Catalysing a low-regret transition: unlocking flexible demand in the commercial and industrial sector

Dani Alexander
University of Technology Sydney
235 Jones Street
NSW 2007
Australia
danielle.alexander@uts.edu.au

Thomas S Brinsmead
CSIRO
10 Murray Dwyer Circuit
NSW 2304
Australia
thomas.brinsmead@csiro.au

Charles Bransden
RMIT University
124 La Trobe Street
VIC 3000
Australia
charlie.bransden@rmit.edu.au

Keywords

demand response, commercial buildings, incentives, research, demand side management (DSM), industry

Abstract

Increasing flexible demand in the commercial and industrial sector should be a win-win-win[1]: businesses pay less for their electricity onsite, benefiting the market; network businesses need to invest less, reducing costs for all customers; and more variable renewables can be hosted. Despite these benefits, it is widely accepted that the demand-side resource is underutilised. In Australia, even a narrow definition of demand response (load shedding to address network instability) offers a technical potential of close to 10 % of total system demand (~3 GW), however only half of this is currently committed to programs[2]. Thus, the problem is twofold: tapping into the existing underutilised sources of demand response; as well as widening the definition of flexible demand to unlock greater energy, cost and decarbonisation benefits for customers.

This paper points towards further research to unlock the achievable value of flexible demand. The most prospective flexible demand opportunities are identified via a priority "HUF" (homogeneity, ubiquity, feasibility) matrix of technologies and sectors[3]. Options for better pricing design and policy incentives are identified to unlock the demand-side resource of the priority targets. Focus is given to segments of the demand-side value stack that are not currently accessible to most customers. The findings of this research will guide progressively funded research through the newly established $350 million 10-year Australian co-operative research centre – Reliable Affordable and Clean Energy for 2030 CRC. The research framework is provided in this paper to benefit other similar energy R&D organisations seeking to prioritise research efforts towards greater demand-side flexibility.

Introduction

As energy systems in Australia advance towards an age of decarbonisation, they face the technical challenge of substituting consistent, dispatchable, thermal power generation with highly variable renewable generation. Resolving this problem will involve a combination of energy storage, backup generation and demand-side management (DSM) (AEMO, 2020). Traditionally, DSM in Australia has focussed specifically on reducing demand at periods of grid peak demand, such as during extreme weather events or network emergencies. While this function is critical to electrical grid reliability, Flexible Demand (FD) is an emerging concept that extends the role of DSM to a wider scope of functions and services, where management of end-use consumption is also regarded as a distributed energy resource (DER). The concept of FD also incorporates increase in consumer demand when excess electricity is available (such as in times of surplus renewable generation). It includes new roles for demand-side resources such as maintaining reliability and contingency reserves, providing ancillary services, optimising renewable integration and yielding a variety of benefits for consumers (Swanston, 2021).

1. Renewable Energy and Load Management for Industry Report, 2017.

2. Energetics, 2020.

3. Solar Optimisation Upgrades in the Victorian Commercial and Industrial Sector, 2019.

Table 1. Summary of Performance Metrics and typical values for FD services.

Metric (units)	Shape	Shift	Shed	Shimmy
Capacity (Watts)	Permanent Load Change	Cyclical Load Change	One-off/event load reduction	Continuous change in load
Energy (Watt-hours)	No net change in consumption. Increased VRE consumption.	No net change in consumption (in principle). Increased VRE consumption.	Reduction in net consumption (except with embedded generation cases).	No change to net energy balance over the duration of response.
Notice Period (time)	Days – months	Hours – days (needs price/ VRE forecasts)	Minutes – hours	Seconds – minutes (usually automated)
Response Time (time)	N/A	Minutes	Minutes	Seconds-minutes
Response Duration (time)	N/A	Hours	Hours	Seconds-minutes (regulation) minutes-hours (load-following)
Physical Availability (activations/time)	Permanent.	A few times per day or per week.	Depends on FD asset.	Continuous or multiple times per day.
Carbon Abatement (kg CO_2e)	Increased VRE utilisation.	Increased VRE utilisation.	Reduced peaking thermal (fossil fuel) capacity requirement.	Reduction in other (fossil fuel) ancillary service sources.

One approach to the definition and categorisation of FD is proposed by the Lawrence Berkeley National Laboratory. In a study assessing the potential and cost of future demand response resources in California (Alstone *et al.*, 2017) developed a taxonomy for flexible loads to describe a diversity of services across different timescales. This taxonomy divides FD resources into 4 main categories:

1. Shape FD is defined as resources that modify the load of an end-user on a consistent or permanent basis, such as through Time-of-Use (TOU) tariffs or programs that change consumer behaviour.
2. Shift FD represents load changes that optimise the use of surplus renewable generation or exploit fluctuations in market prices (times of surplus renewables usually have lower, or even negative prices).
3. Shed FD is the more conventional form of load-flexing, providing downward DR. Loads are curtailed during periods of high demand, without compensating it with increased energy use at other times.
4. Shimmy FD is the most dynamic form of load-flexing, involving rapid response to changes in system demand that affect stability and quality of delivered power.

Table 1 provides a summary of the various performance metrics for the FD categories. A critical review of academic and grey literature on the topic of FD in Australia has been conducted. While not a systematic review, this paper aims for comprehensiveness by utilising aspects of a rapid review process specified by the Reliable Affordable Clean Energy (RACE) for 2030 Co-operative Research Centre[4]. The process involves defining research questions and compiling literature resources by conducting keyword searches on selected databases. Then, the literature is screened according to selection protocols designed to filter all but the most relevant references. The key questions that this paper seeks to answer are:

1. How much flexible demand resource is available in the Australian energy system?
   a. What is the reported technical and economic potential?
   b. Which type of loads and sectors demonstrate the greatest opportunities for flexible demand?
2. What barriers account for the most significant difference between the economic potential for exploiting flexible load opportunities and those that are realised? Which barriers are realistically susceptible to being removed/influenced to realise significant flexible load opportunities?
3. What areas of research most effectively address the most susceptible barriers for greatest impact?
   a. How can Industry 4.0 technology overcome barriers to flexing C&I energy demand?
   b. How can novel pricing and/or incentive options overcome barriers to flexible demand?

