in supporting households' flexibility where appropriate (RQ17) • Appropriate pricing structures and enabling tools for identified segments (RQ18, RQ19) • Innovative business models and contracting to manage complexity (RQ23)	• Voluntary uptake of CRT is greater than 75% (RQ4, RQ21, RQ13, RQ15) • Tariffs and other incentives fully incorporate behavioural aspects and so are actively taken up and responded to by households (RQ22, RQ15, RQ20, RQ25) • Community organisations, NGOs and trusted 3rd parties continue to be actively engaged in supporting households' flexibility where appropriate (RQ17) • Households able to choose business models and contracts appropriate to their appetite for complexity and risk (RQ23)

	• Understanding of household appetite for complexity vs simplicity (RQ23)		
F: Households experiencing vulnerability	• Understanding of the needs and flexibility constraints of these households (RQ24) • Understanding of the relative impacts of different subsidies and incentives on these households (RQ25) • Understanding of particular barriers for renters and low income households in accessing DER and enabling technologies (RQ26)	• Flexibility incentives designed to minimise adverse vulnerability impacts (RQ24, RQ25) • Subsidies and rebates targeted to improve long-term bill outcomes and system benefits (RQ25) • New business models for DER and enabling technology deployment that addresses split incentives and access to capital (RQ26)	• Households experiencing vulnerability supported to engage in flexibility opportunities (RQ25) • Renters and low income households have equitable access to DER (RQ26)
G: Value of flexibility	• Price responsiveness assessments included in tariff trials (RQ22) • A thorough understanding of the influences on net household load obtained (RQ27) • The synergistic interactions between different tariffs/incentives, technologies and behaviour at the individual household level modelled (RQ29) • Methods to assess the system-level impacts of changes to load profiles driven by electricity flexibility developed (RQ30) • Understanding of future changes to value of flexibility due to increased response (RQ28)	• A detailed understanding of price responsiveness according to household demographic and technology types (RQ22) • Improved modelling approaches to model net household load enable accurate measurement of demand response (RQ27) • Policies/tariffs/incentives designed to encourage the uptake and synergistic operation of DER to maximise system-level benefits (RQ29, RQ30) • Future value of flexibility incorporated into modelling and incentives (RQ28)	• The benefits of system-level impacts of electricity flexibility fully incorporated into tariffs and incentives, that optimise both user and system-level benefits, with resultant benefits for all households (RQ28, RQ29, RQ30)

8.7 Impact categories and key performance indicators

The various research projects that arise from the research questions identified in this Opportunity Assessment can have a variety of outcomes that can be traced back to the research priority areas identified in Section 8.1. Table 8-5 lists possible indicators for the outcomes for each research priority along with suitable metrics.

Table 8-5 Categories and KPIs

Priority Area	Indicators	Metrics
Regulation & policy	Better understanding of the degree to which identified regulatory issues limit innovation	Self-reporting by community and industry stakeholders
Data	Uptake of smart meters and other sources of data. Development or researcher databases.	Number of smart meters taken up. Quality and accessibility of databases.
Tariff and incentive design	Cost-reflectivity of retail tariffs. Embedded network tariffs optimise households and system-wide benefits EV charging tariffs are optimised for at-home and public charging.	Percentage of cost-reflective tariffs. Percentage of optimised embedded network tariffs. Percentage of EV charging tariffs that are optimised.
Enabling technologies	Enabling technologies better linked to price signals to drive price response Longer-term, controlled trials of data feedback on households Technology installers effectively advocating for household flexibility	Percentage of enabling technologies Number and quality of trials Percentage of technology installers
Supporting household decision making	Uptake of cost-reflective tariffs and incentives Better designed tariffs and incentives Community organisations and trusted 3rd parties actively engaged in supporting households	Percentage uptake Price responsiveness Number of households supported
Household vulnerability	Flexibility incentives designed to minimise adverse vulnerability impacts Subsidies and rebates targeted to improve long-term bill outcomes and system benefits	Percentage of incentives Percentage of subsidies
Value of flexibility	Understanding price responsiveness according to household demographic and technology types. Accurate models of the impact of policies/tariffs/incentives on DER uptake and load profiles. The value of system-level impacts of changes to load profiles driven by electricity flexibility.	Short-term and long-term price responsiveness indices Number and accuracy of models LCOE of impacts and bill reductions

8.8 Context

Although the focus of this OA is on the design of cost-reflective tariffs and incentives, it is very important to understand the context within which they are implemented. Although many of the following points have been made earlier in this report, it is worth repeating them here.

