RENeW Nexus

Enabling resilient, low cost & localised electricity markets through blockchain P2P & VPP trading

Project Partners & Supporters

Power Ledger
Curtin University
Murdoch University
energyOS
AEMO Australian Energy Market Operator
Australian Government
Low Carbon Living CRC
DevelopmentWA
CSIRO
DATA 61

Highlights

1. The project confirmed that energy trading was technically feasible and desired by customers. One participant remarked, “it’s the way forward” and after the end of the study, most said they wanted to continue that way of managing electricity.

2. Price signals to match average supply and demand were present. Households seemed to be willing and able to shift their energy demands to reflect these price signals. One participant said “It gave me an incentive to move power consumption away from peak periods”.

3. In households that had 10 and 15 kWh batteries, and where there was a VPP in place, payback times for batteries would be less than 6 years. Participants said they were 3 times more likely to buy a battery if they could participate in a VPP.

4. An uptake in 10 and 15 kWh batteries to 50% market penetration would enable a district to become 68% energy autonomous. That means only 32% of their energy would be sourced via high voltage transmission networks. Such a reduction could spell significant network savings in the future.

5. Many households originally bought their solar panels because of feed in tariffs provided by the taxpayer. Energy trading could substitute these tariffs for a real-world revenue stream, for a higher, if less regular amount.

6. The research strongly suggested that such energy trading could help stabilize the grid without any tariff interventions of any kind at all.

Authors: Dr. Jemma Green (Power Ledger), Prof. Peter Newman (Curtin University) and Nick Forse (Power Ledger)

Edited by: Dr. Martin Anda (Murdoch University)

Published: June 2020

This report on the outcomes of the Project was prepared by Power Ledger and Curtin University and edited by Murdoch University.

We acknowledge the following people for their valuable contribution to the project and report: Vinod Tiwari, Guy Chalkley, Jan Peters, Tom Butler, Madison Pigliardo, Declan Kelly, Michael Bradley, Michelle Shepherd, Warren Philipps, Sam Wilkinson, Alexei Fedotov, Professor Deo Prasad, Jill Augustus, Taran Dunn, John Bulich, Anya Nova, Alejandro Aguilera Vega, Heidi Cuthbert and Rene Haagen.

Executive Summary

Background

The rooftop solar revolution has been more successful than anyone ever anticipated, but its addition to a centralised grid system has caused many problems. These can be summed up as market and electrical instabilities:

1. At an electrical level, noon time oversupply of solar PV threatens scheduling of electricity generation and creates reverse flows to distribution networks. This can burnout transformers cause harmonics and voltage outages and demands even more equipment to stabilize the grid.

2. At an economic level, wholesale prices for kWh vary significantly from extremely low or negative midday prices to regularly high evening peak prices and also causing issues to scheduling of baseload generation as intermittent solar generation takes priority during daylight hours.

3. Also at an economic level, increased solar means ancillary services which relate to frequency stability get ever more expensive.

Up until now the industry has employed a patch and fix approach to solving these problems in the hope they'll eventually go away. These are usually in the form of tariffs, but one tariff patch inevitably leads to another. A sense of disgruntlement pervades the industry, consumers and political realm.

The premise for this study was that there could be a more systematic and scalable way to address what the authors see as a suite of related problems.

Research question

Could an arbitrage system, i.e. a highly localised electricity market with clear and real-time price signals solve the suite of three problems described above?

RENeW Nexus project in Perth, Western Australia aimed to assess this question in two separate parts:

Can energy trading reduce stress on the grid?

A solar P2P trading trial, called Freo 48, involved households selling electricity to each other across the grid. There were 48 participants involved in the trial but the scheme was deliberately designed so it could easily be scaled up to a larger group without any significant investment, or special requirements other than a smart meter. The study looked at behaviour to see if energy consumption patterns would change and arbitrage style activities would emerge and whether these would constitute demand response: the shifting of electrical use to reduce stress on the grid.

Executive Summary

What are the effects of arbitrage on payback times for a battery?

In a further part of the project, called Loco 1, a mathematical model was constructed to test typical payback times for a 10 and 15 kWh battery device in a normal household environment. The study went on to evaluate how the payback times could be shortened if the batteries are included in a virtual power plant (VPP) arrangement, evaluating the use of these distributed batteries when aggregated through a blockchain enabled VPP platform for participation in grid balancing and network control services, improving overall grid resiliency.

For the purposes of this project, a localised energy market refers to a group of consumers (both households and businesses) within the same low-voltage distribution area downstream of the same feeder. Each market can be linked to other connected markets within that same part of a distribution network, such that any net energy export from one market, caused by a net excess of solar PV energy within it, could be used to supply another local energy market linked within that section of the distribution network.

Further Work

A live trial into the deployment of a VPP in the SWIS would assist in gaining further insights into how a VPP can provide system benefits. Such a trial could target areas with existing smart meters to understand other opportunities such as maintaining customer grid connection, increased grid utilisation and the provision of network system services, to deliver low cost, reliable, clean and resilient energy.

Recommendations Summary

Recommendation 1: Policy makers and market regulators

Policy makers and energy market rule makers should consider modifications to FiTs such as changing them to a dynamic feed-in-tariff or by removing feed in tariff subsidies, cheap solar P2P energy when available could encourage load shifting and thereby support distribution networks and reverse flow issues.

Policy makers and energy market rule makers should consider coupling P2P with the ability for prosumers with batteries to trade via a VPP where prosumers would be able to monetise their excess solar at all times of the day, without any subsidy, and also provide services to the grid.

Market rules should be revised to allow batteries or VPPs to be able to participate in the market and to incentivise installation of batteries that deliver network and system benefits, not just batteries facilitating self consumption.

Governments and regulators should look into the changes that would need to be made to make P2P and VPP energy trading attractive to consumers to deliver optimal system benefits so that consumers can be the driving force behind the energy transition and clean, lowest cost and resilient energy.

Recommendation 2: Network and market operators

Energy network and market operators should explore alternative methods and structures of charging for network usage to more accurately reflect the reduced use of the transmission and distribution electricity network brought about by peer-to-peer trading.

To facilitate energy trading, network operators should improve metering infrastructure in their systems by installing advanced meters and designing systems for collecting and communicating the metering data to third parties.

Australian network and market operators can learn further from the RENeW Nexus project and should monitor the Loco 2 trial which will examine the East Village project involving a 670kWh battery.

Recommendation 3: Retailers

Retailers should emulate and continue the practice of innovation by conducting more trials and experiments to determine where the opportunities are for empowering and engaging customers, and improving customer outcomes.

Retailers should investigate new retail models that account for the netting off of generation and consumption within their portfolios by offering new products to their customers such as peer to peer trading and VPP's.

Any future deployments of energy trading should be focused on suburbs with advanced meters installed to enable easier metering data provision and enable a valid comparison between baseline i.e. pre and post-trial results.

Recommendation 4: Customers

Consumer behaviour is having an enormous impact on the SWIS and on energy systems more generally. Through the correct regulation and incentives, the power of the consumer can be harnessed to bring about the system changes that are needed to stabilise the grid and reduce it's overall costs.

The results of this report demonstrate that educating consumers on the energy system, the changes that it's undergoing and the reasoning behind proposed reform will need to be a key area of focus for governments, regulators and retailers.

Recommendation 5: Live trial

A live trial of a localised energy community (created through a large community of consumers and prosumers on the same substation-level distribution network trading via P2P and a VPP) be conducted in the SWIS to determine whether it can provide the hypothesised benefits to the wider electricity system and determine the extent of any economic benefits to the various stakeholders involved.

Table of Contents

Table of Contents

Introduction

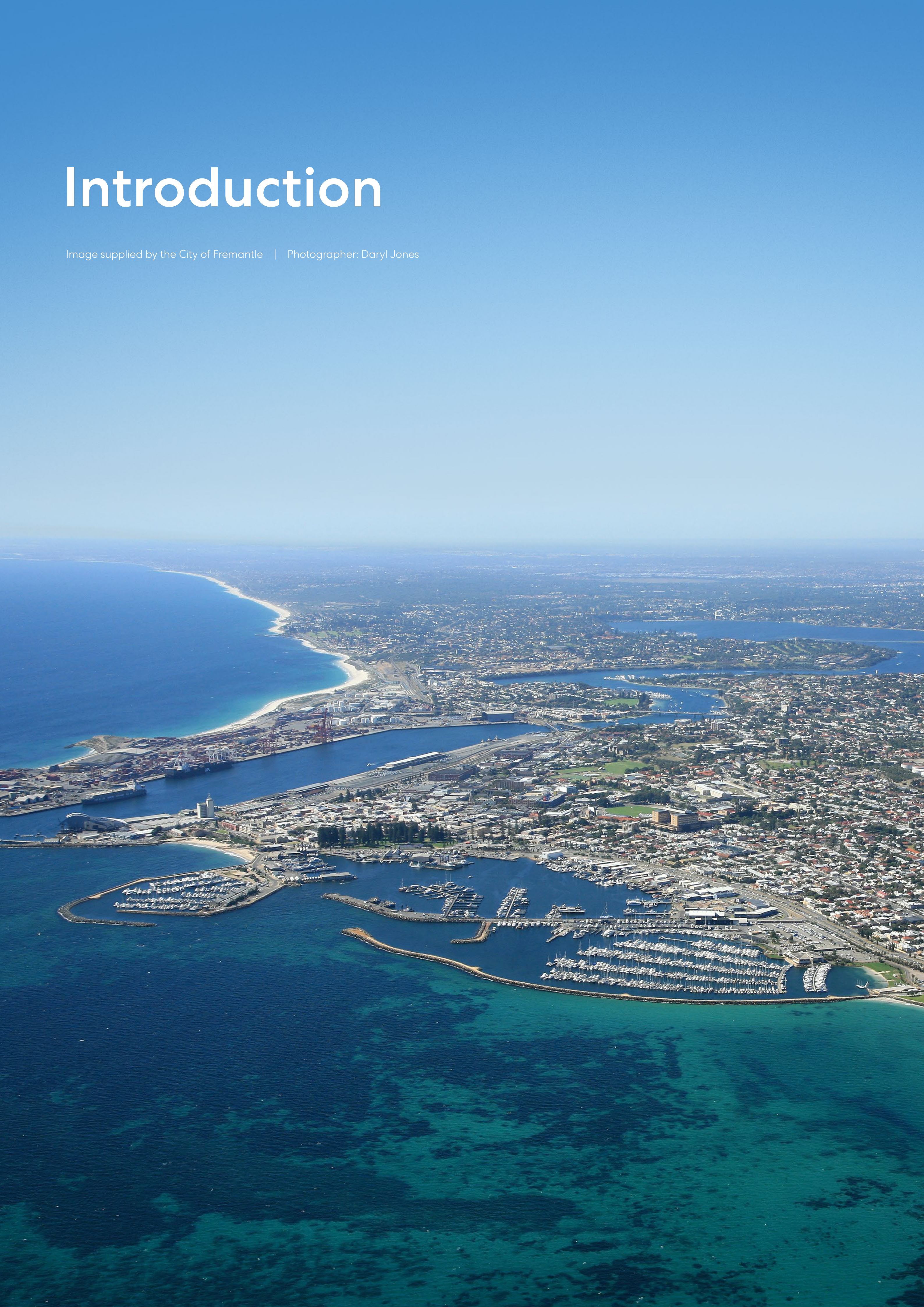


Image supplied by the City of Fremantle | Photographer: Daryl Jones

Introduction

Challenges in the SWIS

Electricity generation from rooftop solar presents a significant challenge to both electricity network operators and market operators as it requires the increased use of appropriate support services such as frequency control, voltage control and peaking generation due to its intermittent nature.