The size of the prize: how much flexible demand resource is available in Australia?

FLEXIBLE DEMAND IN AUSTRALIA TODAY

This section provides an overview of Australian sources of FD. For each flexible load we searched for a description of: services it can provide, how it is operated, which energy actors are involved, the associated costs and the technical potential to provide FD. While load shaping is expected to be possible with all loads, Table 2 summarises each load's ability to provide shift, shed or shimmy services, following (Potter and Cappers, 2017).

This review of FD sources in Australia has revealed significant gaps in information, particularly in the costs of providing services, and the potential capacity of individual sources. There are significant sources of FD in the international context that

4. RACE for 2030 CRC is a 10-year co-operative research program with AUD 350 million of resources to fund research towards a reliable, affordable and clean energy future: https://www.racefor2030.com.au.

Table 2. Summary of FD sources in Australia by the services they provide (Green: already present in Australia. Orange: emerging applications. Red: not currently applicable).

FD source	Description	Shift	Shed	Shimmy
Heating, Ventilation & Cooling	HVAC resources are from electrified (not gas) space heating or cooling. C&I electrified HVAC is provided by sites such as shopping centres, office buildings and universities. Currently, only shed FD from HVAC systems has been implemented in Australia. An example of space conditioning shed FD is **Energy Queensland's Peak Smart A/C program with 89 MW of FD capacity** (Energy Queensland, 2019).	Orange	Green	Orange
Hot Water Systems	Electric hot water systems (HWS) are a significant source of FD. Usually integrated with thermal storage, they permit temporal decoupling of energy consumption from service end-use. There is a long history of HWS load-shaping in Australia, with controlled-load tariffs and built-in time switches (SA Power Networks, 2014). **Some Queensland programs have registered up to 771 MW of controlled load-shaping capacity**.	Green	Green	Orange
Pool Pumps	Pool pumps are a significant source of FD in Australia: 13 % of the population live in a house with a swimming pool. Furthermore, the many commercial aquatic centres in Australia likely have significant pump loads. Pool pump FD has only been implemented locally as shed resources (Potter and Cappers, 2017), however these appliances could likely provide further services through ADR. Extrapolating from pool numbers, it is likely that **upwards of 1.2 GW of FD capacity is available in Australia**.	Orange	Green	Red
Other Domestic Appliances	Other domestic appliances, such as washing machines and dryers, can provide shed FD using DLC and BDR (Energy Queensland, 2019), though potential is limited by short and often unscheduled utilisation periods. Provision of shift and shimmy services from these appliances could be improved with increasing penetrations of smart appliances and implementing ADR control. **As much as 48 MW of load-shaping FD capacity has been developed for other domestic appliances in Queensland**.	Red	Green	Red
Electric Vehicles	EVs are essentially mobile battery storage and can provide shift, shed and shimmy FD by using vehicle-to-grid (V2G) smart-chargers and ADR (Potter and Cappers, 2017). A current Jemena Electricity Networks trial (with ARENA) has recruited 176 EV owners across three states to install smart charging infrastructure at home (ARENA, 2021).	Orange	Orange	Orange
Electrical Energy Storage	The most significant form of electrical energy storage for consumer FD is battery energy storage systems (BESS). BESS are perfect for FD, as they can alternate between drawing and discharging power, providing all FD services.	Green	Green	Green
Thermal Energy Storage	Thermal energy storage for FD provides services indirectly by buffering the electrical load of the connected appliance (Institute for Sustainable Futures and Australian Alliance for Energy Productivity, 2020). As with BESS and HWS, other thermal storage can provide shed and shift FD, as well as shimmy FD with sufficient control capability.	Orange	Orange	Red
Industrial Processes	Industrial processes are a well-established FD source used predominantly to provide shed resources for contingency or emergency events (Petkovic, 2020). Further developments are focussed on shifting FD to optimise onsite solar consumption or to capitalise on low market prices (Wyndham *et al.*, 2019b). It is unclear whether industrial process interruption could provide shimmy FD, as businesses require long notification periods. **In Australia, the potential of industrial shed FD has been estimated in 2014 at approximately 3.8 GW, or 10.5 % of total network demand** (Climateworks, 2014).	Orange	Green	Red
Embedded Generation	Embedded generation is any power generation behind the meter, and in Australia mainly consists of solar PV and standby diesel generators. The GPT group in Australia uses standby generation to provide between 284 kW and 360 kW of load shed from its office building portfolio. However, this creates conflicting impacts, saving costs with an increased carbon footprint. **The potential of embedded generation FD is substantial and estimated to be at least 2 GW** (Petkovic, 2020).	Orange	Green	Red
Material or Inventory Storage	Materials or inventory storage is primarily relevant to the industrial sector where an excess of processed intermediary or final products is stocked as a buffer. Some processes can be interrupted voluntarily without impacting business output. An Australian example is North East Water's storage of excess water in tanks, allowing temporary price-responsive curtailment of water treatment.	Orange	Green	Red
Conservation Voltage Reduction (CVR)	CVR is an asset-independent FD source that uses changes in grid voltage to provide flexible loads. United Energy has a Dynamic Voltage Management System to provide shed services by coordinated reduction of substation voltages (United Energy, 2020). **United Energy can consistently provide 30 MW load response with minimal impact to consumers.** It has also demonstrated shimmy for FCAS with dynamic voltage control.	Red	Green	Orange

this review has found little evidence for in the Australian literature. These sources include, but are not limited to:

