RACE for 2030
RELIABLE
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H3 / H5 Opportunity Assessment

Facilitating smarter homes

Final report

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What is RACE for 2030?

RACE for 2030 CRC is a 10-year cooperative research centre with AUD350 million of resources to fund research towards a reliable, affordable, and clean energy future. https://www.racefor2030.com.au

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1 Glossary of terms

Behind the meter (BTM)—A residential energy meter measures the net power flow of a home and doesn't include individual measurement of DER devices such as solar, battery, and flexible loads. These devices are located electrically behind the energy meter of the home and can be referred to as "behind the meter". Measurements taken of these devices are referred to as "behind the meter" measurements.

CT clamps—Electrical device with open jaws that clamps around a conductor to measure its current.

Demand Response (DR)—DR involves curtailing (either controlled or voluntarily) non-essential customer usage of flexible loads (A/C for example) during times of extreme demand or shifting usage to times of lower demand.

Demand response modes (DRMs)—Modes of operation for flexible loads, which can be requested by a third party during a demand response event.

Demand Response Enabling Device (DRED)—A device that provides the functionalities and capabilities to achieve demand response and that meets the requirements of standard AS/NZS 4755.

Distributed energy resource (DER)—DER are energy devices which are located electrically in the distribution network and are typically located in residential homes. Examples include rooftop solar, batteries, and flexible loads.

DER integration model—DER integration model is the way the behind-the-meter devices (solar, battery, and flexible loads) are managed and interact with the network.

Dynamic Operating Envelopes (DOE)—DOEs vary import and export limits over time and location based on the available capacity of the local network or power system as a whole.

Flexible load—A flexible load is a load which can have it's time of use shifted, this includes electric hot water systems, AC, and PPs.

Home Energy Management System (HEMS)—A HEMS is a system consisting of both hardware and software components that can effectively and efficiently manage the energy consumption and generation within a home or an aggregation of homes.

Internet of Things (IoT)—IoT refers to the interconnection of devices through the internet, making it possible for the devices to exchange data with each other. HEMS uses IoT to control internet-connected appliances automatically, often with mobile phone apps.

Machine learning (ML)—ML is a field of inquiry devoted to understanding and building methods that 'learn', that is, methods that leverage data to improve performance on some set of tasks.

Market services—Market services are a set of services provided to participants in the electricity market to enable them to trade electricity effectively and efficiently. Some examples include participation in the wholesale electricity market where electricity is trade between participants, and participation in the ancillary electricity market, such as the contingency Frequency Control Ancillary Services (FCAS).

National meter identifier (NMI)—The NMI is a unique number for a home or business and is used to identify every electricity connection point in the network.

Network capacity—Network capacity refers to the maximum amount of electricity that can be accommodated in an electricity network without adversely impacting its power quality or reliability for normal operation at any given time. Network capacity is defined by the combination of multiple factors, such as conductions and transformers, loads and generators. Also, the network capacity is dynamic as it can change depending on the load and generation at any given time, which in turn are affected by other factors such as weather conditions and customer preferences.

Network support services—Network support services are non-market services that may be delivered to maintain power system security and reliability. Some examples include procuring network services from DER to manage load peaks.

Operating Envelopes (OE)—OEs represent the technical limits within which customers can import and export electricity.

Smart meters—It is a device equipped with a digital two-way communication system that records households' energy use at least once every 30 minutes and sends this information to retailers on a daily basis.

Smart plugs—Smart plugs can be controlled via a mobile application, a smart home hub or voice-activated smart home technologies such as Google Assistant, Siri, and Apple HomeKit. Smart plugs communicate using the Wi-Fi, Bluetooth, Zigbee, and Z-Wave protocols.

Sensors—Sensors are analogue or digital transducers or actuators that can monitor everything from motion and temperature to humidity, sound, and light. They provide data about households' activity and environmental changes. This can help with HEMS automation functions.

Social licence for DOE—Informal permissions grated by stakeholders for institutions to make decisions on their behalf about the operation of their DER systems.

Virtual power plant (VPP)—A cloud-based distributed power plant that aggregates the capacities of DERs for the purposes of enhancing power generation, trading, or selling power on the electricity market, and demand side options for load reduction.

2 Abbreviations

A/C	Air conditioning
ABS	Australian Bureau of Statistics
ACCC	The Australian Competition and Consumer Commission
ACOSS	ACT Council of Social Services
ADR	Accredited data recipient
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
API	Application Programming Interface
ARENA	Australian Renewable Energy Agency
CBA	Cost-benefit assessment
CDR	Consumer data right
CDR-E	Consumer data right for energy
CEC	Clean Energy Council
CEC	Californian Energy Commission
CECV	Customer export curtailment value
CO_2	Carbon Dioxide
CPUC	California Public Utilities Commission
CSIP	Common Smart Inverter Profile
CSIP	Common smart inverter profile
CT	Current Transformer
CTA	Consumer Technology Association
CX	Consumer experience
DEIP	Distributed Energy Integration Program
DER	Distributed energy resource
DMO	Default Maximum Offer
DNN	Deep Neural Networks

DNSP	Distribution network service provider
DOE	Dynamic operating envelopes
DR	Demand response
DRED	Demand response enabling device
DRM	Demand response mode
DUoS	Distribution Use of System
ECA	Energy Consumer Australia
EECA	New Zealand Energy Efficiency & Conservation Authority
EHW	Electric hot water
EME	Energy Made Easy
EMS	Energy management system
ENA	Energy Networks Australia
EPRI	Electric Power Research Institute
ESB	Energy Security Board
EV	Electric Vehicle
FCAS	Frequency Control Ancillary Services
GET	Green Energy Trading
HEMS	Home energy management system
HVAC	Heating, ventilation, and air conditioning
ICT	Information and communication technologies
ILM	Intrusive Load Monitoring
IoT	Internet of Things
IPART	Independent pricing and regulatory tribunal
LGP	Limited generation profile
LV	Low voltage
MC	Meter coordinators
MCI	Modular communications interface
MDP	Meter data provider
ML	Machine learning

MP	Meter provider
MSO	Model Standing Offer
NEM	National Electricity Market
NER	National Electricity Rules
NERA	NERA Economic Consulting
NILM	Non-Intrusive Load Monitoring
NIST	National Institute of Standards and Technology
NMI	National meter identifier
OCPP	Open charge point protocol
OE	Operating envelope
OSCP	Open Smart Charging Protocol
P2P	Peer-to-peer
PAS	Publicly available standard
PIAC	Public Interest Advocacy Centre
PIP	Passive-interactive-proactive
PP	Pool pump
PQ	Power quality
PRISMA	Preferred items for systematic review recommendations
PV	Photovoltaics
RA	Research Activity
RERT	Reserve emergency reliability trader
RQ	Research question
RT	Research Topic
SAPN	South Australian Power Network
SM	Smart meter
SVDP	St Vincent De Paul
TL	Transfer Learning
VEC	Victorian Energy Compare
VPP	Virtual power plant

3 Introduction

This opportunity assessment (OA) reviewed the potential to maximise the benefits of improved energy technologies for Australian homes directly and for providing grid support and the potential for smart algorithms to assist customers to optimise energy choices, in the context of the clean energy transition. The expected benefits of improving home energy technologies include reducing energy bills, reduced carbon emissions, improved utilisation of rooftop solar and network power quality through provision of network services. The scope of the OA was guided by two themes:

H3: Using home energy technologies for grid support. This theme aims to address current and possible future energy supply industry practice and home energy technology standards to facilitate smarter energy use, particularly for load shifting, dynamic export limits, provision of reactive power and voltage support.