The increased distributed generation trend is prominent in the SWIS, where the Australian Energy Market Operator (AEMO) is now considering the 1.1 GW of connected behind the meter photovoltaics (PV) [1]. Importantly, this behind-the-meter solar PV generation is displacing synchronous generators (e.g. traditional thermal generators like coal) that provide a range of technical services to the grid [2]. As DERs and large scale, renewable generation become more common and displace conventional generation sources, services will need to be procured from alternative sources or new services may be required to appropriately manage a more variable energy mix [3]. AEMO highlights this future: 'The SWIS could become inoperable under its present operating parameters' [3].

Electricity generation and distribution systems are changing significantly. Electricity supply is becoming a hybrid of centralised and distributed systems as a result of increased rooftop solar generation and more recently, battery storage in the network. These systems are collectively called distributed energy resources (DERs) and are not controllable in the sense that traditional generation assets are, causing new challenges to grid stability. Changes are needed to ensure a stable and low-cost energy system, and a wide variety of solutions are being investigated such as changes to market rules, tariffs, increased technical standards and two-sided markets. Energy trading is one such solution that has been proposed to solve these issues and complement other solutions [4]. Energy trading can occur via solar systems or from coordinating battery sources to form a virtual power plant (VPP).

The SWIS requires a minimum amount of net demand at any one time, stated by AEMO as 700 MW, below which it risks a cascading failure of the entire network [3]. Due to the large proportion of DERs in the SWIS causing a sharp reduction in demand during the day, there is an expected increase of hours per year below this limit from 10 hours/year in 2022 (potentially requiring the disconnection of up to 60,000 households through the shutoff of distribution feeders in areas with particularly high DER export) to 150h/y in 2026 (up to 300,000 households) [3].

Related issues including ramping, load-shedding, restart services, dispatch of out-of-merit generation and increased frequency of negative trading intervals are stated as issues by AEMO [3], [4]. To avoid these problems, changes must be made to Western Australia's energy market, regulations and systems [4].

To address the issues outlined above, various industry bodies, regulators, market operators and network operators propose a number of potential solutions. The WA State Government has established an Energy Transformation Strategy and Energy Transformation Taskforce to develop a Whole of System Plan (WOSP) and DER Roadmap [5]. The Government is examining possible changes to market rules and regulations to ensure system security and reliability, while also deriving as many benefits as possible from the increase of DERs in the SWIS [5].

Some of the proposed areas for reform include:

- Changes to retail tariffs and network tariffs to implement Time of Use (TU) pricing and locational network pricing [4], [6];
- Updates to inverter technical standards to mandate all inverters have their advanced capabilities and two-way communications enabled by default [3], [4];
- Changes to the WEM (Western Australia's wholesale energy market) market rules to allow large scale batteries to participate in the wholesale market [4], [7];
- The increased use of Standalone Power Systems (SPS), microgrids and community batteries in areas where it is economic to do so [4], [6], [8]; and
- Further investigation into the ways that DER can support the network (for example, through aggregation into a VPP that provides localised network support) [4].

Consumer energy trading has been cited by the Australian Energy Market Commission (AEMC) as having the potential to help resolve some of the issues cited above [9], [10]. There can be no single silver bullet to solve the problems facing the SWIS and other Australian energy markets such as the National Electricity Market (NEM). P2P and VPP energy trading are potential solutions that could help alleviate some of the problems while complementing other solutions, potentially making them more effective [11].

Energy trading, including P2P and VPP trading are being examined by industry bodies to deliver system and market benefits. The rule-maker for the NEM, the AEMC, is looking to reward consumers for sustainable behaviour and views energy trading as part of how consumers will interact with the electricity system. This is summarised by; "The Commission's vision for the future electricity system is one of two-way trade of electricity and services in a wholly connected energy market", adding that the energy services will be provided with dynamism, and the "...electricity network is becoming a trading platform ..." [9].

AEMO, which operates Western Australia's Wholesale Energy Market (WEM), has echoed the AEMC's vision of a two-sided market, calling for "changes to the WEM Rules to allow 'multiple trading relationships', whereby an end consumer can benefit by offering services to the market via a third-party aggregator while retaining a relationship with their retailer" and changes to regulations and metering provisions to reach a point where "residential customers can trade their energy between themselves (peer-to-peer), either as part of an embedded network or outside of an embedded network." [3]. As is happening in other countries, such as Japan, aggregators could act as P2P buyers of energy from consumers for both solar and battery sourced electricity [12] [13].

Future energy trading platforms would need to be capable of integrating with the market operators market dispatch platforms and would also require AEMO's cooperation to do so. The AEMC highlights in its 2018-19 annual report that Australian energy markets will continue to become more consumer-centric: "The technology revolution offers opportunities and benefits for customers to take control of how they buy, sell and use energy. Over time, this should allow for greater utilisation of the existing stock of generation and network capacity, lowering average costs for all consumers" [10]. Activities such as customer energy trading can be considered consistent with the WA State Government's view, outlined in their DER Roadmap report, of an energy system whereby consumers can use their DER systems to provide network services to the Distribution Service Operator and participate directly in the Wholesale Market [4]. Without a market mechanism such as a localised energy market enabled by P2P trading, the focus of consumers will be on load defection. But with a market mechanism they are incentivised to have a new relationship with the grid where they provide network services and energy to their neighbours.

Introduction

Due to a lack of research into the topic, there is a need to investigate the potential of energy trading systems to address and resolve some of the challenges facing Australian energy markets and networks. Specifically, energy trading has the potential to create a localised energy market of consumers (both households and businesses) within the same low voltage distribution area that gives residential customers a more cost-reflective rate for the electricity they use and produce during the day. These lower electricity costs could act to shift usage behaviours to the daytime when energy is cheapest, alleviating network problems associated with lack of daytime demand and the reverse flow of energy. Additionally, it could produce a number of non-economic benefits such as empowering consumers with a greater sense of agency and control by allowing them to participate in the market directly [10].

In summary, Western Australia's energy system is facing significant challenges in accommodating the rapid increase in DERs. In the mix of potential changes required to address these challenges, regulators are beginning to investigate the possibility of a decentralised energy market that allows greater direct customer participation, incentivising the optimal physical generation and network outcomes for the energy system - a marked change from the current highly-centralised model, which built the physical system first and designed the market later.

The Project: RENeW Nexus - A study of localised energy markets

The RENeW Nexus project was conceived to understand the potential of localised energy markets and how technology platforms can facilitate more efficient outcomes to the energy system [14]. The project was supported by the Australian Government through the Smart Cities & Suburbs Program.

As a part of the project, in Fremantle, Western Australia, a solar P2P trial called Freo 48 was run that consisted of two Phases: Phase 1 included 18 participants and ran for seven months - November 2018 to June 2019. Phase 2 initially had 30 participants (a single participant withdrew after 2 months due to the increase in costs) and ran from October 2019 to January 2020. A subsequent trial called Loco 1, consisting of the modelling of a VPP, was undertaken to better understand the financial benefits prosumers could realise from having a battery installed and participating in a VPP as well as the benefits to the energy system. Another aspect of the Renew Nexus project is the Loco 2 trial being run at the East Village at Knutsford project. This project is being developed by DevelopmentWA in Fremantle, Western Australia and involves a microgrid with a 670kWh shared battery system which will facilitate 36 households trading excess energy with each other via the battery. East Village is still under construction and the Loco 2 trial will be the subject of further analysis and reporting in due course.

As was outlined in the DER Stocktake [15], the purpose of these trials was:

- To demonstrate proof of concept test for P2P electricity trading;
- To understand the value of P2P for customers and project partners; and
- To trial the technological interoperability between the Power Ledger platform, Synergy (energy retailer), Western Power (network operator) and supporting technologies, and test the Power Ledger platform capability as a client P2P solution.

Introduction

A secondary objective of the trials was to investigate whether P2P energy trading had the potential to incentivise customers to stay connected to the grid and change energy consumption patterns throughout the day to better support the grid and deal with reverse flows of energy due to excess solar electricity during the day.

The Freo 48 trial provided the opportunity to assess participants' perception of and experience using energy trading technology. It also provided an opportunity to assess any behaviour change and/or changes in energy consumption habits by consumers, though these insights were limited by a lack of historical consumption data with which to quantify any changes.

This report summarises the localised energy project, looking at the integration of the Freo 48 trading results, modelling of additional VPP benefits, customer insights provided through multiple surveys, as well as information collected in workshops and discussions undertaken between project partners. This report also provides an analysis of barriers and best-case scenarios for localised energy trading and the benefits to the system, and next steps that could be taken by the relevant stakeholders.

Methodology

Image supplied by the City of Fremantle

Methodology

Freo 48

A solar P2P trading trial, called Freo 48, was undertaken and involved households selling electricity to each other across the grid. Freo 48 had two parts: Phase 1 and 2.

The Power Ledger P2P energy trading platform allows users to trade energy between each other, giving prosumers the ability to sell their excess energy and enabling consumers to purchase that energy at a price agreed between them.

Participants set their own rates for the energy they bought and sold from each other as part of a world-first in dynamic P2P pricing that was introduced in Phase 1. Prosumers with the lowest sell prices and consumers with the highest buy price had first priority for trading, with the transaction settling at the buyer's price.

Allowing participants to set their rates dynamically had the practical effect of creating a localised energy marketplace that uses pricing incentives to balance out the supply of exported energy and consumer demand. If there was an excess of energy available for purchase, prosumers were incentivised to reduce the price to make sure their energy was sold, and consumers could afford to set their prices higher. The reverse is also true - when there was a deficit of exported energy, prosumers could afford to raise the price and consumers would have to lower their preferred price to ensure their demand would be satisfied. The pricing worked as a normal marketplace would - that is, if the prosumers are receiving high prices for their exported energy then the consumers are paying high prices and vice versa.