- Electrified C&I hot water systems (Wohlfarth, Klobasa and Gutknecht, 2020)
- Commercial refrigeration (Hirsch *et al.*, 2015)
- Data centre cooling systems (Ghatikar *et al.*, 2010)
- Commercial/service sector lighting (Khorram *et al.*, 2018)
- Variable frequency drives (VFD) and variable frequency pumps (VFP) (Alstone *et al.*, 2017)
  - Fan and ventilation advanced controls
  - Agricultural or water service pumping

FLEXIBLE DEMAND IN AUSTRALIA TOMORROW

Looking to the next viable tranche of FD in Australia, the FD potential for different sectors is reviewed here. Based on electricity consumption and current engagement in demand response schemes in the above, it is estimated that approximately half the industrial subsectors have a moderate capacity for FD. Industries with more limited potential are metals: both non-ferrous and iron & steel; food processing; and chemicals. This is primarily due to the limited flexibility of, and importance of energy in, their production processes. The oil & gas extraction subsector has particularly poor potential. Most emerging FD opportunities appear to be in the commercial sector. This is because 1) many large-scale industrial plants are already strongly participating in demand response; and 2) enabling technologies (often categorised as "Industry 4.0") are becoming available to aggregate (through advanced monitoring and control technologies) loads across organisations. Thus, this section is focused on prioritising prospective flexible loads in smaller industrial and larger commercial businesses.

Given typical commercial arrangements in these sectors – where businesses are often independently operated – a successful FD solution must be replicable and scalable. Thus both the load and the sector should be homogenous and ubiquitous, as well as, of course, feasible. Feasibility entails not only techno-economic potential, but also the realistic potential, to acknowledge the behavioural factors associated with activating demand-side resource. Table 3 outlines a qualitative framework for assessing these four factors in a "HUFF Matrix" for both sectors and loads.

Each factor is given a score from 1 to 3 based on the qualitative assessment described above. The score for the type of electricity load is calculated as the sum of each of four factor scores for a result ranging from 4–12, with the sector score calculated similarly. Each load and sector scores for the C&I sectors were multiplied to deliver an overall matrix with scores ranging from 16–144 (Tables 4 & 5).

Priority loads and sectors

Given the results in the tables, it appears that the key C&I sectors that show the most promise for future development in Australia, with a score of 90 or above, are:

- **Agriculture.** With more than 85,000 agribusinesses in Australia and many flexible loads onsite, there seems to be large untapped potential. Although few agribusinesses in Australian are in demand response schemes, irrigators in South Africa have participated in DSM since 2004 (Storm, Gouws and Grobler, 2016).
- **Manufacturing.** Manufacturing consumes over half of Australia's industrial energy with more than 86,000 businesses.

Table 3. "HUFF Matrix" scoring framework – homogeneity, ubiquity, feasibility (techno-economic), feasibility (actual/realistic).

Load				
Score	**Homogeneity**	**Ubiquity**	**Feasibility** *(techno-economic)*	**Feasibility** *(realistic)*
1	Businesses need to design a bespoke version of the equipment to flex	<1,000	Enabling control technologies are unavailable	No proven examples of flexing this load
2	Businesses can buy the equipment off the shelf but need an external aggregator/controller	<10,000	Some enabling technologies available at reasonable costs	Proven examples of flexing this load abroad or domestically
3	Businesses can buy the equipment off the shelf and install/flex it themselves	>10,000	Many enabling technologies available at low, competitive costs	Proven examples of flexing this C&I load in Australia
Sector				
Score	**Homogeneity**	**Ubiquity**	**Feasibility** *(techno-economic)*	**Feasibility** *(realistic)*
1	This sector's businesses have bespoke operations, designed specifically for purpose	<1,000	Assets not designed for flexibility & large significant expenditure required needed to redesign **or** electricity consumption <1 % of total industry	No proven examples of flexing this load
2	Businesses can operate in different ways but use off-the-shelf equipment	<10,000	Assets have some inherent flexibility & could be improved with investment **and** electricity consumption is <2 % of total industry	Proven examples of this sector flexing demand abroad
3	Businesses operate in a very similar manner, with the same off-the shelf equipment	>10,000	Assets are ready-to-flex at low-cost given appropriate control technologies **and** electricity consumption is >2 % of industrial	Proven examples of this sector flexing demand in Australia

Table 4. The "HUFF Matrix" across industrial sectors.

	Refrigeration	Heat pumps	Irrigation	Thermal storage	Processes	Material storage	Embedded generation	Electrical storage
Iron & Steel		56		56	70		70	63
Pulp & Paper		64		64	80	64	80	72
Cold stores	72	72		72			90	81
Water utilities		72		72	90	72	90	81
Agriculture	80	80	90	80	100		100	90
Mining		64		64	80		80	72
Chemicals	56	56		56	70		70	63
Cement		64		64	80	64	80	72
Manufacturing	80	80		80	100		100	90
Aluminium		56		56	70	56	70	63

Table 5. The "HUFF Matrix" across commercial sectors.

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

Several manufacturers are already participating in Australia's emergency DR scheme "RERT".

- **Water utilities.** While there are fewer than 200 water and wastewater businesses in Australia, they consume 2.6 % of Australia's industrial energy. There is significant interest in FD from large water utilities. Some, like North-East Water in Victoria, are already exposed to wholesale spot prices.
- **Apartments.** The sheer number of apartment blocks would be a huge resource if certain loads could be made flexible, particularly given most of Australia's annual peak demand days are driven by residential air conditioning. The European "DR-BOB" pilot at Teeside University and Cluj Napoca University has been testing the FD capacity of residential highrise buildings, which could be applied in Australia.
- **Public buildings.** While public buildings tend to be heterogeneous – including schools, hospitals, offices, prisons, sporting and arts facilities – there are several examples of Local Governments successfully participating in demand response and wholesale price exposure.
- **Supermarkets.** HVAC&R is a large opportunity for supermarkets to engage with FD, however there is concern within industry given the perishable nature of their product. A pilot test has been undertaken by NREL in the US and UK that could also be tested in Australia (Hirsch *et al.*, 2015).