H5: Smart algorithms for optimising home energy supply and use. This theme seeks to identify opportunities for useful algorithms to reduce energy costs both for householders and for the energy system as a whole. Collaborating with customers, energy technology start-ups and energy utilities, this objective includes implementing real-world trials of such algorithms. Associated customer apps would seek to map a path for optimising the use of resources from retailers and more independent resources like Energy Made Easy and Consumer Data Right (CDR) for the benefit of customers.

This report consists of the following deliverables –

- State of the market and research literature review
- Research gaps and recommended research activities
- Technology and market potential scenario modelling
- Business opportunities
- Key metrics

State of the market and research literature review. The literature review is the core of the OA and informs the other deliverables. It consists of a review of the current state of the market and technology, and of the academic literature. The key outcome of this review is the identification of findings, barriers, and research questions (RQs) related to the expected medium-term and long-term outputs of the H3 and H5 themes.

The following deliverables draw on the findings and barriers identified in the literature review:

Research gaps and recommended research activities defined research questions and derived associated research activities or recommendations designed to address the research question and alleviate the barrier.

Technology and market potential scenario modelling modelled the technology and market potential for household flexible loads out to 2030 and 2035 for both a baseline and accelerated scenario(s). The barriers identified in the literature review were used as input into the modelling and the difference between the baseline and accelerated scenarios is defined by the extent to which these barriers are assumed to be resolved.

Business opportunities identified economic development or commercialisation opportunities for RACE for 2030 partners and the Australian economy in accelerating technologies and practices related to this research theme.

Key metrics propose impact KPIs and a formal measurement and evaluation process for quantifying the achievable value of the expected benefits which come from each recommended research project, particularly in relation to customer energy bill reduction and carbon emissions reduction.

A schematic describing the project activities and deliverables is given in Figure 1.

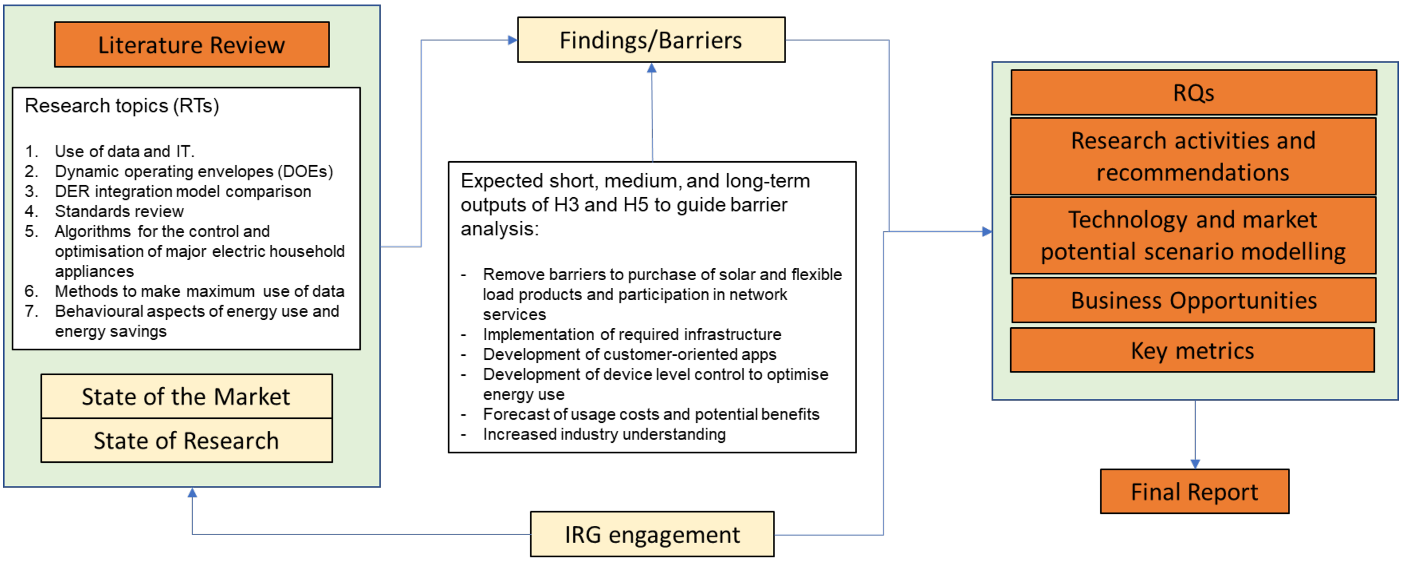

Figure 1 Project activities and deliverables

4 State of the market and research literature review

The literature review consists of a review of the current state of the market and technology and of the academic literature. The review was broken into the following research topics (RTs):

- Use of data and IT
- Dynamic operating envelopes (DOEs)
- Household level appliance/PV integration model comparison
- Standards review
- Algorithms for the control and optimisation of major electric household appliances
- Methods to make maximum use of data
- Behavioural aspects of energy use and energy savings

The review of the current state of the market and technology examined all applicable content but focussed mainly reports from industry and government to assess the current scale of the market and cost of the technology/practice, international and Australian industry current practice and best practice, and to identify global and Australian leaders in technology and best practice. Authors also drew on feedback from the industry reference group (IRG). The review of the current state of research examined all academic literature to assess the current state of research, both in Australia and internationally.

The key output of this review is the identification of findings, barriers and RQs to the expected medium-term and long-term outputs of the H3 and H5 themes. The findings, barriers and RQs were used to derive the recommended research activities and input into the technology and market potential scenario modelling, identification of business opportunities, and key metrics. The expected medium-term and long-term outputs of both themes are:

- Removal of barriers (technical, regulatory, policy, standards) to enable flexible load management to increase solar hosting capacity, soak excess solar export, and increase self-consumption, while also providing benefits through provision of network services.
- Implementation of the required infrastructure (physical, digital, regulatory, market) to support smart homes and smart grids.
- Development of customer-oriented apps, tools, and resources to assist customers use/understand/manage their own data and better understand retail offerings, home energy technologies and home energy management products.
- Optimisation of rooftop solar and flexible loads to encourage participation in new network services, both directly and through third parties such as distribution system operators (DSOs) and aggregators.
- Unlocking flexible residential demand (and efficiency) in space heating and cooling, water heating, and pool pumps.
- Forecast expected usage costs to be passed down to the customer due to required changes in inverter and appliance standards and industry practices.
- Forecast how smart home technologies indirectly (through system-wide reduction in cost of electricity) and directly (though reduced electricity bills) provide economic benefits to customers.
- A framework (technical, regulatory, standards) that ensures a grid fit for purpose in the energy transition, and an equilibrium between the needs of customers and networks.
- Increased industry understanding of:
  - the relative viability of improving home energy technologies for home and grid support, and
  - the role customers can play in demand management in terms of cost versus convenience and choice.