If P2P energy supply was greater than demand in any given interval, the most expensive energy was sold back to the retailer at a fixed price of 4.0c/kWh (Phase 1) and 3.5c/kWh (Phase 2). If there was more energy demand than supply, the buyers with the lowest offers bought energy from the retailer at a preset rate. Participants had visibility over the quantity of energy they traded and over energy consumed from the grid at times when solar P2P trading does not occur (when the sun is not shining).

To facilitate the solar P2P trading:

1. Granular interval data from real-time electricity meters was installed at the participant's house which was first communicated to energyOS's platform. NB: this is not a requirement for P2P trading, it can also be done with a revenue grade smart meter.

2. Data was then transferred to Power Ledger's system via a secure Application Programming Interface (API).

3. Trading was then carried out on a per-interval basis (i.e. every 30 minutes) by matching prosumers and consumers based on their preferred buy and sell prices. This real-time data was not compliant with state regulations for use in billing customers, so the retailer passed through a data file at the end of each month, which contained the readings taken from the network operator's advanced meters installed at each property to reconcile any differences. No major differences were found, with the only discrepancies occurring when the real-time meters went offline.

4. All transactions for the month were re-run using the network operator's data file and aggregated into a summary file which was then passed through to the retailer via secure file transfer.

5. This data was input into the retailer's customer billing system, used to invoice the customers for the energy they bought and sold, both from the grid and each other.

Each participant's real-time bidirectional energy flow data was measured by a Saturn South three phase mini-meter. These DIN-rail mounted electricity meters were installed in participants' switchboards, or in a standalone IP-rated enclosure where the switchboard proved unsuitable. Readings from the mini meter were wirelessly communicated to a SS9002 ESBox LT gateway device that was connected to each participant's router, which in turn fed the readings to energyOS's platform.

Methodology

The tariffs used in each Phase of the trial were designed to reflect the relative proportions of the various underlying costs of providing energy to the consumer, i.e. a combination of network costs, which cover the cost of building, maintaining and administering the transmission and distribution networks, capacity costs and retailer's energy costs. The network and capacity costs are fixed and distributed evenly across the residential consumer base in line with Western Australia's Uniform Tariff Policy [16].

The tariffs used were "unbundled" (i.e. the fixed and variable costs were separated out) to ensure that a solar P2P energy market could be created. Participants paid fixed charges of $3.30 per day, consisting of a $1.10 capacity charge paid to the retailer and a $2.20 network charge for the network operator, plus a variable trading fee charged by Power Ledger (0.5c per kWh traded P2P). These fixed charges were determined by the retailer and network operator calculating the average per-connection charges required to recover their respective fixed capacity and network costs for supplying the entire residential customer base.

Households in the SWIS usually pay these costs through a combination of the fixed charge component and variable energy charge component of the residential tariff. The network operator elected to provide a discount to the network charge component of 9%, bringing it down to $2.20 (from $2.40).

The rates for energy not purchased via solar P2P trading was charged on a Time-of-Use (ToU) basis and differed between the two trial phases. These rates were based on the average of WEM balancing market prices for the preceding 12 months of each trial period, adjusted for marginal loss factors. Table 1 documents the tariffs used in each trial phase and a similar table can be found in Appendix A comparing the trial tariffs with the most common flat rate residential tariff in Western Australia [17]. All energy purchased from the retailer is hereby referred to as being "bought from grid", as opposed to energy purchased from peers.

Rate	Time	Phase 1 Tariff	Phase 2 Tariff
Retailer Everyday Peak Rate	3:00pm - 9:00pm	9.90 c/kWh	7.80 c/kWh
Retailer Everyday Off-Peak Rate	All other times	5.72 c/kWh	4.90 c/kWh
Retailer Buy Back Rate	Daily	4.00 c/kWh	3.50 c/kWh
RENeW Nexus P2P Energy Rate	Any time	Set by participants	Set by participants
Power Ledger Transaction Fee	Any time	0.50 c/kWh	0.50 c/kWh
Retailer Capacity Charge	Daily	$1.10 / day	$1.10 / day
Network Operator Network Charge	Daily	$2.20 / day	$2.20 / day

Table 1: Phase 1 and 2 Tariffs.
Note: prices include GST.

Methodology

Any energy that was exported by a prosumer and not traded P2P was sold back to the retailer at a predetermined rate. This was set at 4.0c/kWh for Phase 1 and 3.5c/kWh for Phase 2. Both these rates are significantly lower than the Renewable Energy Buyback Scheme (REBS) rate (currently set at 7.135c/kWh), a government funded feed in tariff subsidy in Western Australia aimed at incentivising the installation of rooftop solar PV systems [18].

Learnings from Phase 1 were integrated into Phase 2. Many participants in Phase 1 had a below-average daily energy consumption and therefore saw an increase in costs due to high fixed charges, calculated based on an average customer consumption profile. Recruitment for Phase 2 was initially targeted at households that consume between 11-16 kWh/day, but this band was expanded above 16 kWh/day late in the recruitment period due to difficulties attracting participants that threatened the trial's viability.

The ratio of prosumers to consumers was also modified from Phase 1 to 2. The Phase 1 cohort consisted of ~70% prosumers, which led to an overabundance of exported solar energy during the day. The ratio was reversed for Phase 2, initially consisting of 67% consumers to 33% prosumers. This new ratio not only balanced the amount of exported energy but was more representative of the overall mix of households with DERs in the SWIS today - estimated by the Australian PV Institute as 28.8% of households in the SWIS [19]. As one consumer installed a solar PV system during the middle of the trial, the ratio changed to 62% consumers to 38% prosumers. This highlights the need to achieve the requisite market composition i.e matching buyers and sellers throughout the day as well as grid stability. This is also discussed in the DER Roadmap's vision for a Distribution Market that is balanced by the coordinated dispatch of DER systems. This demonstrates that the introduction of distributed batteries could provide a more efficient way of dealing with this issue by storing some of this surplus solar electricity which can then be dispatched at times of day for which there is demand [4].

Loco 1

In a further part of the project, called Loco 1, a mathematical model was constructed to test typical payback times for a 10 and 15 kWh battery device in a normal household environment. The study went on to evaluate how the payback times might be shortened if the batteries were included in a virtual power plant (VPP) arrangement.

In this analysis, prosumers can use their energy in any one interval for either P2P or VPP trading, but not both during the same interval. Using a battery coupled with VPP, would mean that consumers could purchase locally sourced energy from prosumers with batteries throughout the day, not just when the sun was shining. It also means that batteries could help the grid in dealing with reverse energy flows and provide system services to stabilise the grid, and in doing so pay back the investment a prosumer made in the battery faster.

To investigate these potential system benefits and the ability to deliver localised energy markets, an analysis was undertaken taking account of market conditions, average user profiles and using the Power Ledger VPP energy trading platform. This system provides an interface to VPP operators to inform the DER dispatch decisions and uses a blockchain to create a market mechanism that provides secure trading and fast settlement between customers and energy retailers. Batteries connected to VPP software need to be capable of receiving dispatch instructions from a software control layer, so customers with eligible systems could bring their own DER systems into the VPP. The only other hardware requirements are a smart electricity meter and internet connection.

Methodology

Western Australia's energy market, the WEM, has two distinct markets - a capacity market that pays generators for the available capacity they could provide to the market if required (regardless of whether they actually generate electricity or not), and an energy market for the electricity that has actually been generated. The energy market comprises three parts: Bilateral Contracts between market participants (settled off-market), the Short Term Energy Market (STEM) (a day-ahead market to adjust positions), and the Balancing Market (a market for generators to meet actual instantaneous system demand). Market customers need to purchase from the Balancing market to account for any differences between their net contracted position (STEM + Bilateral purchases) and their actual energy requirements. Historical half-hourly STEM price data was used to determine when the VPP discharged to bid into the STEM rather than offsetting the consumers' energy use. The STEM was chosen as the market that the VPP would dispatch into since a price forecast is required to determine an opportunity for arbitrage - the Balancing Market has ex post (after the fact) price determination so no price forecast is available.

To determine the benefits that a residential VPP could offer in the SWIS, which could also contribute towards localised energy markets, two models were constructed. The first model used the residential A1 tariff, LFAS and STEM pricing information for 2019 and an average Perth household's energy consumption and demand profile to determine the financial benefits for an individual consumer from participating in a VPP. A second model was created to determine the degree to which this VPP could contribute towards localised energy autonomy.

The first model assumed that:

- User consumption of 20 kWh/day. This is above the SWIS average of 13.426 kWh/day as it was assumed that smaller customers had less financial incentive to install battery systems.
- Two options were analysed where a prosumer household had a 5kW solar system and a 3.3kW/10kWh battery or an 8kW solar system and a 5kW/15kWh battery. These were chosen as they are the typical sizes that are currently being sold in the market. Modelling on a larger system was done to examine the benefit from having a higher discharge capacity and longer discharge duration.
- The P2P trading rate was set at the REBS FiT rate of 7.135 c/kWh + 10%.
- The VPP was 10MW in size and could bid into the WEM as a scheduled generator.
- The batteries received a capacity credit for providing LFAS services. The 10kWh battery was able to provide 2.5kW of power post application of de-rating factors; the 15kWh battery was able to provide 3kW.
- All consumers were within the same low voltage distribution network.
- If there was a STEM high price event or LFAS dispatch opportunity, the battery would dispatch for the highest value event, otherwise all energy exported to the grid was traded P2P. VPP participants can participate in both P2P trading and a VPP providing grid services, but not both during the same interval.

Results

Results

Freo 48

Phase 1

Phase 1 of the Freo 48 trial led to a financial loss for a majority of the participants - 17 of the 18 households (94%) experienced higher costs than they would've received under the regulated A1 tariff. Contributing factors are outlined below:

- Because energy generation costs are a relatively small component of delivering electricity to households in the SWIS (approximately 15-20%), reduced daytime energy costs were not sufficient to offset high daily fixed charges for the majority of participants. All participants that were worse off had an average consumption below 11.5 kWh/day. Unbundled tariffs that reflect system costs via a high fixed-supply charge favour higher energy consumption because higher energy use brings down the per-unit cost.

- The suboptimal ratio of prosumers and consumers (70% prosumers to 30% consumers) led to limited demand of P2P energy (more supply than demand) resulting in more rooftop solar electricity being sold to the retailer than traded P2P (18.0% of exported energy sold P2P vs 82.0% sold back to the retailer) attracting a lower rate (4.0 c/kWh and a trading cost of 0.05 c/kWh traded) than otherwise received from the REBS (7.135c/kWh). In addition, the P2P trades that cleared were on average below the REBS rate, which also relates to the relative cost of the off-peak time-of-use tariff (5.72c/kWh) used in the trial.

Any participants that were financially worse off compared to the A1 tariff were credited the difference after the trial ended.