Within these sectors, specific loads that could be leveraged more easily through the emergence of new technologies or business models may be:

- **Embedded generation in the industrial sector.** Standby backup diesel generation has been proven to provide emergency response. There are opportunities to expand this to renewable options such as biodiesel and/or "soaking" more onsite solar (Wyndham *et al.*, 2019b).
- **Industrial processes.** While this is a well-established form of FD, it is industry and process specific. A particular opportunity that has not been fully realised is water pumping, including irrigation (see above).

- **HVAC in commercial buildings.** HVAC&R uses more than 22 % of Australia's electricity. There are examples of shedding HVAC through Energy Queensland's Peak Smart Program (Energy Queensland, 2019), however this could be expanded to include pre-cooling options.
- **Electrical storage.** An ideal flexible load – which can shape/shed/shift/shimmy – however often with payback periods of 5–10 years that are outside most C&I business case thresholds (Wyndham *et al.*, 2019a).

Which barriers to flexible demand could be unlocked by research?

The analysis above suggests that there is a significant gap in Australia between the techno-economic potential of FD, which is yet to be fully characterised, and the "actual" potential (Wohlfarth, Klobasa and Gutknecht, 2020). The actual potential is the FD resource that is economically feasible from the end-user's perspective and what remains after other barriers take effect. These "institutional barriers" include: regulatory hurdles; externalities and price structures; the payback gap; split incentives; a lack of information; cultural barriers; and general confusion about preferred actions (Dunstan *et al.*, 2011). For example, although many physical assets and technologies currently provide FD services, most are used only for load-shedding. While there are many pilot projects to extend these capabilities, particularly load-shifting, their ultimate impact on the energy system is uncertain. Furthermore, economic potential is difficult to determine given the scarcity of cost information.

There are numerous barriers specific to FD in the literature. However, the important question is which are relevant to contemporary Australian electricity markets. Table 6 organises barriers according to commonly used categories in the literature and matches them against both (i) actors in the electricity market (regulators & planners, networks, aggregators, and retailers), and (ii) customer sectors (industrial & large customers, commercial & medium scale customers, or residential & small scale customers). The importance of these barriers are colour coded to indicate relative importance. Red in a given electricity market actor category indicates that the barrier is recognised as being highly relevant, or that it is their responsibility to address the barrier. For customer categories, red indicates that the barrier is perceived as highly relevant (whether strongly recognised by the customer or not). Green and yellow represent low and medium relevance/responsibility.

The table shows that there are many barriers that are highly relevant to several actors and customers. Key points are summarised below. The biggest **economic barrier** is lack of certainty, from the perspective of all actors, of net benefit, which is needed to justify investment (Nolan and O'Malley, 2015). This is due to a lack of market transparency, high transaction costs for retailers and aggregators, and the relatively small residual benefits for the customer (particularly if they are medium to small business). This could be a target for effective energy policy and regulatory reform.

Regulatory and policy barriers affect energy market participants and customers in different ways. Participants need more clarity on the role and priorities of regulators, better co-ordination of regulatory activities, and a level playing field for FD resources (Greening, 2010). Existing regulations, including technical standards, may favour incumbent, supply-side solutions, discouraging customer engagement (Moreno, Pudjianto and Strbac, 2012).

Market barriers are most keenly felt by the customer. Incentives are often not attractive or cost-reflective and, due to a lack of transparency, there is low commercial certainty of a return on investment (Dunstan *et al.*, 2017). This makes it challenging to justify high capital costs for large (thus impactful!) FD investments.

A critical **behavioural and cultural barrier** in the electricity industry may be cultural bias in favour of centralised, capital intensive, and supply side solutions, which is not necessarily recognised by regulators who work on the assumption that market behaviour is economically rational. Institutional structures, by definition, impose some degree of inertia which mutually reinforces the cultural bias (Engelken *et al.*, 2016). Behavioural factors, misaligned incentives, and perceived risks of disruption are significant barriers to customers. Industrial FD can impact on production, and many customers are constrained by legacy capital equipment and operational logistics that were designed for least cost rather than operational flexibility to enable agile business strategies (CADMUS, 2018). In the commercial sector, smaller energy savings from smaller site loads can be difficult due to challenges with interoperability and scalability for sufficient resource (Kim and Shcherbakova, 2011).

OVERCOMING BARRIERS TO FLEXIBLE DEMAND THROUGH INDUSTRY 4.0

One on the key strategies for overcoming barriers to FD in the commercial and industrial sectors fall under the umbrella of "Industry 4.0" – the fourth industrial revolution – that is, the digital transformation of industry. Industry 4.0 is inherently "enabling informed yet autonomous decisions" for flexibility and agility (Ghobakhloo and Fathi, 2021), which directly translates to the objectives of FD. Innovations that can facilitate these and other solutions include: artificial intelligence (AI), Internet of Things (IoT), remote control, robotics and automation, and cloud computing. In a study of 163 interventions to encourage FD (Faruqui and Sergici, 2013) find that enabling technologies, such as automated load control, systematically increases responsiveness to time-varying pricing. These advances have the potential to overcome technical (metering, communication, control and aggregation), economic (transparency and engagement), market (capacity), and behavioural barriers.

To assess the current state of Industry 4.0 for FD, this research uses the CSIRO framework for Digital Innovation that describes how digital innovations combine to create business processes that integrate data through to decision making. The cycle of advanced data systems moves from data capture, through data management, and data analysis, to decision and action (AlphaBeta, 2018). Applied to FD, this framework can account for key Industry 4.0 technologies in the electricity industry:

- Data capture: IoT (including new sensors) and digital twins of loads, sites or even customers
- Data management: energy and building management systems (EMS/BMS), digital user interfaces, behind the me-

Table 6. Flexible demand barriers by stakeholder role and customer segment.