The literature review is categorised into the following research topics (RTs), which are explored in detail in the relevant Appendix sections (in brackets). This OA focuses on rooftop solar, flexible loads, and their integration; content on household batteries, electric vehicles (EVs) and their chargers was only provided for context or to comment on any synergies.

4.1 Use of data and IT

This RT gives a comprehensive review of the regulatory framework for metering services, the Energy Security Board (ESB) data strategy, the Consumer Data Right for Energy (CDR-E), and the US technology Green Button, expanding on the work undertaken by the H4[1] and N2[2] OAs. This review is given in Section 10 of the Appendix.

Regulatory framework for metering services. In November 2015, the Australian Energy Market Commission (AEMC) made a rule to introduce a competitive framework for metering services. The rule sought to facilitate a market (consumer)–led deployment of smart-meters (SMs). The rule commenced operation in December 2017. The regulatory framework for metering services (the framework) was expected to lead to extensive smart-meter uptake, enabling consumers to access new services and to facilitate more effective and efficient management of the electricity grid. Unfortunately, the commencement of the rule was followed by several implementation issues, including in relation to customer experience. The AEMC therefore initiated a review of the rule in response to these issues and asked for feedback from industry stakeholders. The feedback from industry stakeholders was reviewed and the key findings identified were that:

- Increased consumer control of their own energy data is expected to be disruptive mainly to retailers as smart-meters enable a change in consumer energy consumption behaviour which may undermine their existing business models.
- Households will need to invest in new equipment (grid2.0 consumer technologies) to take advantage of new tariffs, participate in energy markets, provide network services, or participate in DOEs, and cost is considered the main barrier to their purchase. Should these technologies be subsidised? Answering this question requires the quantification of the costs of investing in grid2.0 consumer technologies against the benefits that their large-scale deployment brings to the electricity industry as a whole.
- The AEMC has recommended the legacy meter retirement plan for the accelerated rollout of SMs to be market driven and led by retailers, but to include the phased replacement of legacy meters with smart-meters. In response, some respondents are arguing for it to be managed by DNSPs. The new plan does not necessarily remove the disincentive retailers have to install SMs and assumes effective cooperation between industry participants (which has not been evident to date), putting the success of the plan at risk. The new plan also does not seem to consider the difficulties associated with installing SMs at remote and difficult-to-service geographical areas.

ESB Data Strategy. The ESB Data Strategy is designed to provide direction for the data management needed to manage changing data needs in the energy transition and optimise the long-term interests of energy consumers in a digitalised economy. According to the report, there is a need for:

- the research sector to have access to good quality data for the development of new services and use cases, and optimising integration of emerging technologies and

[1] https://issuu.com/racefor2030/docs/h4_oa_final_report_17.11.21

[2] https://issuu.com/racefor2030/docs/n2_oa_project_final_report_2021

- the development of common guidelines on collecting and sharing data and identification of issues and progress with relevant technical standards and
- the pioneering of best practice for DER data platforms, requiring advanced skills and clear processes to navigate, manage and protect, ensure good governance, and to support safe and efficient access to data.

To meet these needs, the strategy recommends that an independent DER data platform (iDDP) be created. The iDDP would be open source and owned and managed by a non-commercial entity. It would serve as a free source of DER data for researchers and as a platform for the development of innovative use cases and services and the trialling of new technologies. This would dissolve barriers to data access through the development of a data format, management (collection, consent, sharing), security, and communication standards, and pioneer best practice for DER data platform governance and operation.

Consumer Data Right for Energy. The Competition and Consumer (Consumer Data Right) Rules 2020 (CDR) have been developed to facilitate CDR as an economy-wide right. The CDR in Energy (CDR-E) is being rolled out to give Australians greater control over their energy data. The ACCC asked electricity industry stakeholders to respond to its draft rules for CDR-E in 2020. These responses were reviewed, and it was found that the CDR-E still had many decisions to make on which data should be shared and how to share them. The key issues raised by respondents are given below:

- The CDR-E is not clear on what the priority use cases are (i.e., what are the most important consumer use cases the CDR-E is expected to facilitate).
- Behind-the-meter (BTM) data isn't currently included in the CDR-E, despite it being required for a number of important use cases, such as assessing the viability of VPPs, energy efficiency assessment, tariff comparisons, and for helping households make informed DER purchasing decisions.
- Respondents want more clarity/specifics on what data should actually be included for metering, NMI standing, and DER register data.
- Views differ on how much historical Metering data is required to meet use case needs. Also, historical Metering data may need to come from previous eligible CDR consumers at a property, and how to manage access to these data has yet to be addressed by the CDR-E.
- There is contention around whether providing Metering data is a security risk to the consumer, and whether it has the potential to allow third parties to know the occupancy patterns of a property.

Green Button (GB). The GB data-sharing model looks to be similar to the CDR residential model. Where the CDR could look to GB is in regard to:

- Sensitive data and consent. With GB, a consumer can authorise/restrict access to their meter data according to the interval of reading (e.g., monthly, daily, hourly), the level of personal information, and the duration of the authorisation.
- Standard data file format and included information. GB are using XML, with standard development managed by the OpenADE Task Force.

The application of GB also applies to the regulatory framework for metering review, specifically to consumers owning and controlling their own data.

4.2 Dynamic operating envelopes (DOEs)

Dynamic operating envelopes (DOEs) are limits on how much electricity households can import and export over time and location. DOEs have become a significant consideration for DNSPs as DOEs are related to grid constraints, access, and fairness. There is a need to balance efficiency and fairness when applying DOEs at different locations in the grid, from households to various levels of aggregation. This RT reviewed the implementation of DOEs, the implications for households, and balancing outcomes to meet households and network needs. This review is given in Section 11 of the Appendix. Key findings are given below.

DOE allocation principles. Initial DOE allocation principles have been developed by the Distributed Energy Integration Program (DEIP) DOE Working Group (WG), which guides the design of DOE and the implementation process by DNSPs. However, more work is required to systematically study multiple options of location-scale levels and capacity allocation methods and to assess their impact under real conditions. And although the established DOE allocation principles consider households (i.e., transparency, customer choice and fairness), it remains unclear how households will respond to those principles and how they will inform their decisions on DER investment and operation. Additionally, DOE allocation principles still need to be determined for import.