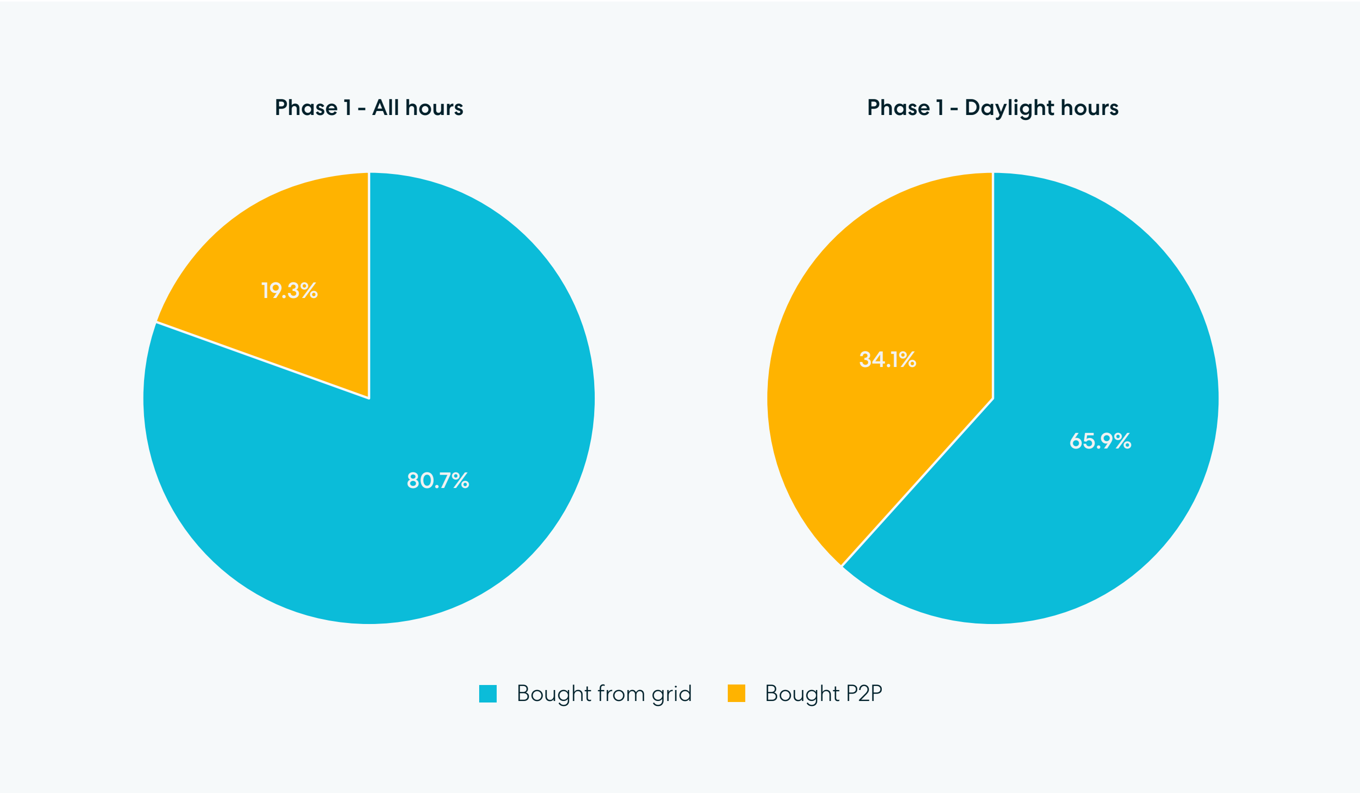


Figure 1: Energy sources.
Relative consumption volumes for trial Phase 1, all hours vs daylight hours.

Results

Participants in Phase 1 consumed 35,796 kWh of total electricity. Of that total, 6,901 kWh (19.3%) was purchased from peers, with the remaining 28,894 kWh (80.7%) purchased from the retailer. Note that these totals include consumption at night when there is no possibility of purchasing solar energy P2P. When narrowed to daylight hours (5:00am to 7:30pm in Phase 1), the percentage of energy sourced from peers changes to 34.1% (6,901.36 kWh), reducing the local markets' need for grid-supplied energy to 65.9% of their daylight consumption. This highlights the ability of localised energy markets to source a significant portion of consumption from themselves and in doing so deal with system challenges from reverse energy flows from excess solar. Figure 1 shows these amounts as a percentage of their respective import/export type.

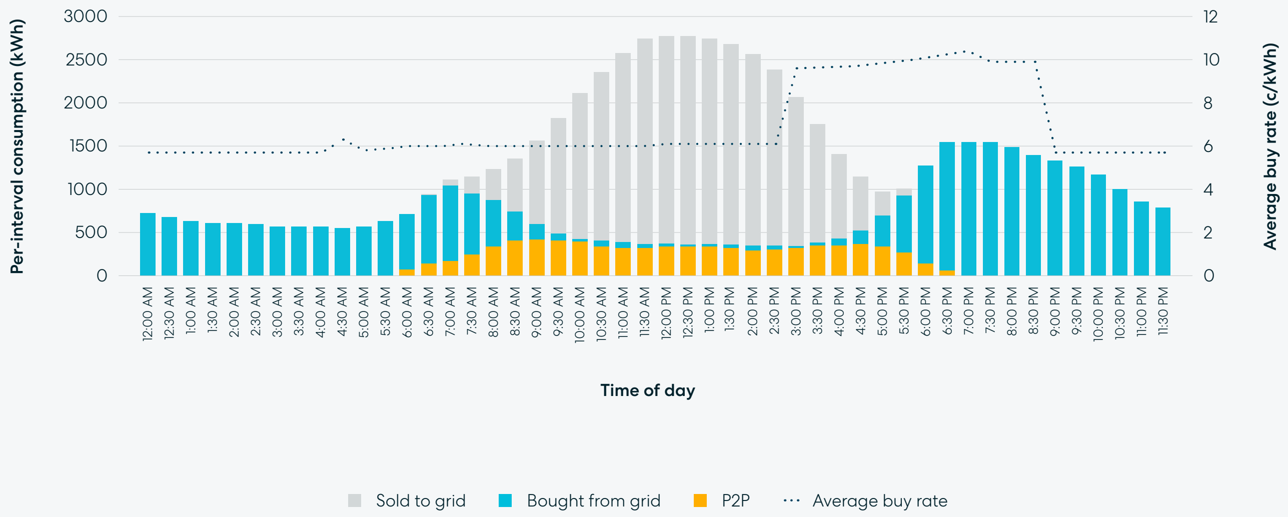


Figure 2: Average transaction type and price.
Summary of Phase 1 transactions, averaged per half-hourly interval.

The prosumers in Phase 1 exported a total of 38,264.92 kWh into the grid over the course of the trial. Of that generation, 6,901.36 kWh (18.0%) was traded P2P and 31,363.56 kWh (82.0%) was sold back to the retailer at the default buyback rate. Appendix B details total consumption and generation information for each Phase 1 participant across the trial, and Figure 2 shows these figures averaged over 30-minute intervals. The large amount of "spilt" exported solar energy in Phase 1 clearly demonstrates the need for more consumers with daytime consumption to absorb the daytime solar generation.

Results

Phase 2

Phase 2 aimed to address some of the learnings from Phase 1. The prosumer to consumer ratio was reversed to reduce the amount of exported energy sold to the grid, with the new cohort initially consisting of 20 consumers and 10 prosumers. Customers with a historical average of 11-16 kWh were recruited to take part in the trial, which aimed to cover the $3.30 total daily fixed costs when compared against using the A1 tariff.

These measures were moderately effective, with the percentage of "spilt" energy (i.e exported solar PV energy that was sold to the grid instead of P2P) reduced to 61.2% in Phase 2 compared to 82.0% for Phase 1.

This was still above the expected level however and can be explained by:

- Below-average targeted consumption by numerous participants. Despite recruitment based on historic energy use of 11 kWh/day, many customers during the trial period had an average daily consumption below this level.
- Seven consumers never logged into the platform and were therefore not able to set up their system and trade. In Phase 1 all participants logged in, thereby reducing the amount of participating consumers. Additional recruitment was not undertaken to address this deficit in consumers.
- Not enough local energy demand during daylight hours. Even though more consumers were added to the Phase 2 trial, their total consumption during daylight hours (5:30am - 7pm) was not enough to consume all the excess exported energy from the prosumers. This suggests that while the trial participants consumed a relatively large amount of energy, the majority of this consumption was not during daylight hours when the prosumer solar PV systems are generating. Despite the excess of generation in the middle of the day, highlighted in Figure 4, ~65% of participants' demand during daylight hours was still sourced from non-P2P generation sources. These figures highlight the mismatch between consumer demand and the availability of solar PV generated energy.

Appendix C shows the relative generation and consumption information for each trial participant in Phase 2, and Figure 4 shows these totals plotted over the relevant 30-minute interval. Participants in Phase 2 consumed a total of 41,164.24 kWh, of which 8,224.78 kWh (20.0%) was sourced P2P and the remaining 32,939.46 kWh was sourced from the retailer (80.0%).