Barrier	Regulators	Networks	Retailers	Aggregators	Industrial	Commercial
	Actor				*Customer*	
Technology Barriers						
Metering: More (and improved) metering is required for network visibility and for financial settlement	Amber	Red	Red	Red	Amber	Red
Communication and control: • Communications connectivity and automation is required to integrate end-users with markets for firm capacity • Changing consumer consumption patterns is difficult without automation • Lack of standards and interoperability impact on scalability in the commercial sector	Green	Red	Amber	Amber	Amber	Red
Aggregation: High proportion of demand is required to be responsive to fulfill the needs of many electricity industry applications	Amber	Red	Amber	Amber	Green	Amber
Economic Barriers						
Certainty: More certainty of net benefit is required to justify investment	Red	Red	Red	Red	Red	Red
Transparency: Many markets are either absent or lack transparency	Amber	Red	Amber	Red	Amber	Amber
Engagement: Retailers face high transaction costs and end-user apathy	Green	Amber	Red	Amber	Amber	Amber
Business case: • Customer savings may not be material to overall financial consideration • Smaller energy savings from smaller site loads makes the business case more difficult	Amber	Amber	Amber	Red	Red	Red
Regulatory & Policy Barriers						
Policy priorities: • Clarity is required on the role and priorities of regulators • Lack of targets to support improved prioritization of FD	Red	Red	Red	Red	Amber	Amber
Inertia: Technical standards favour incumbent solutions	Amber	Red	Amber	Red	Red	Amber
Level playing field: Network services from FD need a supportive regulatory framework	Amber	Red	Amber	Red	Red	Amber
Competition: Aggregators require a level playing field with other actors in the market	Amber	Amber	Amber	Red	Red	Red
Market Barriers						
Incentives: Buyers of FD lack strong financial incentives	Amber	Amber	Amber	Red	Red	Red
Capacity: More clarity is required on registration of capacity in markets and how to determine demand response baselines	Amber	Amber	Amber	Red	Red	Red
Capital: Access to capital may be an issue for high capital cost interventions	Green	Green	Green	Amber	Red	Red
Pricing: Cost reflective options are often not offered to industry and a fair proportion of value created from FD may not be passed-through to industry	Green	Green	Amber	Amber	Red	Red
Behavioural & Cultural Barriers						
Cultural biases in favour of supply side solutions exist in the electricity industry	Red	Red	Red	Red	Amber	Amber
Behavioural factors: • A range of behavioural factors impact on customer perceptions e.g. misaligned incentives, and perceived risks of disruption • Financial benefits, risk, ease-of-use, and trust, are important factors for customers	Green	Green	Amber	Red	Red	Red
Risk to production: Load flexing in the industry sector can impact on production	Green	Amber	Amber	Red	Red	Amber
Government procurement: Government building portfolios could influence the market but must overcome internal purchasing/ decision making barriers	Green	Green	Amber	Amber	Green	Red

ter aggregation (e.g. Virtual Net Metering Infrastructure (NMIs), peer-to-peer trading via blockchain)

- Data analysis: applications of AI such as forecasting or designing schedules or pricing schemes
- Decision and action: Distributed Energy Resource Management Systems (DERMS, which are largely for commercial customers), Automated Demand Response (ADR) and transactive control

This section summarises relevant peer-reviewed and industry research under the framework for digital innovation, to identify the key technological improvements under Industry 4.0 that could unlock substantial FD resource. These technological improvements are likely to be impactful options for targeted research funding in the future.

Data capture – the Internet of Things (Kailas, Cecchi and Mukherjee, 2012; Onile et al., 2021)

The concept of IoT is creating a local network of devices – e.g. loads, generators, sensors – that can enable energy management applications to monitor and control. It is about building a *platform* for communication[5]. There no definitively 'best' IoT platform, and choosing one requires a number of tradeoffs. The key tradeoffs that need to be considered are: range, power consumption, interoperability, bandwidth and cost. For instance, cellular networks are a widespread and reliable option, but often come at a high financial and energy cost. ZigBee is a lower cost wireless option, while still being reliable, however it is not as easily integrated, requiring a ZigBee to IP translation. LPWANs are emerging as a strong internet-connected alternative that is low cost and low bandwidth, however these technologies are still under active development. **Thus, investigating IoT options, particularly LPWANs, for FD applications is a promising candidate for future research.**

A data capture innovation complementary to IoT is the advent of digital twins. Digital twins have been defined as "a virtual representation of a rare or real-life assets such as services, products or machine with the models" (Onile *et al.*, 2021). They allow real-time data to be integrated, analysed and manipulated without adverse consequences to the machine itself e.g. different process schedules to maximise FD can be tested on the digital twin before onsite implementation, reducing unforeseen impacts if the FD strategy is not successful. The usefulness of a digital twin for IoT platforms for FD are expected to be threefold:

- Better energy consumption forecasts, which can help shore up a business' FD resource
- Better understanding of behavioural factors, that will improve energy management services
- Optimising machine/device operations by intelligent service updates e.g. by responding to market signals or early detection of faults

Several commercial offerings of digital twins have already entered the market – e.g. Honeywell's energy monitoring software and ABB's PV solution product – however there is still **a very active research area investigating how digital twins can maximise and extend FD resources that could be further explored.**

Data management systems

Information provided by IoT platforms is only useful if acted on e.g. via an EMS or BMS. However, an EMS or BMS does not require an IoT platform. While an EMS/BMS needs information to recommend action, it can be from un-networked sensors or monitoring devices. While they can directly control the devices that are managed, they can instead passively provide information to a manual operator. There are many EMS/BMS commercially available. Thus, innovations in the provision of data to the EMS/BMS (new IoT and AI options) and device control once that data has been received (e.g. ADR, market platforms) appear to be fruitful areas for research.