Trial DOE projects. DOEs are being tested in many jurisdictions across Australia, which may help to analyse the DOE implementation under diverse conditions. The majority of projects focus on export limits only, noting that import limits will be examined in the future. While an equal allocation method has been the norm historically, recent trials are testing different approaches, which require more complex algorithms and additional tools. Unfortunately, all trials to date suffer from a lack of social research on the implications DOEs have for consumers.

Regulatory framework. It is evident that the AER have started to assess the need to facilitate the implementation of DOEs. Key aspects which still need to be addressed include (i) capacity allocation methods, (ii) network visibility, (iii) data protection and privacy, (iv) contractual mechanisms, (v) monitoring of DOE performance and application, and (vi) demonstrating investment need. Stakeholder feedback on existing workstreams will be essential to identify gaps and propose solutions to flagged challenges as well as outcomes from existing and emerging trial projects.

Household considerations. The DEIP DOE WG and AER reports on DOE have established initial household considerations for implementing DOE and point out that that enabling the potential benefits of DOE depends on the willing participation of households. These reports highlight the importance of explaining what DOEs are, their benefits, and their impacts on customers. How this information is communicated to households will be crucial in gaining acceptance and social licence for the service.

Implementation pathway. Existing trials, such as VPP SA trial project and Flexible Export Limits for Solar PV, and findings in the DEIP DOE Working Group have identified technical issues with implementing DOEs. These include poor equipment compatibility, how to manage lost communications, and the need for a nationally consistent approach to implementing DOEs. Finally, DNSPs are still facing data access challenges, slowing the improvement/evolution of their DOE operational processes.

Academic literature. The majority of the academic literature on DOEs centres on defining and explaining the concept of DOEs, as well as evaluating various calculation methods such as optimisation algorithms, state estimation techniques, and data-driven methods. Interestingly, the formulation and calculation of both export and import limits are well-established in academic literature. Most research, however, focusses on rooftop solar and battery systems rather than flexible loads. Recent work on DOEs explores the use of reactive power, network planning applications, market participation and integration with DER aggregation models. Another key consideration is the application of DOE in unbalanced distribution networks.

DOEs internationally. Australia is leading the work and research in DOE around the world. The considerations suggested by EPRI are aligned with the outcomes of DOE grey and academic literature in Australia. Interestingly, practical implementation of DOE in the U.S. is facing challenges that were previously also experienced in Australian trial projects.

4.3 Household level appliance/PV integration model comparison

The integration of behind-the-meter DER has the potential to provide significant benefits, providing households with the flexibility of DER to manage their consumption to reduce electricity bills, provide network support, and support the increase of DER penetration. Because of the breadth of potential benefits of DER, different approaches for integrating DER into power systems have been developed. This RT reviews and examines the implications of these approaches for households. This review is provided in Section 12 of the Appendix; key findings are summarised below.

More studies needed. No studies or projects compare all DER integration models under similar operating conditions or case studies. This is an important gap because the assessment and comparison of each DER integration model's benefits, challenges and drawbacks can vary depending on the specific operating conditions.

Savings to households. Aggregated models are more likely to achieve more household savings than individual household-level integration models. Savings in household-level integration models are limited to tariff rates. For example, households can avoid peak prices by shifting loads and receive incentives by exporting power to the grid. In contrast, aggregated levels are likely to unlock more DER values and savings for households.

Benefits to DNSPs. DER has the capability to help DNSPs manage network congestion and defer or avoid costly network investment. However, some DER integration models do not explicitly consider technical and operating constraints associated with the electricity network, which may lead to network problems such as overvoltage and overloading. Hence, household-level DER integration models are suited to networks with low DER penetration, but when the amount of DER increases, the aggregated DER integration models are likely to be more appropriate.

Household preferences. DER integration models have different ways of considering and satisfying household energy consumption preferences, and consumers may experience a trade-off between financial benefits and household preferences. Household-level integration models can directly meet household preferences as the control of the DER is conducted by households. In contrast, households in aggregated models likely need to cede a certain level of control in exchange for rewards since the aggregator needs to align the preferences and goals of all participants.

Computation and communication. The computation and communication requirements increase with the number of DER to control and household participants in aggregation programs. Household-level integration models carry out the schedule of DER locally based on their individual preferences. In contrast, the schedule in the aggregated models requires the exchange of information between households and aggregators through two-way communication channels with adequate latency and bandwidth to dynamically receive and send signals. The communication and communication burden can become unwieldy in large-scale aggregated systems. Hence, aggregated models are now considering decentralised approaches that distribute the computation and communication burden among the participants to improve performance of the system.

Value proposition. Each DER integration model has unique benefits or services to attract households. Household-level integration models can offer effective control and operation of DER without costly ICT, and the value proposition lies in allowing households to effectively schedule their DER to reduce electricity bills while satisfying their preferences (such as comfort levels or environmental goals). For directly controlled aggregated models, DER value is unlocked through the control and coordination of delivery of network and market services. Specifically, this helps to manage peak demand and generation, resulting in cost savings for households and networks and improving grid reliability and stability. For aggregated, indirect, bilateral control models such as P2P trading, value is unlocked through allowing households and communities to trade excess energy generated by their renewable energy sources directly with their neighbours instead of selling it to the grid.

Maturity of DER-integration models. Most of the considered DER functional areas are at a trial stage. The most common area being trialled is the aggregated-mediated model, which essentially comprises VPPs and community batteries. However, the emerging outcomes from these trials may help establish consensus between key stakeholders to improve the maturity of DER integration and promote commercial deployment. There are still many gaps in relation to regulatory reforms that are required to clarify DER market services, incentives, DER capabilities, communication standards and interoperability.

4.4 Standards review

This RT reviews the progress of standard AS/NZS 4755 and alternative standards such as IEEE 2030.5 alongside updates to the inverter standard AS4777.2 and a recent AEMC determination that disallows curtailing of PV export. This review is given in Appendix Section 13. Key findings are summarised below.

AS/NZS 4755. AS/NZS 4755 is in the process of being modernised. In its current form, this standard is considered by some stakeholders to be too prescriptive, one-way, out of date and designed to reduce peak demand rather than address minimum demand. The new draft of AS/NZS 4755.2 aims to address these shortcomings and provide a modernised framework for residential DER as well as mapping functions to international standards OpenADR, IEEE 2030.5, and CTA 20245.

International. OpenADR, IEEE 2030.5 and CTA 20245 have gained some traction internationally, but despite this traction, few international jurisdictions have mandated standards for flexible loads. Some have taken tentative first steps by outlining the architecture and communications required for residential DER to participate in demand response.

Challenges. There is a concern that standardisation carries risk, primarily that it can hinder product development. With standards expected to rely on Wi-Fi and/or 4/5G, it has also been suggested that standards include a loss of communications component. Also, standardisation cannot be applied to existing devices, and while numerous retrofitting options are available, the challenge remains how and whether to incorporate the large number of non-standard flexible loads in people's homes.