Results

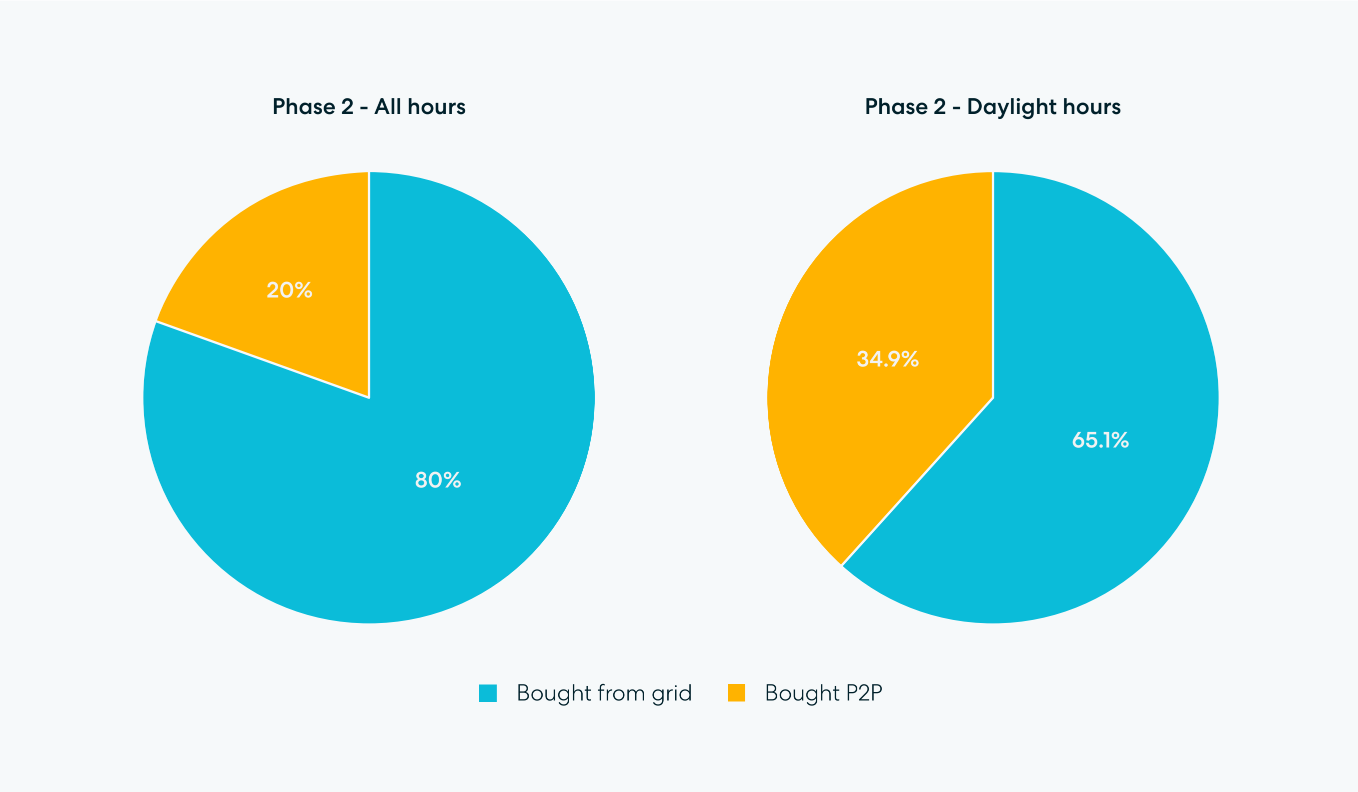


Figure 3: Energy sources.
Relative consumption volumes for trial Phase 2, all hours vs daylight hours.

When only daylight consumption is factored in these totals (i.e between 5:30am and 7:30pm in Phase 2), the percentage of consumed energy sourced from peers increased to 34.9% (8,224.78 kWh) and the remaining 65.1% was sourced from the grid (15,319.77 kWh). Figure 3 shows the average percentage of energy bought in Phase 2, between all hours and daylight hours.

Prosumers exported a total of 21,176 kWh, of which 38.8% was traded P2P and the remaining 12,951 kWh (61.2%) was sold back to the retailer for the default buyback rate.

Phase 2 resulted in a financial benefit for a majority of participants: 18 of the 29 participant households (62%) experienced lower costs than if they'd been charged the A1 tariff whereas 11 participants (38%) experienced higher costs.

These results can be explained due to two major factors:

- P2P trades constituted a very small percentage of the participants' overall costs. Of the registered participants subsequently traded P2P, percentages of P2P trades as part of their overall cost across the trial ranged from 0.1% to 10.2%, with an average of 2.8% and a standard deviation of 2.6%. Any savings derived from purchasing P2P energy instead of grid energy was minor due to the volumes and small price difference involved.

- Average consumption volume (measured in kWh/day) was a much better predictor of a participant's end financial position. A total of 77% (14/18) participants that saw a financial benefit had a consumption level above 11 kWh/day, whereas 80% (10/12) of the participants were worse off compared to the A1 tariff which had a consumption below 11 kWh/day.

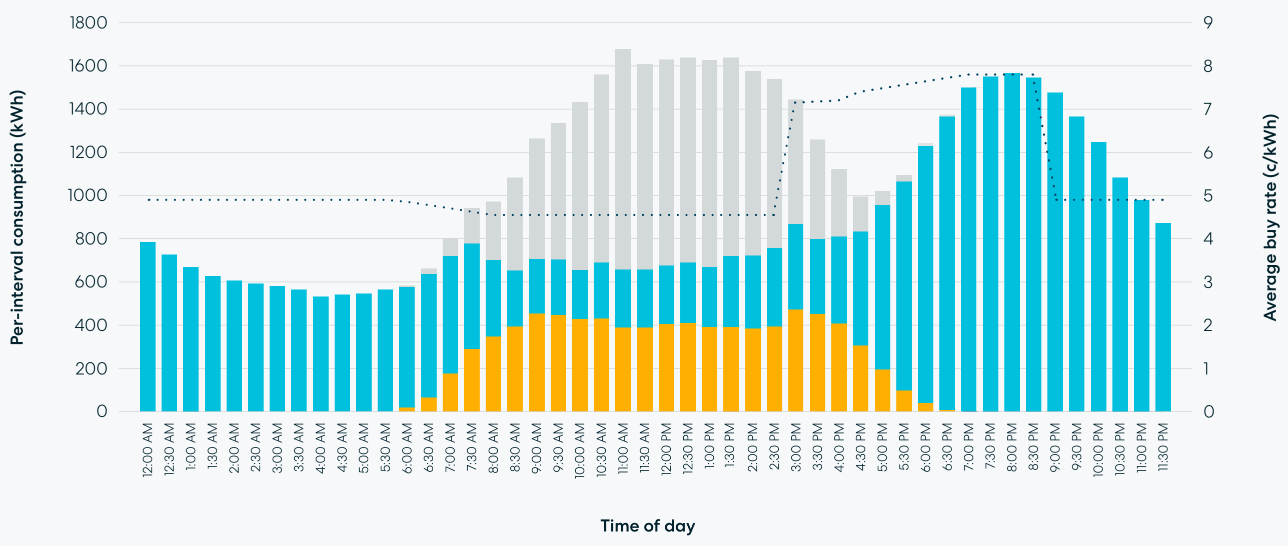


Figure 4: Average transaction type and price.
Summary of Phase 2 transactions, averaged per half-hourly interval.

Technical Outcomes

To facilitate real-time solar P2P trading, additional metering hardware was installed in customers' homes. Real-time metering was intended to provide participants instantaneous feedback on their energy consumption, which in turn was hypothesised to influence their energy consumption behaviour. Real-time metering, however, is not essential for P2P energy trading and the cost and disruption of installing these additional meters to enable this functionality was not seen to be justified by the benefit of having live data. Remotely-read interval meters (usually called 'smart meters' or 'advanced meters') are currently being installed in the SWIS which would instead suffice for solar P2P trading. Future planned upgrades to the network operator's metering infrastructure (both hardware and software) could reduce the time delay between trade and confirmation of the trade. It should be noted that the brand of meter is not relevant, the only requirement for participation in P2P trading is a smart meter with remote communication capabilities and the ability to provide this data regularly and reliably.

The Power Ledger platform and the retailer's billing system was integrated smoothly, with minor modifications to the retailer's systems required to accept trading results and ensure consumption and trading data matched 100%. The data provision from the network operator to the retailer proved adequate for the trial's needs.

Results

Recruitment

The recruitment of consumer participants proved to be more difficult than was originally anticipated.

In Phase 2, all participants fitting the criteria were targeted with an email. Within the City of Fremantle and the suburbs of North Coogee, Palmyra and Hamilton Hill there are some 20,000 households. Due to the high daily fixed charges in the trial, only 200 prosumers were identified as fitting the daily consumption criteria of 11-16 kWh/day, whereas approximately 3,000 consumer households were identified as fitting this daily consumption criteria.

Although there was a small pool of 200 eligible prosumers, recruitment of the 10 prosumers to the trial was relatively straightforward. By contrast, it was significantly more difficult attracting 30 consumers from the 3,000 candidates.

It is hypothesised that prosumers have a greater awareness of electricity markets, having already made a significant investment in their solar PV system and are thus more motivated to participate in schemes or projects that maximise the return on that investment. Consumers, by contrast, have not made such an investment and therefore lack a deeper understanding of reasons to participate. This highlights the need for proactive engagement and communication in offering new products and tariffs into the market.

Survey Results

Seven trial surveys and workshops were undertaken from Phase 1 and Phase 2 participants to gain insights into the participants' experiences during each phase:

- Phase 1
    - A pre-trial survey (48 respondents);
    - Two post-trial participant surveys (10 respondents and 12 respondents respectively);
    - Two workshops, one pre-trial and one post-trial; and
    - An exit survey of recruits that withdrew before the trial started (13 respondents).
- Phase 2
    - A post-trial participant survey (13 respondents).

Results

Participant motivations

Participants were primarily motivated to join the trial for non-financial reasons. The key reasons given were; wanting to be more sustainable, to be part of something innovative, to be part of a community initiative and to learn more about peer-to-peer energy trading. Figures 5.1 and 5.2 outline the responses from participants in Phase 1 (n = 10) and Phase 2 (n = 13) respectively.