A promising area of data management for the development of new market mechanisms, is aggregating devices, sites and/or customers behind the meter. Some Australian businesses have aggregated loads and generators (e.g. wastewater treatment, refrigeration, onsite generation) under a "Virtual NMI" to maximise benefits from FD e.g. by "soaking up" more onsite solar to reduce electricity costs. A similar approach for different business sites or even different customers (e.g. peer-to-peer trading) is possible, though may not be supported by current market regulations. **Novel business models within the current rules and reform options to improve energy market regulation may be two options for policy researchers to pursue.**

Data analysis – applying Artificial Intelligence (Antonopoulos et al., 2020)

AI, the study of intelligent agents, is a popular research area across many disciplines and FD is no exception. An agent is anything that can perceive its environment and act upon it, and there are many areas where improved data analysis through AI can assist FD. In particular, there are significant research efforts towards more accurate load and price forecasting and/or better (including more granular) control of loads. Four AI approaches[6] show promise for future research:

- Reinforcement learning (a subset of machine learning) for dynamic control (e.g. ADR) of aggregated assets. This is particularly relevant for smaller residential and commercial loads, which are often heterogeneous and distributed. However, **there is room to improve the reliability of the method, which is still less mature than model predictive control methods.**
- Multi-agent systems have been shown to be useful in designing pricing and incentives for similar groups of disaggregated entities. In these cases it is critical to factor in the interests and objectives of the participating entities for best practice design. However, **these are highly complex problems to solve and may be best approached in a hybrid manner in future research.**

5. There are many options for a platform, which can be either wired or wireless. Wired communication requires an electrical, telephone or optical fiber line e.g. ethernet or fiber optic. Wireless, radio frequency, communication has overtaken most wired options. Common wireless options are cellular (3/4/5G), WiFi, Zigbee, Bluetooth (BLE) and Low Power Wide Area Networks (LPWANs e.g. LoRaWAN).

6. A useful visual representation of corresponding methods is provided in (Antonopoulos *et al.*, 2020).

- Nature-inspired algorithms have also been used pricing and incentive design, as well as task scheduling. However these are less common, and have had issues with premature convergence and unpredictable results.
- Artificial Neural Networks are sometimes considered categories of either machine learning or nature-inspired algorithms. However, ANNs are strongly utilised in FD applications, particularly forecasting. **There is an opportunity to extend previous research from "single-layer ANN" to Deep Learning, where there are two or more layers for multiple levels of machine learning.**

There is also a gap in research on the commercial & industrial (C&I) sector, as most research has been conducted on residential customers. AI research is well suited to smaller C&I loads that are heterogeneous, disaggregated, and owned by different entities each with their own interests.

Decision and action – advanced control (Samad, Koch and Stluka, 2016; Hu et al., 2017)

Much proposed AI research relies on the deployment of ADR. While ADR is not new – the OpenADR Alliance was formed by industry in 2010 – it is still far away from reality. The potential of FD will not be realised without it, since human intervention time scales are too slow for real-time responsiveness for many applications e.g. "shimmy" FD. Most examples of ADR to date have been in either HVAC or lighting, thus there are many options to expand its application in pilots or demonstrations.

In addition to remotely controlling loads, there is also a need to transact with the market. Current options are limited and, in Australia, require a Market Participant i.e. a retailer or aggregator who transacts on behalf of a customer directly into the market or through a contract for service. Transactive control is "a framework that enables actors to interact with each other through an economic signal, in order to optimize the allocation of resources" (Hu et al., 2017). This is an attractive solution for controlling and coordinating a disaggregated suite of DER that is expanding on distribution networks worldwide. While many versions of transactive control have been implemented, they are largely either: a one-time information exchange (e.g. the more commonly applied clearinghouse, useful for designing real-time controllers); or an iterative information exchange (more useful for real-time scheduling). Most commercial demonstrations of transactive control use the simpler strategy but emerging research is investigating iteration, particularly for EV smart charging. The decentralised energy exchange (deX), developed in 2017, is an Australian example.

Areas for future research in ADR and transactive control include: understanding the responsiveness of DER for different customers; creating standard, efficient, and transparent, markets and interfaces for customers; characterising baselines for accurate transactions; and modelling lead and rebound effects.

OVERCOMING ECONOMIC BARRIERS TO FLEXIBLE DEMAND THROUGH PRICING AND INCENTIVES

While technical solutions will go some way to addressing barriers to FD, another key lever is better incentives and/or pricing. Rebates and cash inducements, are frequently offered to encourage demand side management. A smaller proportion of programs are based on tariff or pricing based incentives. Other incentives include subsidised improvements to customer energy efficiency (free or subsidised equipment, discounted equipment from facilitated bulk purchase, attractive finance terms) and gifts or merchandise. However, there is significant opportunity to innovate pricing and incentives to achieve a better outcome for both the customer and buyer of FD. If successful, these novel mechanisms have the potential to overcome economic (certainty, engagement and business case), market (inertia and level playing field), market (incentives, capital, capacity and pricing) and cultural bias barriers.

If tariffs or pricing incentives are to encourage the discretionary deployment of demand flexibility, they must be dynamic (time-varying). This includes time-of-use tariffs with relatively muted difference between peak and off-peak prices, and critical peak pricing tariffs or peak time rebates, with typically shorter and more infrequent peak periods featuring a larger price premium. There is strong evidence that a larger price premium increases the magnitude of the demand response, although this effect eventually saturates (Faruqui and Sergici, 2013). And of dynamic pricing schemes, those with larger peak premiums were found to be most popular in a survey of United States industrial customers (Wang and Li, 2015). Dynamic pricing is suitable to incentivise shift demand response for addressing the variable generation of renewable energy or narrowing extreme loads (maximum and minimum loads) on network infrastructure. To further encourage FD deployment that will promote savings in network investment, network tariffs could move to much higher peak prices during periods where total demand is close to peak. For large customers, the terms and conditions for calculating network charges, such as for maximum demand, could be better designed to encourage FD deployment at the appropriate time periods, and be guaranteed to be maintained for sufficiently long contract periods to support investment payback.