4.5 Algorithms for the control and optimisation of major electric household appliances

This RT reviewed the scope for algorithms of home energy management systems (HEMS) adopting flexible loads with high power ratings and solar photovoltaics (PVs). HEMS algorithms can provide optimal or real-time decision making on scheduling or controlling flexible loads, bringing economic and/or technical benefits. Mainstream algorithms for HEMS are rule-based control and centralised optimisation algorithms, while emerging ones include distributed control/optimisation, hierarchical coordination, and machine learning (ML)-based algorithms. This review is given in Appendix Section 14; key findings are summarised below.

Interoperability. Currently, commercially available HEMS have poor compatibility with flexible loads as well as with controlling and measurement devices, which usually have specific and confidential communication protocols. In addition, controlling devices are not typically suitable for integration with a HEMS using distributed optimisation or ML algorithms.

Cost. Installing HEMS and the controlling devices generally requires qualified professionals which can be expensive. In addition, costs increase with sophistication; advanced, centralised optimisation algorithms (cloud-based), for example, require high computing capability and data storage, which adds additional costs relative to locally controlled algorithms. More advanced algorithms also often utilise optimisation, which requires access to forecast data, weather, and pricing. These data also have a cost, and easy access to these data for HEMS is not yet established.

Gap between academic and commercial sectors. There is a perceptible gap between the commercial HEMS industry and the research sector. There is a dearth of research articles where advanced algorithms are implemented in trials, while the studies that do exist are simulated and heavy with assumption, bringing into question their practicality. Partners involved in HEMS trials are not inclined to share their IP, but trials are needed where algorithms are open source and tested for the benefit of both researchers and the HEMS industry.

4.6 Methods to make maximum use of data

Energy awareness is an effective way to drive consumer behaviour change. Traditional energy bills inform households about their usage on a monthly and seasonal basis, but information is too coarse to identify when and where energy was consumed, where waste took place, and how it could have been avoided. These shortcomings have prompted smart-meters and other smart monitoring devices to be introduced. Smart-meters can certainly be useful, but without user-friendly, in-home displays or apps with useful graphs and visualisations that are simple and informative for consumers, smart-meters may be ineffective at encouraging customer engagement. Against this background, this RT looks at methods to maximise the use of both synthetic and measured data from HEMS devices (smart plugs, for example), behind-the-meter DER monitoring devices, and smart-meters. The aim of this research is to establish how to maximise the use of this data to inform, advise, and empower customers to reduce their energy usage—and thus their utility bills—in their homes. This review is given in Appendix Section 15. Key findings are summarised below.

Non-intrusive load monitoring (NILM). Even when using the most popular machine learning methods, such as DNN, it is challenging to develop an algorithm that can identify all types of appliances within a reasonable computational time with a high level of accuracy and without requiring a great deal of training data. Some household appliances such as stoves, air conditioners and refrigerators use a lot of energy and are known as top consumers. Other appliances such as laptops, DVD players, and routers consume very little energy. It is hard to track the power signature of small consumers because the top consumers are so dominant. Therefore, the NILM methods only focus on identifying the top consumers. Interestingly, despite considerable research on NILM algorithms, few apps (only Sens, and Samppee) use NILM methods.

Data access. Access to suitable data is necessary for the evaluation of different NILM methods, as well as for app development and assessment. This is difficult for Australian researchers due to a lack of publicly available datasets of household power usage. Also, when a consumer switches apps, historical data must be transferred and compatible with the newly installed app, and consumers have reported encountering difficulties doing this.

Functionality. There is demand for apps with greater functionality to give consumers more information about their energy consumption behaviour beyond what they have generated or consumed. Households seeking convenience would also benefit from an appliance-control automation feature, something that is lacking in most of the available apps.

4.7 Behavioural aspects of energy use and energy savings

This RT aims to provide an overview of the state of the residential energy market by collating various energy reduction strategies and user behaviour interventions that are in practice. This review is given in Appendix Section 16. To guide the review, the following questions were explored:

- What is the extent of knowledge about energy use and energy reduction among residential consumers?
- What are the drivers and barriers that encourage residential consumers to reduce their energy consumption removing energy load from the grid?
- What are the available effective strategies for reducing energy consumption and energy load from the grid for residential consumers?

The review yielded two recommendations:

i. **Communication strategy research**. An effective communication strategy is required that directs consumers on the transition towards grid2.0. It is recommended that this strategy consider not only the primary customer in each household but also the effect of family dynamics in terms of energy decision making in Australian households, as well as the degree of trust (or lack thereof) that consumers have towards key industry actors (retailers, DNSPs, technology providers, government). It is expected that lack of trust can be alleviated through knowledge to help clarify risks (perceived or real) and the benefits/impacts/outcomes which may come from purchasing a new technology, participating in a new service, or changing to a new tariff.

ii. **Communication strategy design**. Rather than an expert-driven approach, it is recommended that co-design be used when developing the communication strategy, incorporating feedback and input from consumers. The strategy design should also draw more attention to the direct (and indirect) impact of consumers' energy consumption on the environment. A mass media campaign should be considered to gain traction with the wider community and embed the topic of grid2.0 into the social consciousness. The campaign's design should attempt to develop a social norm on the topic by providing people with information about what others are doing. This can be achieved through provision of anonymous consumer information related to this topic through, for example, HEMS reviews/examples/testimonials and statistics.

5 Research questions, activities, and recommendations

This deliverable draws on the findings and barriers identified in the state of the market and research literature review to define research questions (RQs). The RQs were then taken from all research topics and grouped under six industry objectives that would be needed to facilitate the transition to grid2.0:

1. Effective dynamic operating envelopes (DOEs)
2. Effective HEMS operation
3. Engaged and informed consumers
4. Appropriate design of AS/NZS 4755.2
5. Uninhibited data access
6. Informed industry decision-makers

RQs with synergy were identified and then merged; the merged RQs are given in Table 1 below. The associated research activities and recommendations are given in Section 5.