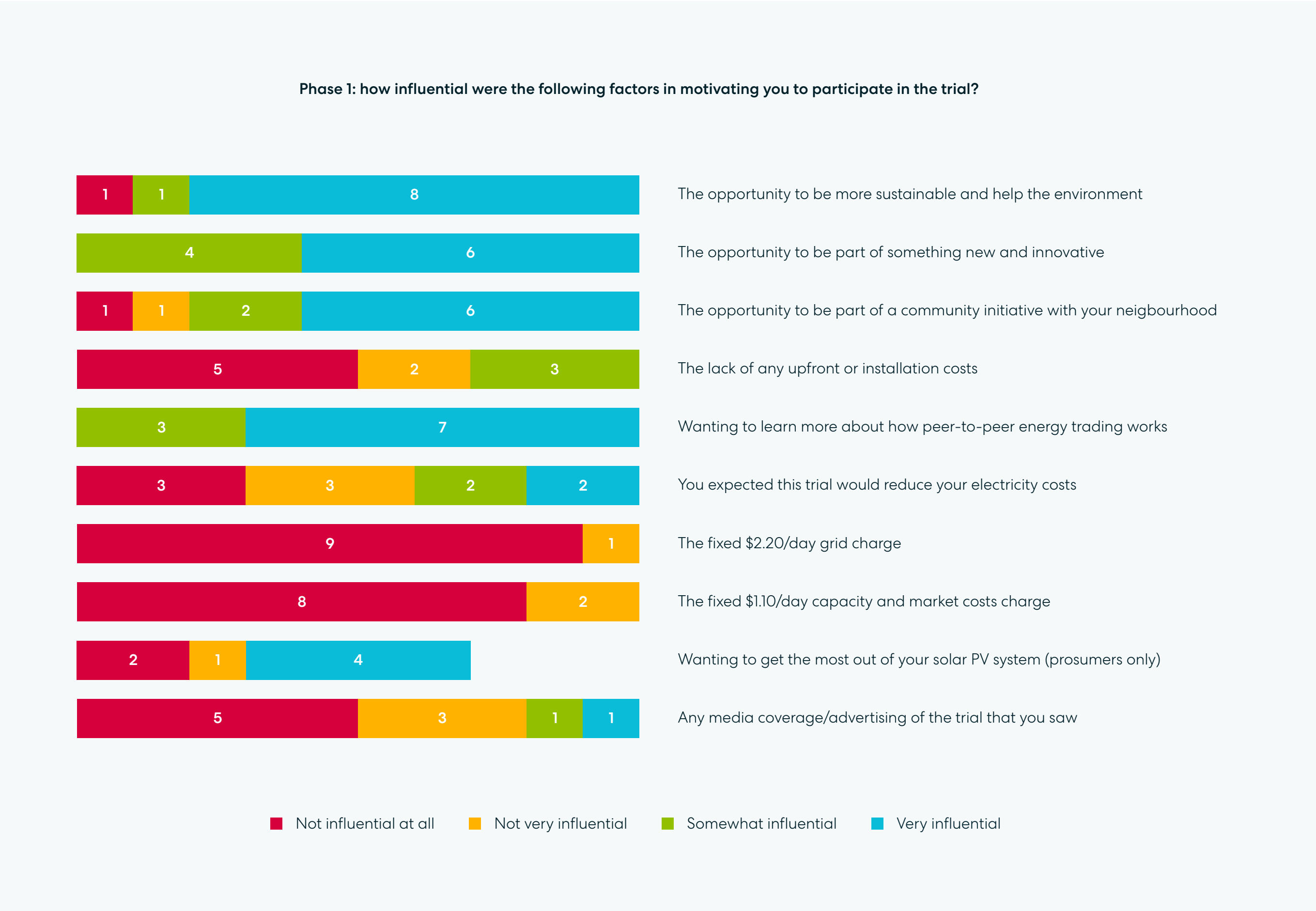


Figure 5.1: Participant motivations for joining.
Phase 1 participant motivations for participation.

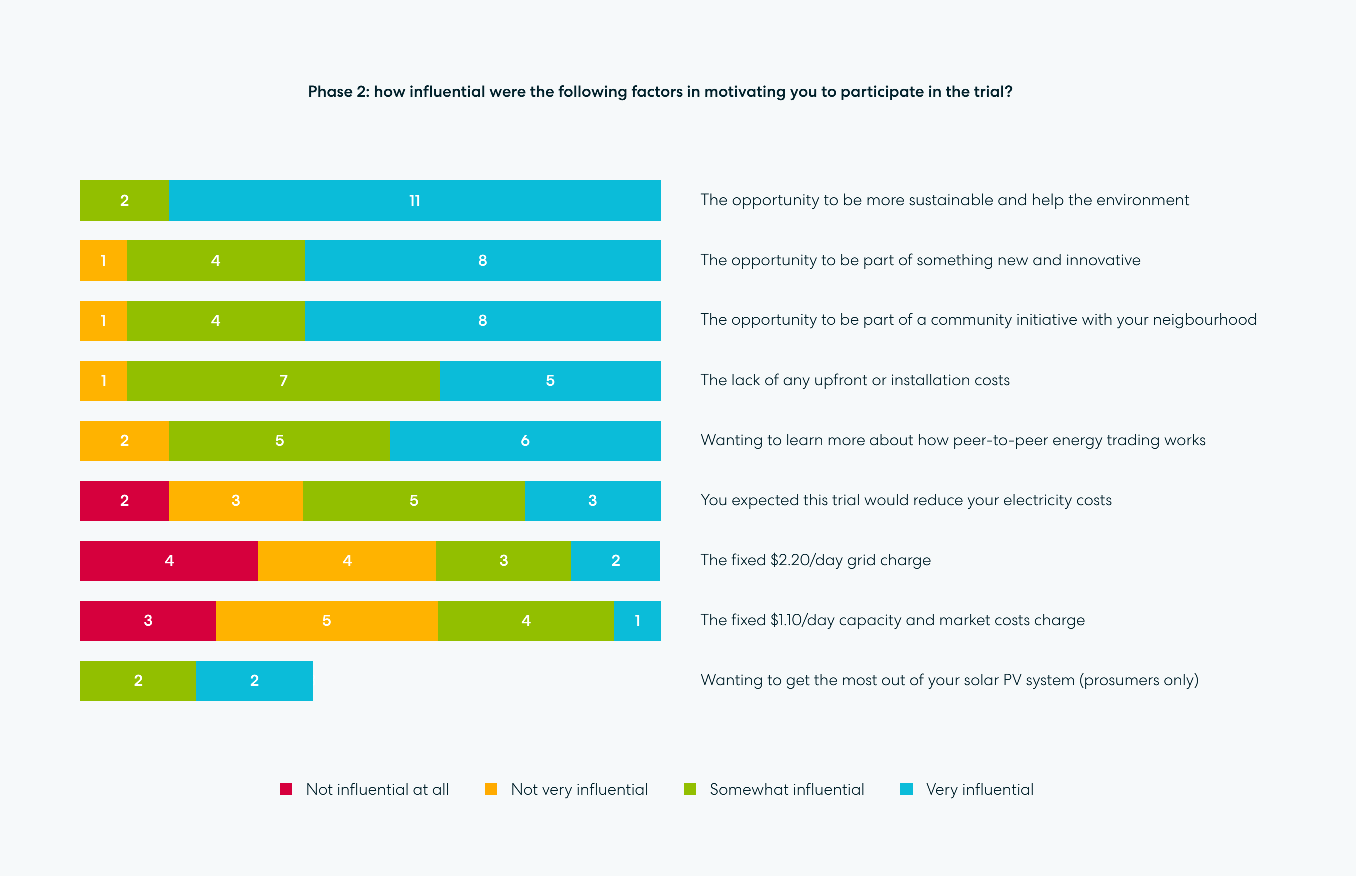


Figure 5.2: Participant motivations for joining.
Phase 2 participant motivations for participation.

An exit survey was sent by Curtin to the Phase 1 participants who initially registered their interest but did not actually sign up. When asked about their reasons for withdrawing, participants cited two main reasons as being because the fixed fees were too high, and that the trial tariff rewards big energy users.

Broadly, the results of the exit survey indicated that these households refused to take part because the tariff (and, by extension, the underlying economics of the SWIS) meant that they would not see a material financial benefit from participating in energy-only solar P2P trading [20]. Figure 6 summarises the responses.

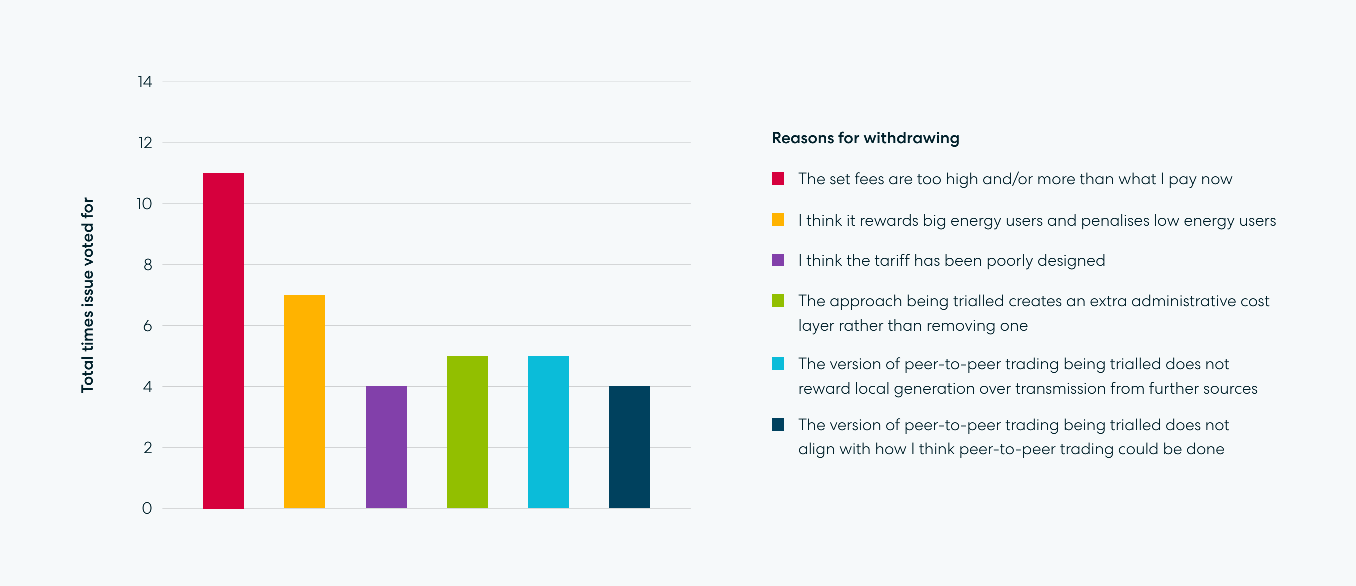


Figure 6: Participant motivations for leaving.
Participant motivations for withdrawing from the trial.

Perception of pricing

Generally, there were mixed perceptions of the charges used in the trial tariffs in both Phase 1 and 2. Participants in Phase 2 perceived the fixed charges more negatively and were less likely to recognise the need for these charges compared to the Phase 1 participants. This is likely due to the higher engagement level with the Phase 1 participants compared to the Phase 2 participants, which led to a better understanding of the costs of generating and delivering electricity. Unsurprisingly, participants viewed the low variable energy rates much more positively relative to the fixed charges. Figures 7.1 and 7.2 display the results from the Phase 1 and Phase 2 post-trial surveys respectively.