However, dynamic energy tariffs are not as appropriate for encouraging shed and shimmy FD. Encouraging additional shimmy resources would entail facilitating further participation in the frequency control ancillary services market, which may require aggregation across numerous customers to meet minimum scale market entrant requirements. Existing contracts for demand response rely on high quality standards of metering of individual customers for measurement and verification. There may be scope for lower cost verification of demand response that has been aggregated over numerous small contributors, such that the deemed response is inferred probabilistically rather than determined to a high degree of accuracy.

Encouraging additional shed resources to be made available could be achieved through the existing system reliability schemes – e.g. Australia's Reliability and Emergency Reserve Trader scheme – by **increasing transparency regarding conditions under which the market operator is willing to pay for demand response capacity (availability) rather than only delivery**. Additional incentives (or mandates) could be provided to **register demand response capability through the wholesale demand response mechanism**. This would increase the visibility of the capability, and improve transparency and predictability of the wholesale market, rather than relying on observations of past behaviour to estimate wholesale market demand elasticity (implicit demand response). It has further been recommended that **energy use intervention schemes**

should not only offer rewards, but also concurrently include elements of both providing information and employing social influence (Mazur-stommen and Farley, 2013).

To facilitate better pricing and incentives, it is imperative that market regulations support a "level playing field" for FD with traditional network investments. At least three principles should be upheld:

- Retailers and intermediaries engaging in demand flexibility should not be overly disadvantaged compared to network operators, and emerging intermediary market participants are not overly disadvantaged compared to incumbent retailers with existing customer relationships;
- Regulations should be actively investigated to confirm they do not present unnecessary barriers to the formation of FD trading markets; and
- According to (Pérez-Arriaga, Jenkins and Batlle, 2017), regulators should more explicitly assign responsibility for collation of, storage of, and access to, energy market relevant data and information.

Conclusions: which areas of research can unlock the most flexible demand?

This paper provides a useful framework for policy makers to evaluate and prioritise research and development opportunities to unlock greater FD resource. This is of great importance as countries seek to decarbonise their electricity sectors and integrate high proportions of variable renewables on electricity grids. Using the terminology pioneered by Lawrence Berkeley National Laboratory – shape, shift, shed, shimmy – the framework is delivered in four stages: 1) a techno-economic assessment of the current and future FD resource; 2) an evaluation of the most prospective sectors and loads for future research using the novel "HUF" (homogeneity, ubiquity, feasibility) matrix; 3) identifying barriers to FD in the local context and in relation to the priority sectors; and 4) identifying likely research priorities to overcome the most influential barriers.

When applying this framework to the Australian context, the research identified a suite of research priorities for the newly established $350 million 10-year Australian co-operative research centre – Reliable Affordable and Clean Energy (RACE) for 2030 CRC. The priority sectors that were identified for unlocking FD potential in Australia were agriculture, manufacturing and water utilities in the industrial sector, and apartments, public buildings and supermarkets in the commercial sector. Within these sectors, loads that offered the greatest FD potential were: embedded generation, particularly in the industrial sectors; industrial processes, particularly water pumping for irrigation; and heating ventilation and cooling in commercial buildings. Electrical storage is very attractive from a technical point of view, however the business case for C&I customers is still challenging.

The research identified two key research areas to overcome the major barriers to FD in these priority areas: advances towards Industry 4.0, and innovative pricing and incentives. Industry 4.0 research topics included:

- new IoT options and digital twins for better data capture;
- for improved data analysis using AI, improving the reliability of reinforcement learning approaches,
- hybrid approaches for multi-agent systems, and extending ANN approaches to two or more layers; and
- extending ADR and transactive control technology, particularly by better characterising baselines to understand rebound effects.

Research topics for improving pricing and incentives included: more deeply investigating optimal ratios of availability and delivery payments for FD resource in system stability programs; improving the registration transparency of wholesale market pricing programs, which would in-turn improve the predictability of the FD resource to ideally overcome cultural biases; and experiments to expand the remit of incentive schemes to also provide information and social capital to address behavioural barriers to FD uptake.

References

AEMO (2020) 'National Electricity Market Integrated System Plan', (July).

AlphaBeta (2018) *DIGITAL INNOVATION: AUSTRALIA'S $315B OPPORTUNITY*. Available at: https://data61.csiro.au/en/Our-Research/Our-Work/Future-Cities/Planning-sustainable-infrastructure/Digital-Innovation.

Alstone, P. *et al.* (2017) *Final Report on Phase 2 Results 2025 California Demand Response Potential Study Charting California's Demand Response Future*.

Antonopoulos, I. *et al.* (2020) 'Artificial intelligence and machine learning approaches to energy demand-side response: A systematic review', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, p. 109899. doi: 10.1016/j.rser.2020.109899.

ARENA (2021) *Jemena Dynamic Electric Vehicle Charging Trial*. Available at: https://arena.gov.au/projects/jemena-dynamic-electric-vehicle-charging-trial/ (Accessed: 7 February 2021).

CADMUS (2018) 'Assessment of Barriers to Demand Response in the Northwest's Public Power Sector', p. 183.

Climateworks (2014) *Industrial Energy Efficiency – Industrial demand side response potential*.

Dunstan, C. *et al.* (2011) *Institute for Sustainable Futures, UTS Institutional Barriers to Intelligent Grid: Working Paper 4.1 Intelligent Grid Research Program Project 4 Authors*. Available at: www.igrid.net.au.

Dunstan, C. *et al.* (2017) *Demand Management Incentives Review*. Available at: https://www.uts.edu.au/sites/default/files/article/downloads/Dunstanetal2017DemandManagementIncentivesReview_2.pdf.

Energy Queensland (2019) *Demand Management Plan 2019–20*.

Engelken, M. *et al.* (2016) 'Comparing drivers, barriers, and opportunities of business models for renewable energies: A review', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, pp. 795–809. doi: 10.1016/j.rser.2015.12.163.