Table 1 List of merged research questions

ID	Industry objective	Synergy	Merged RQ
RAR1.1	Effective DOEs	Consumer and network impact	How will DOEs impact on consumer behaviour and network load profiles? How can flexible loads be incorporated to manage DOEs?
RAR1.2	Effective DOEs	DOE framework	What components, if any, of DOE implementation should be standardised? Components include DOE calculation method, communication protocols, compliance, and performance measurement and monitoring.
RAR1.3	Effective DOEs	DOE calculation method	What are the DOE calculation methods which best meet the DOE allocation principles? Are they suitable for real-world distribution networks? What level of visibility is required? Unbalanced networks?
RAR2.1	Effective HEMS operation	HEMS functionality and performance	What functionality is required by HEMS devices to meet expected levels of performance (savings objectives, DOE setpoints)? How do different HEMS architectures, automation levels, and DER-integration models influence performance and required functionality?
RAR2.2	Effective HEMS operation	HEMS algorithms	How do the different HEMS algorithms compare? What are the comparative ICT costs? What are the key factors which determine the performance of each?
RAR2.3	Effective HEMS operation	Non-intrusive load monitoring (NILM) algorithms	Is it possible to effectively disaggregate the overall energy consumption to the appliance level without having to install additional current transformer (CT) clamps, sensors, or plugs using NILM algorithms?
RAR3.1	Engaged and informed consumers	DOE operation	What information do households need to make informed decisions about DOEs? What is the best way to communicate this information?
RAR3.2	Engaged and informed consumers	Tariff analysis and tool development	With new retail tariffs expected to become more complicated, moving away from the historical structures, what tools are required to assist households make decisions on tariffs? Should information on how tariffs are presented by templated?
RAR3.3	Engaged and informed consumers	Consumer facing apps	Users are giving feedback that consumer facing apps are poorly designed and don't suit their needs. How can developers be assisted/informed to build better apps?
RAR3.4	Engaged and informed consumers	HEMS operation	What information do households need to make informed decisions about HEMS? What is the best way to communicate this information?
RAR3.5	Engaged and informed consumers	Communication strategy–research	As part of the research component required for the development of a communication strategy on grid2.0, what are the effects of family dynamics on the energy decision-making process? And what is needed to understand and overcome any existing and unwarranted lack of trust that consumers may have towards actors (retailers, DNSPS, technology providers, government) in the electricity industry?
RAR3.6	Engaged and informed consumers	Communication strategy–recommendations	As part of the design component of a communication strategy on grid2.0, it is recommended that the following RQs be considered: Should it be co-designed with consumers? Should consumers receive personalised information about the environmental impact of their energy consumption to incentivise them to change their consumption

			behaviour? Is a mass media campaign the way to gain traction with the wider community? Should a social norm on the topic be developed by sharing what others are doing (HEMS reviews/examples/testimonials)?
RAR4.1	Appropriate design of AS/NZS 4755.2	Grid2.0 consumer technologies–Interoperability	It is recommended that HEMS device technologies be compliant with IEEE 2030.5 to address concerns around interoperability. How effectively does the new version of AS/NZS 4755.2 enable interoperability between all HEMS devices, smart-meters, and consumer-facing apps?
RAR5.1	Uninhibited data access	Consumer facing apps	There are few quality household energy consumption data sets available to researchers that are required for the evaluation and development of consumer facing apps. How can the creation of these data sets be facilitated?
RAR5.2	Uninhibited data access	HEMS algorithms	For most HEMS algorithms to be effective, they need access to data, such as historical and forecast weather data and energy prices, that is typically only available commercially. What is the current status of access for the above data types?
RAR5.3	Uninhibited data access	Consumer data right for Energy–Use case analysis	The Consumer Data Rights for Energy (CDR-E) still has many decisions to make on what data should be shared and how to share it, and use-case analysis is key to understanding this. What use-case analysis should be prioritised? How are they to be identified?
RAR5.4	Uninhibited data access	Consumer data right for Energy–My Energy Marketplace	RQs which arose from WattWatchers (WW) My Energy Marketplace platform include: Should non-energy metadata be included in the CDR-E? WW currently legally owns data collected through their devices; can this ownership be transferred to the consumer?
RAR6.1	Informed industry decision makers	Consumer control of data disruption	What are the consequences of the disruption of consumers gaining control over their energy data on the electricity industry and retailers in particular?
RAR6.2	Informed industry decision makers	Smart-meter rollout policy	To assist the AEMC with their smart-meter rollout policy, what studies or evidence are EU jurisdictions using to justify their policies on accelerated SM rollouts? Has Australia implemented similar studies and/or provided similar evidence? What are the important tenets of each policy? What can Australia learn from SM rollout policies implemented in the EU?
RAR6.3	Informed industry decision makers	Cost-benefit analysis on smart-home technologies	Do the costs of investing in grid2.0 consumer technologies outweigh the benefits that their large-scale deployment brings to the electricity industry as a whole? Properly quantifying benefits to the network would also help determine pricing thresholds for progressive tariffs and the provision of network support services.
RAR6.4	Informed industry decision makers	Cost-benefit analysis on physical LV models	Calculating DOEs currently requires electrical LV network models. However, the creation of accurate network models is time-consuming and expensive. It is also challenging to create accurate network models due to data errors in topology and lack of data generally. What is cost benefit of investing in the creation of accurate physical LV models?
RAR6.5	Informed industry decision makers	Cost-benefit analysis on legacy retirement plan	RQs raised in response to the AEMCs decision to implement the legacy retirement plan include: Is it more efficient and cost-effective for DNSPs to manage the SM rollout? Is it cost-effective for DNSPs manage and pay for targeted SM rollouts in areas in rural and remote locations? How do SM-install prices vary according to geographical area and remoteness? Are there methods to estimate the increase in SM penetration through the various accelerated SM rollout plans (especially the legacy meter retirement plan) proposed by the AEMC?

The merged RQs were then prioritised by assessing how well they each met the H3H5 theme medium and long-term objectives, and also by the expected level of interest from each sector of the industry. How well a merged set of RQs met the objectives determined its impact, and the level of interest from industry determined its likelihood of attracting funding from RACE industry partners. Merged RQs were given a rating of 1-5 for impact, where 1 = very poor, and 5 = very well. For industry interest, merged RQs were given a rating of 1-5, where 1 = very low, and 5 = very high. Table 2 gives the impact scores for each merged RQ, Table 3 gives the industry interest scores, and Figure 2 shows the priority of each merged RQ by mapping the impact to the industry interest score.

Table 2 Impact scores for merged research questions

ID	Implementation of the required infrastructure (physical, digital, regulatory, market) to support the implementation of smart homes and smart grids	Development of customer-oriented apps, tools, and resources to assist customers use/understand/manage their own data, and better understand retail offerings, home energy technologies and home energy management products	Optimisation of rooftop solar and flexible loads to encourage participation in new network services, both directly and through third parties such as distribution system operators (DSOs) and aggregators	Unlock flexible residential demand (and efficiency) in space heating and cooling, water heating, and pool pumps	Forecast of - expected usage costs to be passed down to the customer due to required changes in inverter and appliance standards and industry practices - how smart home technologies indirectly (overall system-wide reduction in cost of electricity) and directly (reduced electricity bills) provide economic benefits to customers	A framework (technical, regulatory, standards) which ensures a grid fit for purpose in the energy transition and an equilibrium between the needs of customers and networks	Increased industry understanding of - the relative viability of improving home energy technologies for home and grid support - the role customers can play in demand management in terms of cost versus convenience and choice	Impact score
RAR1.1	5	2	5	5	2	5	5	29
RAR1.2	5	4	3	3	2	5	1	23
RAR1.3	5	2	3	3	2	5	1	21
RAR2.1	5	3	4	4	2	5	4	27
RAR2.2	2	4	4	4	2	2	4	22
RAR2.3	3	4	4	4	2	3	4	24
RAR3.1	2	5	3	3	2	2	2	19
RAR3.2	3	5	3	3	2	3	4	23
RAR3.3	2	5	4	4	2	2	4	23
RAR3.4	2	4	3	3	2	2	4	20