8.8.1 Price is not everything; price is not nothing

Increasing household electricity flexibility is not an end in itself but is a means of supporting the transition to a low-carbon electricity system by increasing capacity for (distributed and utility) renewable generation, reducing reliance on fossil fuels, while minimising costs for all households. Flexibility incentives reward households for managing their energy consumption and generation to reduce system-wide costs (by lowering spot prices, reducing network peaks in demand and solar export) or provide system benefits (ancillary services).

Incentives for household flexibility include cost-reflective tariffs, other financial rewards and non-financial benefits such as reduced emissions or positive social outcomes. But incentives alone will not create household flexibility; increased deployment of DER, particularly batteries and EVs, as well as enabling control technologies are necessary to enable many households to respond to incentives.

8.8.2 State of transition

The electricity market in Australia, and indeed markets throughout the world, are undergoing a period of transition and transformation. It is not possible to identify perfectly efficient prices in such a market. It is also not realistic to design static tariffs and incentives. In addition, the development of tariffs and incentives occurs within an electricity market that will never be perfect – simply because it will never be perfectly designed and structured and so will never be truly cost-reflective, especially where participants such as networks are regulated (because the regulators don’t have perfect information and foresight). Rather, the focus should be on developing processes that will tend towards preferred outcomes over time. It is no exaggeration to say that the NEM is a live experiment, which will constantly need to adapt to new information, technologies and behaviours.

8.8.3 Households are heterogenous and may not respond as ‘expected’

There is significant diversity between households, and even within a household, and the characteristics that lead to such heterogeneity can change over time. This means there will be no ‘one size fits all’ either for tariffs or for incentives or for the myriad other tools that households may find useful. Thus, at the broader level, the electricity market cannot be designed based on a singular set of assumptions about households’ responses to that design. It must be robust to a wide range of potential household responses.

Only a small proportion of households are likely to respond ‘rationally’ to price signals (most likely those that are capable of – and choose to adopt - close to full automation), with the remainder ranging down to close to zero price responsiveness, and this will change over time. Thus, there is a need for a range of other incentives (both price-based and non-price).

As the market becomes more complex (as envisioned in the Post 2025 design process), it will become harder and harder for many people to be engaged, and they will have less and less inclination to do so. It will also be more difficult for them to judge value-for-money. This issue will be exacerbated by the fact that electricity is viewed as an essential service, and so many households view its reliability, sustainability and price as the responsibility of governments, rather than themselves.

Because automation is not suitable for – or wanted by – all households, universal household flexibility is not a realistic outcome, but nor is it a necessary one. However, there is a risk that households that don’t respond ‘as expected’ to tariffs and incentives could be left behind (with those who do respond receiving the greatest benefit, resulting in a wealth/benefit transfer). Therefore, there is a need for tariff and incentive design to consider ‘non-participants’, not only by recognising the diversity of possible responses, but also by ensuring the benefits are passed on to those who may not be able to or inclined to respond.

8.8.4 Boundary of the research

The boundary of the research is important. Tariff and incentive design needs to take into consideration the fact that what each household does (in terms of its electricity use) can affect other households. Therefore, when optimising outcomes, it is not enough to maximise benefits for a single, participating household, but instead the electricity industry must be included along with households within the ‘boundary’. This is not in order to maximise benefits for the electricity industry per se, but to ‘increase the pie’ of system-wide benefits that are then passed on to other households. For example, decreased demand during peak periods can place downward pressure on both spot prices and network costs, which are then passed on to all households. Thus, although there is a need to focus on what households really want - this knowledge should then be used to generate broader societal benefits.

8.8.5 The way forward

The perfect is the enemy of the good, so rather than attempting to design perfect tariffs and incentives, we should instead move along the path to sustained incremental improvement. Indeed, it is likely that the only way that the impacts of different tariffs and incentives will be known is once they have been made available to households. In this way the household can be seen as the ‘filter’ through which all the various potential ’signals/inputs’ pass, and their response is the only thing that matters.

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