Faruqui, A. and Sergici, S. (2013) 'Arcturus: International Evidence on Dynamic Pricing', *Electricity Journal*, 26 (7), pp. 55–65. doi: 10.1016/j.tej.2013.07.007.

Ghatikar, G. *et al.* (2010) *Demand Response and Open Automated Demand Response Opportunities for Data Centers*.

Ghobakhloo, M. and Fathi, M. (2021) 'Industry 4.0 and opportunities for energy sustainability', *Journal of Cleaner Production*. Elsevier Ltd, 295, p. 126427. doi: 10.1016/j.jclepro.2021.126427.

Greening, L. A. (2010) 'Demand response resources: Who is responsible for implementation in a deregulated market?', *Energy*. Elsevier Ltd, 35 (4), pp. 1518–1525. doi: 10.1016/j.energy.2009.12.013.

Hirsch, A. *et al.* (2015) *Pilot Testing of Commercial Refrigeration-Based Demand Response*. Available at: www.nrel.gov/publications.

Hu, J. *et al.* (2017) 'Transactive control: a framework for operating power systems characterized by high penetration of distributed energy resources', *Journal of Modern Power Systems and Clean Energy*. Springer Berlin Heidelberg, 5 (3), pp. 451–464. doi: 10.1007/s40565-016-0228-1.

Institute for Sustainable Futures and Australian Alliance for Energy Productivity (2020) *Renewable Energy and Load Management REALM for Industry Report*.

Kailas, A., Cecchi, V. and Mukherjee, A. (2012) 'A survey of communications and networking technologies for energy management in buildings and home automation', *Journal of Computer Networks and Communications*. Department of Electrical and Computer Engineering, University of North Carolina Charlotte, Charlotte, NC 28223-0001, United States. doi: 10.1155/2012/932181.

Khorram, M. *et al.* (2018) 'Office building participation in demand response programs supported by intelligent lighting management', *Energy Informatics*. Springer Science and Business Media LLC, 1 (1), p. 9. doi: 10.1186/s42162-018-0008-4.

Kim, J. H. and Shcherbakova, A. (2011) 'Common failures of demand response', *Energy*. Elsevier Ltd, 36(2), pp. 873–880. doi: 10.1016/j.energy.2010.12.027.

Mazur-stommen, S. and Farley, K. (2013) 'ACEEE Field Guide to Utility-Run Behavior Programs', *New Directions for Youth Development*, 2013(137), pp. 11–14. Available at: http://aceee.org/research-report/b132.

Moreno, R., Pudjianto, D. and Strbac, G. (2012) 'Integrated reliability and cost-benefit-based standards for transmission network operation', in *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*, pp. 75–87. doi: 10.1177/1748006X11424103.

Nolan, S. and O'Malley, M. (2015) 'Challenges and barriers to demand response deployment and evaluation', *Applied Energy*. Elsevier Ltd, pp. 1–10. doi: 10.1016/j.apenergy.2015.04.083.

Onile, A. E. *et al.* (2021) 'Uses of the digital twins concept for energy services, intelligent recommendation systems, and demand side management: A review', *Energy Reports*. Elsevier Ltd, 7, pp. 997–1015. doi: 10.1016/j.egyr.2021.01.090.

Pérez-Arriaga, I. J., Jenkins, J. D. and Batlle, C. (2017) 'A regulatory framework for an evolving electricity sector: Highlights of the MIT utility of the future study', *Economics of Energy and Environmental Policy*, 6 (1), pp. 71–92. doi: 10.5547/2160-5890.6.1.iper.

Petkovic, M. (2020) *Demand response in the National Electricity Market*.

Potter, J. and Cappers, P. (2017) *Demand Response Advanced Controls Framework and Assessment of Enabling Technology Costs*.

SA Power Networks (2014) *SA Power Networks: Flexible load strategy*.

Samad, T., Koch, E. and Stluka, P. (2016) 'Automated Demand Response for Smart Buildings and Microgrids: The State of the Practice and Research Challenges', *Proceedings of the IEEE*. Honeywell Automation and Control Solutions, Golden Valley, MN 55422, United States: Institute of Electrical and Electronics Engineers Inc., 104 (4), pp. 726–744. doi: 10.1109/JPROC.2016.2520639.

Storm, M. E., Gouws, R. and Grobler, L. J. (2016) 'Measurement and verification of irrigation pumping DSM projects: Application of novel methodology designs', *Journal of Energy in Southern Africa*. School of Electrical, Electronic and Computer Engineering, North-West University, Potchefstroom Campus, Private Bag X6001, Potchefstroom, 2520, South Africa: University of Cape Town, 27 (4), pp. 15–24. doi: 10.17159/2413-3051/2016/v27i4a1647.

Swanston, M. (2021) *Flexible demand: What's in it for the consumer?*, *Variable Generation, Flexible Demand*. Elsevier Inc. doi: 10.1016/b978-0-12-823810-3.00013-3.

United Energy (2020) *United Energy Demand Response Project Performance Report – Milestone 7*.

Wang, Y. and Li, L. (2015) 'Time-of-use electricity pricing for industrial customers: A survey of U.S. utilities', *Applied Energy*, 149, pp. 89–103. doi: https://doi.org/10.1016/j.apenergy.2015.03.118.

Wohlfarth, K., Klobasa, M. and Gutknecht, R. (2020) 'Demand response in the service sector – Theoretical, technical and practical potentials', *Applied Energy*. Elsevier Ltd, 258. doi: 10.1016/j.apenergy.2019.114089.

Wyndham, Joseph *et al.* (2019a) *Solar Optimisation Upgrades in the Victorian Commercial and Industrial Sector*. Available at: www.isf.uts.edu.au.

Wyndham, Joseph *et al.* (2019b) *Upgrades in the Victorian Commercial and Industrial Sector*. Available at: www.isf.uts.edu.au.