RAR3.5	1	1	3	3	2	1	5	16
RAR3.6	1	1	3	3	2	1	5	16
RAR4.1	5	4	5	5	2	5	2	28
RAR5.1	2	5	4	4	2	2	4	23
RAR5.2	4	4	4	4	2	4	2	24
RAR5.3	4	4	4	4	2	4	4	26
RAR5.4	3	3	3	3	2	3	3	20
RAR6.1	2	2	2	2	5	2	4	19
RAR6.2	4	2	2	2	4	4	4	22
RAR6.3	4	2	2	2	4	4	4	22
RAR6.4	4	4	4	4	2	4	2	24
RAR6.5	4	1	1	1	4	4	3	18

Table 3 Industry interest scores for merged research questions

ID	Networks	Consumers/consumer groups	Technology/solutions providers	Retailers	Industry interest score
RAR1.1	2	3	3	3	11
RAR1.2	2	1	3	1	7
RAR1.3	3	1	3	1	8
RAR2.1	1	1	3	3	8
RAR2.2	1	1	3	3	8
RAR2.3	1	1	3	2	7
RAR3.1	1	3	3	3	10
RAR3.2	1	3	3	3	10
RAR3.3	1	3	3	2	9
RAR3.4	1	3	3	3	10
RAR3.5	2	3	2	3	10
RAR3.6	2	3	1	3	9
RAR4.1	2	1	3	2	8
RAR5.1	1	3	2	1	7
RAR5.2	1	3	2	2	8
RAR5.3	3	3	2	3	11
RAR5.4	1	2	2	2	7
RAR6.1	3	2	2	3	10
RAR6.2	3	1	1	3	8
RAR6.3	3	1	3	3	10
RAR6.4	3	1	2	1	7
RAR6.5	3	2	1	3	9

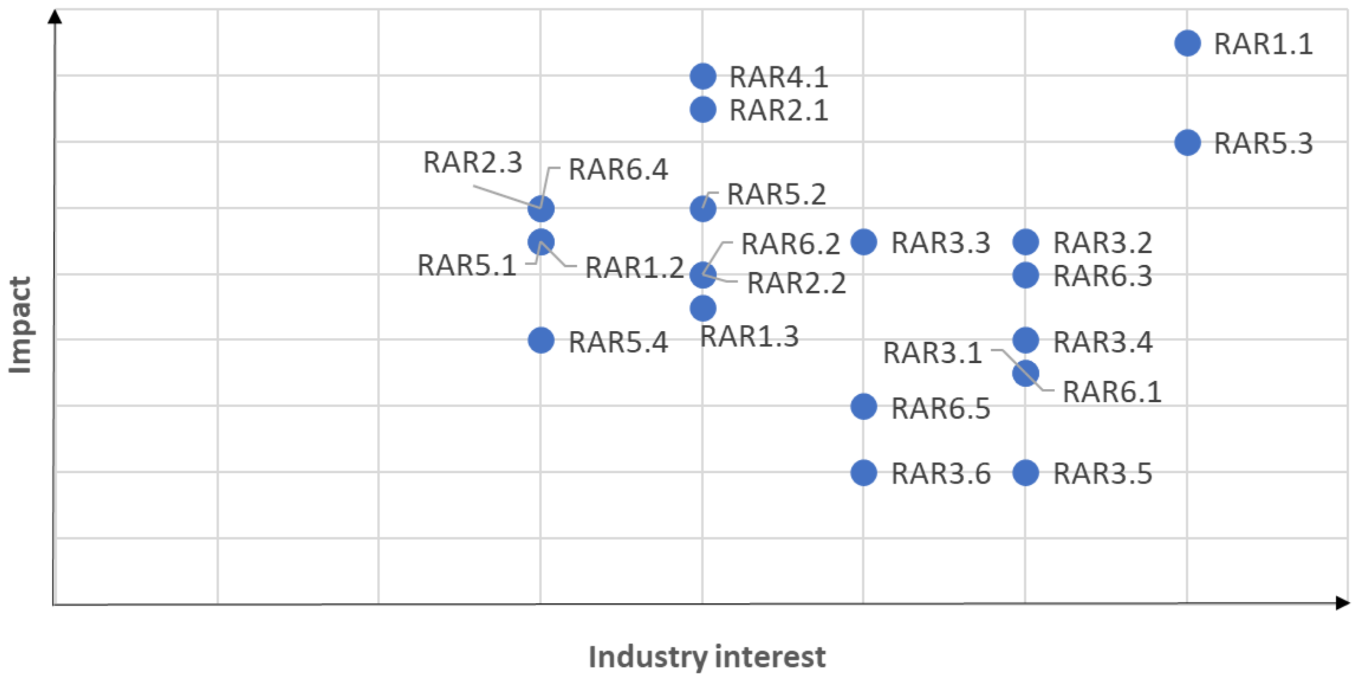

Figure 2 Merged RQ prioritisation mapping

6 Technology and market potential scenario modelling

The results in this analysis represent an approximate national average. As with many energy parameters for households, there is a significant spread due to factors such as climate, dwelling type, household usage patterns, and so on. The largest opportunity for flexible control of household loads comes from water heating. There are many reasons for this:

- Water heating is one of the largest consumers of energy in a home.
- Energy can be stored in water heaters for significant periods.
- Control of electric water heaters is technically straightforward (on/off relay with associated control and communications electronics).
- Customers are agnostic to when the water is heated, providing that hot water is available when it is required.

This analysis showed that transitioning to flexible control of water heaters could provide around ~24 GWh per day of shiftable load under a BaU trajectory of water heating stocks. As shown in Roche et al. (2023), this figure will increase if gas water heaters are phased out in favour of electric heaters.

Pool pumps present a smaller opportunity than water heating as they use less energy, comprise a smaller stock, and have fewer units technically suited to flexible control. Customers are, however, equally agnostic to when pool pumps are used, provided that appropriate pool sanitation is maintained.

Air conditioning also presents a smaller opportunity than water heating due to the difficulty in controlling A/C units and the amount of energy that can be shifted using either curtailment or pre-heating/pre-cooling (estimated to be around 20% of total A/C energy use). Customers are also more sensitive to changes in operating patterns of A/C than for water heaters and pool pumps.

Average customer financial benefits from changing from peak/shoulder/off-peak tariffs to a 'solar soak' tariff are modest, ranging from $50 p.a. for A/C to $350 p.a. for large off-peak water heaters. This may not be enough to motivate large numbers of customers to make the change, and other financial incentives may be required.