Results

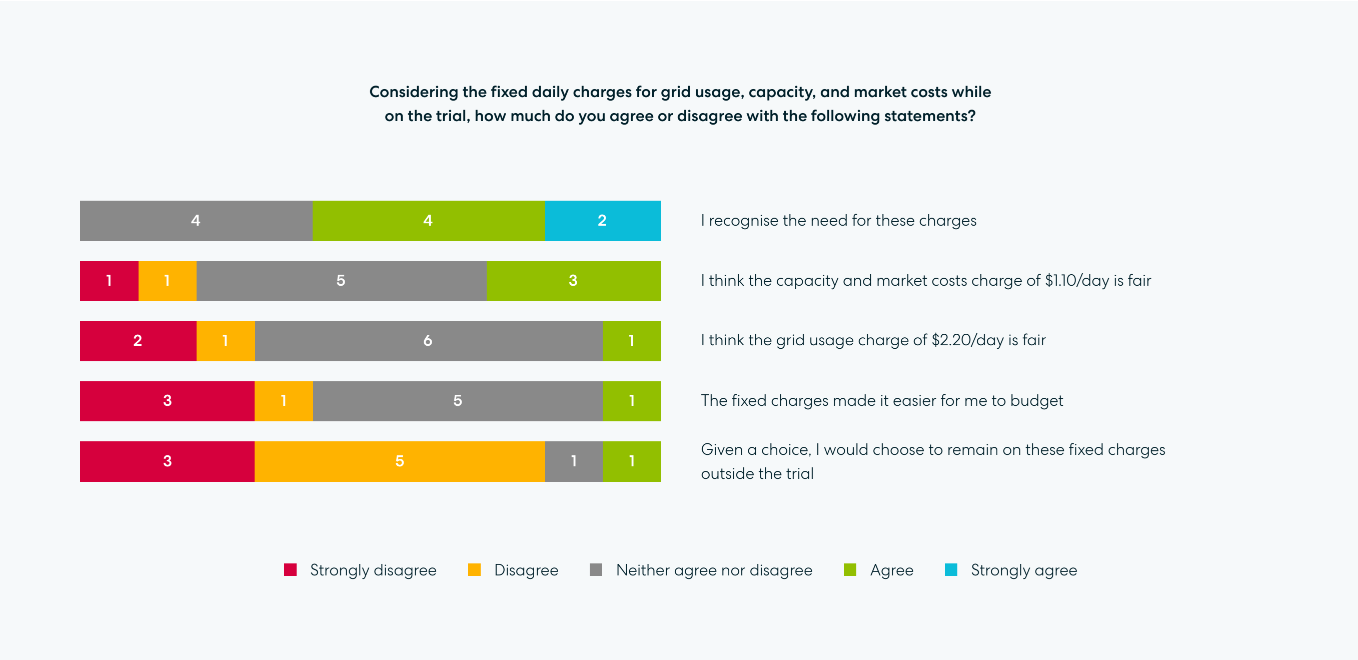


Figure 7.1: Fixed charge perceptions.
Phase 1 participant perceptions of the trial's fixed charges.

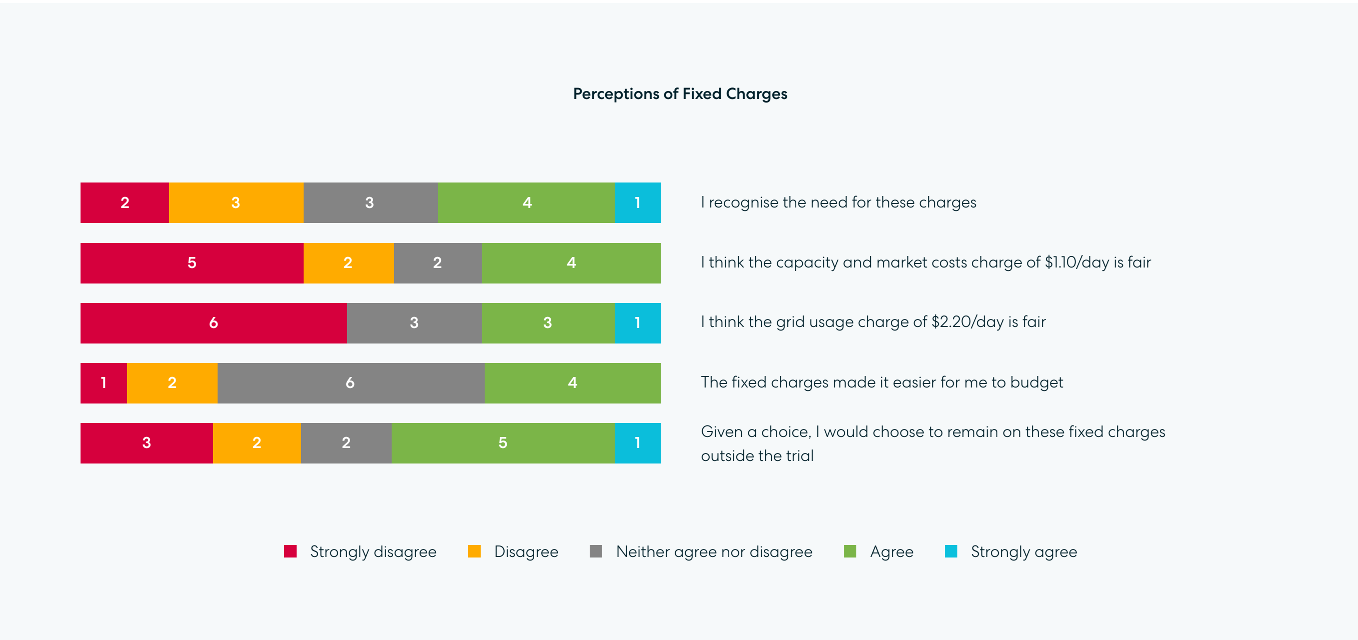


Figure 7.2: Fixed charge perceptions.
Phase 2 participant perceptions of the trial's fixed charges.

These sentiments were also shared by those who registered interest in participating but withdrew before it started. A survey conducted by Curtin University from Phase 1 indicated that households did not proceed because the tariff (and, by extension, the underlying economics of the SWIS) meant that they would not see a financial benefit from participating in energy-only P2P trading.

Phase 2 participants had a much lower understanding of the need for the fixed charges, compared to Phase 1 participants, suggesting that it is possible for consumers to accept change but that the rationale for change needs to be adequately explained to ensure there is consumer acceptance.

The exact rates can be found in Table 1, located in the Methodology section.

Perception of P2P trading

Post trials, when the participants of both phases were asked about their understanding of P2P trading, a majority (17/23, 74%) said that they understood it very well or well enough - these results are shown in Figure 8.

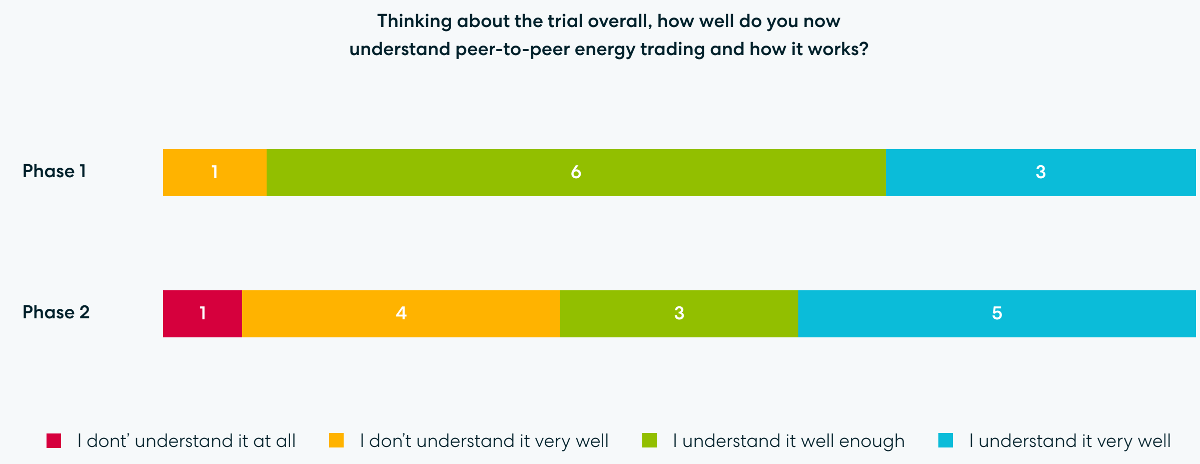


Figure 8: P2P trading perception.
Participant self-evaluations of their understanding of P2P energy trading.

When asked if they would continue with P2P trading outside of trial, most Phase 1 participants were interested or undecided whereas a clear majority of Phase 2 participants were interested. Figure 9 outlines these findings and some of the reasons given for why they were interested.

Results

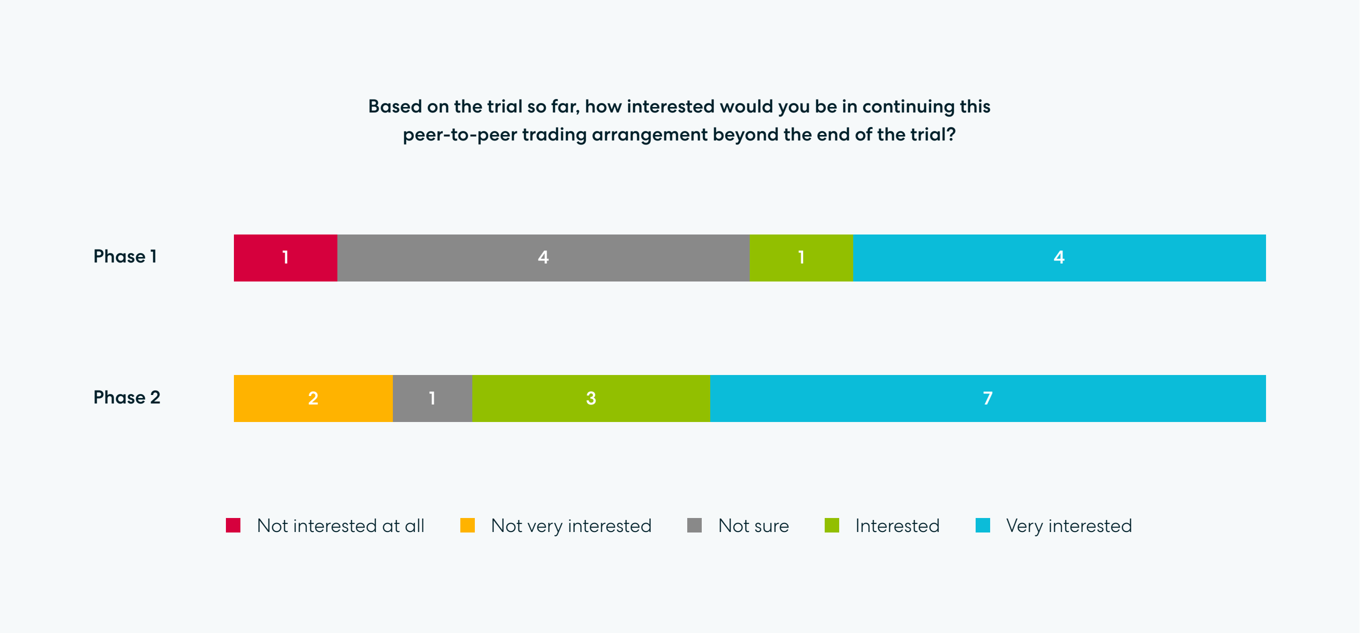
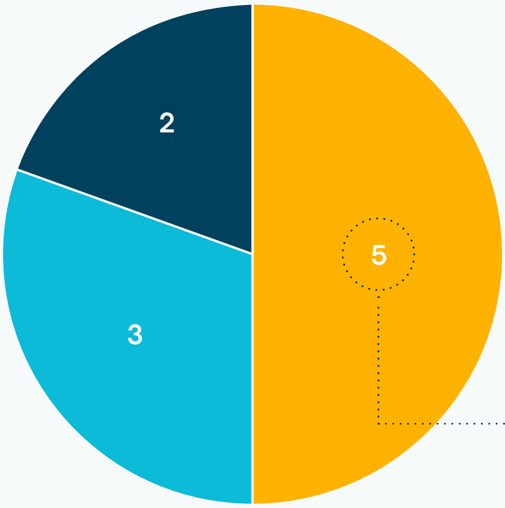


Figure 9: Continuing with P2P trading.
Participants' desire to continue with P2P trading.