7 Business opportunities

This report proposes high-impact business opportunities (economic development or commercialisation) for RACE for 2030 partners and for the Australian economy by accelerating technologies and practices related to the H3/H5 opportunity assessment. Business opportunities are designed to address the barriers identified in the state of market and research literature reviews. Business opportunities are given in Table 4.

Table 4 Business opportunities

Sector	Opportunity	Description	Barrier
Software and data	Middleware to enable interoperability of legacy devices.	Similar to the way an aftermarket remote control can control all makes and models of televisions, middleware could be developed using a single user interface which controls devices from various manufacturers or that use different operating protocols. Advances in this area would require significant development work and field testing.	Existing devices will not benefit from standards (RT4); lack of a common interface for all appliances (RT7)
	Generation of publicly available energy datasets	The cost of access to representative residential energy datasets needs to reduce in order to encourage innovation. Government-funded collection of data (e.g., smart-meter, NILM) and use of AI to generate Australian household data sets would assist app and device developers during their design processes. Industry and government could be encouraged to fund national trials of large-scale, representative data collection and enable proof-of-concept for a broader rollout.	Lack of Australian household data sets (RT6)
	Development of a standardised data model	A standardised data model could be developed for all relevant parameters that would assist a HEMS or PV/battery in making decisions about operating patterns. This could stimulate a range of products and services. Useful data (provided in real time and with forecasts by region) includes weather, insolation, energy price, energy mix, grid stability, etc. This could be provided in a standardised data model, from machine to machine, in real time.	Data availability (RT6)
Hardware	Smart device useability / improved user interfaces	Smart devices can be excessively difficult to operate, with complex user interfaces which require significant effort to understand. Improvement in smart device usability and user interfaces is likely to increase consumer acceptance	Complexity of smart devices (RT7)

	More efficient / powerful pool pumps	Increasing the efficiency of pool pumps, with a corresponding increase in flow rate for the same power, could allow water turnover to be achieved in a shorter timeframe (i.e., within a limited 'solar soak' window). Significant study is required to assess the impacts of this on other areas (pipe friction losses, filter head losses, etc.).	Modelling revealed a barrier regarding pool pumps. Pool pumps need to turn over a minimum volume of water each day to maintain pool hygiene. Restricting pool pump operation to a limited 'solar soak' window might not allow sufficient turnover.
	Connectivity alternatives	Adoption of wireless (or wired) communications protocols other than Wi-fi or Bluetooth would benefit hard-to-reach outdoor appliances such as pool pumps. There are numerous examples of this being done using IoT devices.	Wi-fi reach for appliances such as pool pumps or other outdoor appliances (RT6)
Services	Pre-purchase advice for smart devices	When deciding on smart devices, PV, battery and HEMS systems, consumers are faced with a bewildering array of information and product offerings. For example, the PV installer is often the go-to for advice, however, many operate a high volume, low margin business and are not prepared to invest the time and effort required to provide bespoke advice about the most suitable equipment for a customer (only to have this advice used to find a cheaper quote). Providing independent, subsidised, fee-for-service design advice would be invaluable for many consumers (prosumers) seeking to enter the smart energy realm. Offering advisory services to consumers prior to solar/battery/car-charger installation, along with smart device and vehicle selection, could be another aspect of this service.	Confusing and disconnected marketing information for appliance purchases, solar, battery, HEMS, etc. (RT7)
	Outsourced management of smart devices	For less advanced users, development of outsourced services to manage HEMS and DER in a limited but co-ordinated manner could see smaller benefits across a large user base.	Complexity of smart devices (RT7)
	Advanced energy consumers	Whilst a large number of consumers might oppose ToU tariffs, a portion of 'early adopters' is open to taking advantage of ToU and even dynamic, wholesale energy tariffs. There may be opportunities to expand these offerings to technically and commercially minded consumers.	Negative consumer sentiment towards ToU tariffs (RT7)
	Delivery of non-energy benefits	As was also found during RA2 (modelling), the business case for increasing household appliance flexibility is not overly compelling. Adding non-energy benefits could increase consumer attraction to appliance flexibility. One real-world example of this is Pooled Energy, which made its offering much more attractive by adding pool hygiene as a key selling point	Individual appliance running costs are low (RT7)

		alongside ease of use, taking away the headache of managing pool hygiene from the customer. Similar opportunities might exist whereby benefits such as pool hygiene, pool safety (e.g., fence breach detection), thermal comfort and hot water hygiene/delivery could be added to the consumer offering. This could go further into fire monitoring, security, air quality, etc. with potentially reduced insurance premiums.	
Financing and incentives	Development of financing alternatives	Whilst dedicated financing is readily available for PV systems and batteries, expanding this offering to HEMS and smart DER would help overcome the upfront cost barrier	Cost of smart devices (RT7)
	Energy cooperative (enhanced VPP)	An energy cooperative is similar to a VPP, however, it has a distinct cooperative ethos and added services. Like-minded customers would band together to share resources (e.g., community battery), provide member households with advice, and bulk purchase discounts for hardware and services. Energy purchase itself could also be aggregated and purchased at bulk rates. Other add-ons include peer-to-peer trading of energy and demand response.	Lack of incentives (RT7)

8 Key metrics

Table 5 below proposes KPIs and a formal measurement and evaluation process for assessing (by quantifying the achievable value of the expected benefits which come from each future research project, particularly relating to customer energy bill reduction and carbon emission reduction) the impact of the recommended research activities.

Table 5 Proposed key metrics

Area	Metric	Data collection & modelling process
Uptake of flexible control of household DER	Quantity of participating households	Data collection from energy utilities, aggregators, VPPs, and market regulators
	Quantity of participating DER (numbers of water heaters, pool pumps, A/C units)	
Load shapes	Change in participating customers' individual load shapes Change in overload market load shape	Data collection from participating households (with permission, e.g., smart-meter data) Collection of household type data (e.g., PV fitted, house/apartment, demographics, etc.) Collection of provider type data (aggregator, VPP, retailer, etc.) Modelling and assumptions where required (e.g., a counterfactual baseline)
Actual flexibility achieved	Quantities of shifted load (MW, MWh)	
Customer benefits from flexibility	Net household financial gain ($)	
Network benefits from flexibility	Capital deferral and operating cost savings for distribution network operators Improvements in power quality and reliability	
Market benefits from flexibility	Improved market efficiencies Creation of new business models and employment	
Reduction in carbon emissions	Reduction in carbon emissions (tCO_2e)	
Products & services – models available for purchase Products & services – actual sales	Quantity of DERs with flexible capability	Market surveys Product sales data (e.g., GfK)
	Quantity of HEMS	
	Quantity of relevant apps, software, platforms	
	Quantity of DOEs	
	Quantity of related products & services (define each when it becomes available)	
	Quantities and types of market participants	
	Quantities and types of jobs created	
Customer reactions	Customer perceptions of service, value for money, etc.	Customer focus groups

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