When asked about whether participants would actually continue with P2P trading, 78% (18/23) said they would continue if it saved them money or didn't cost them any extra, while 22% (5/23) of the participants said they would regardless of whether it cost them money. Figures 10.1 and 10.2 break down the participants' savings expectations from each trial phase.

Results



In deciding whether to continue with peer-to-peer energy trading, which of the below statements best describes your thoughts?

- I would only continue in peer-to-peer trading if it meant I was saving money off my bill costs
- I would continue in peer-to-peer trading as long as it doesn't add to my bill costs
- I would continue in peer-to-peer trading regardless of whether I was saving or adding to my bill costs

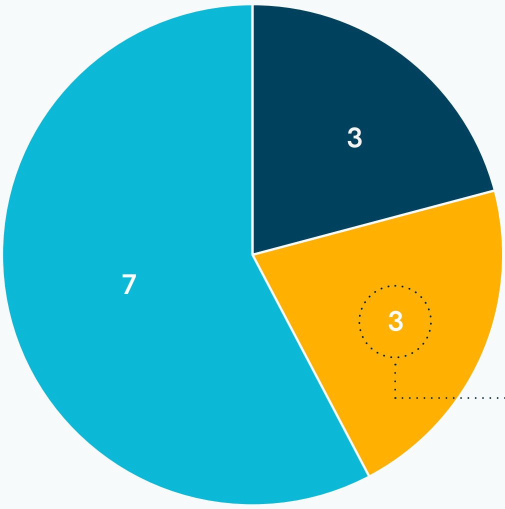
How much would you have to save off your bill to want to continue with peer-to-peer trading?

2 respondents said at least 1 - 10%

1 respondent said at least 11 - 20%

2 respondents said at least 21 - 30%

Figure 10.1: Importance of saving with P2P.
Phase 1 participant expectations of savings required to continue with P2P trading.



How important is the need to save with P2P?

- I would only continue in peer-to-peer trading if it meant I was saving money off my bill costs
- I would continue in peer-to-peer trading as long as it doesn't add to my bill costs
- I would continue in peer-to-peer trading regardless of whether I was saving or adding to my bill costs

How much would you have to save off your bill to want to continue with peer-to-peer trading?

2 by at least 11 - 20%

1 by at least 31 - 40%

Figure 10.2: Importance of saving with P2P.
Phase 2 participant expectations of savings required to continue with P2P trading.

When the Phase 2 participants were asked about their experience with using the Power Ledger platform, 42% (5/12) had a positive or very positive experience using it. 50% (6/12) had a neutral experience, with the single participant (8%, 1/12) citing a negative experience.

Perceptions of energy use

A secondary aim of the trials was to investigate whether solar P2P could encourage participants to shift their consumption to the middle of the day (when solar generation is at its maximum) and away from the morning and evening peaks.

The results of the post-trial surveys indicated that participants were significantly more aware of their energy usage habits. A majority of participants (69%) in both phases stated they considered shifting their energy usage to daylight hours when tradable energy was available (P1: 7/10, P2: 9/13) and most of this subset (75%) stating they made an effort to alter their usage habits (P1: 5/7, P2: 7/9). This indicates that participation in P2P energy trading did make users more conscious of their energy use and were inclined to change their behaviour depending on the price of electricity. Figures 11.1 and 11.2 outline the participants' subjective evaluations of whether their behaviour changed during the trial, separated by trial phase.

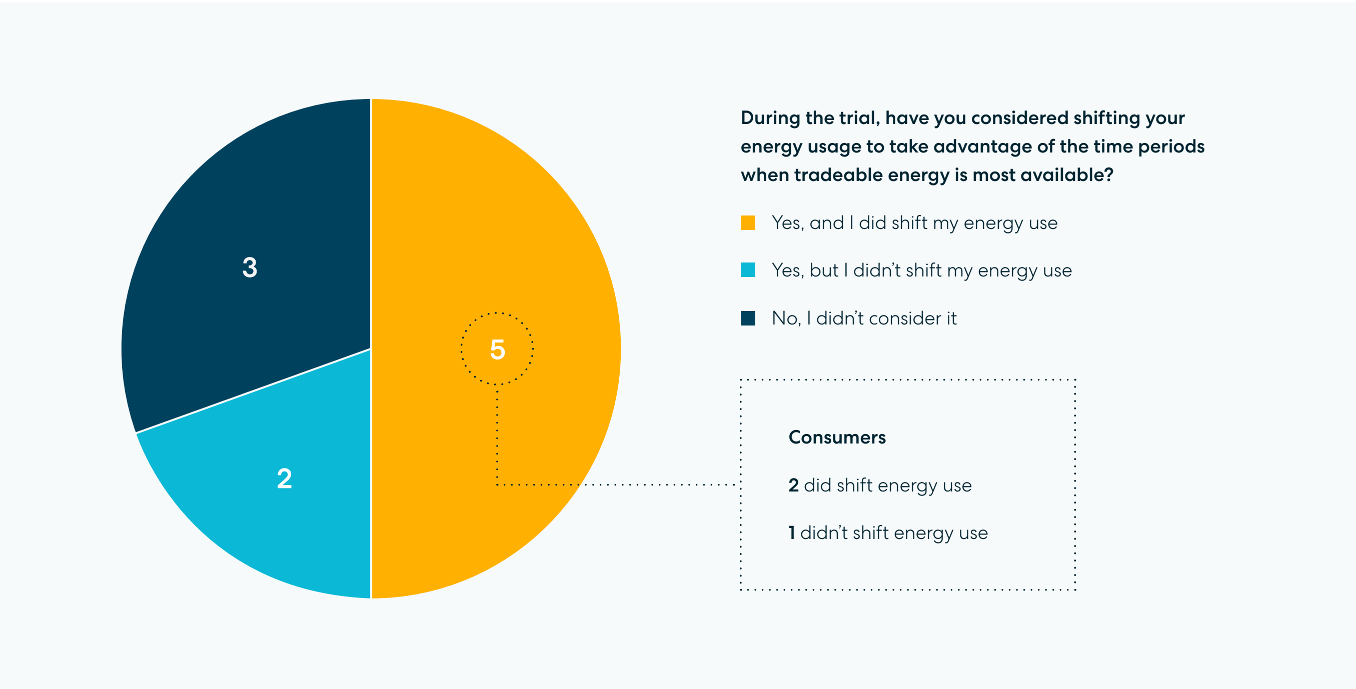


Figure 11.1: Energy consumption behaviour.
Phase 1 participants subjective evaluations of their energy usage behaviour.

Results

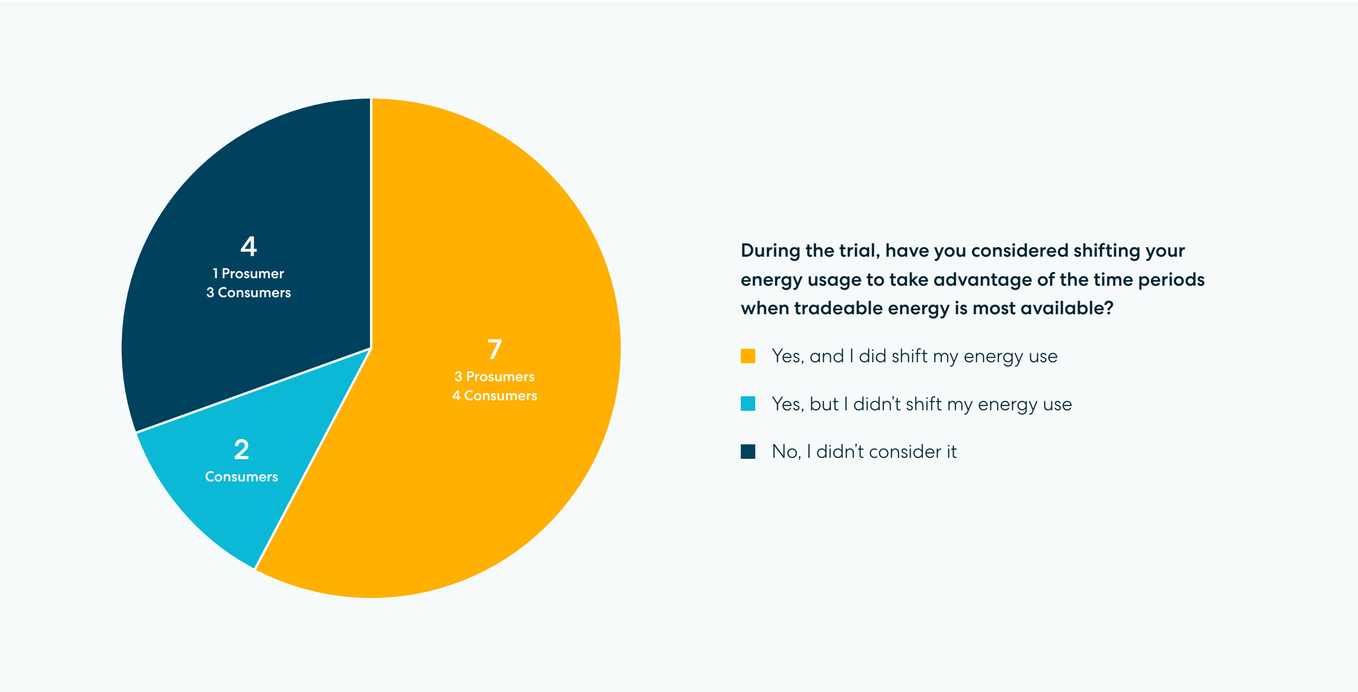


Figure 11.2: Energy consumption behaviour.
Phase 2 participants subjective evaluations of their energy usage behaviour.

As there was no historical data to compare baseline participant consumption against, it was not possible to objectively determine whether solar P2P trading trials led to behavioural change. Future trials should focus on households with a smart meter that has been installed for a number of years to enable a comparison.

Openness to DERs

When asked about their intentions to purchase a solar PV system, most consumers stated that they intended to purchase a solar PV system within the next 5 years. Most consumers said no when asked if they would install a battery system within 5 years, whereas all 4 prosumers that responded said they were likely or very likely. Interestingly, participants were more likely to install a battery system if they could participate in a VPP. Figure 12 outlines these results.

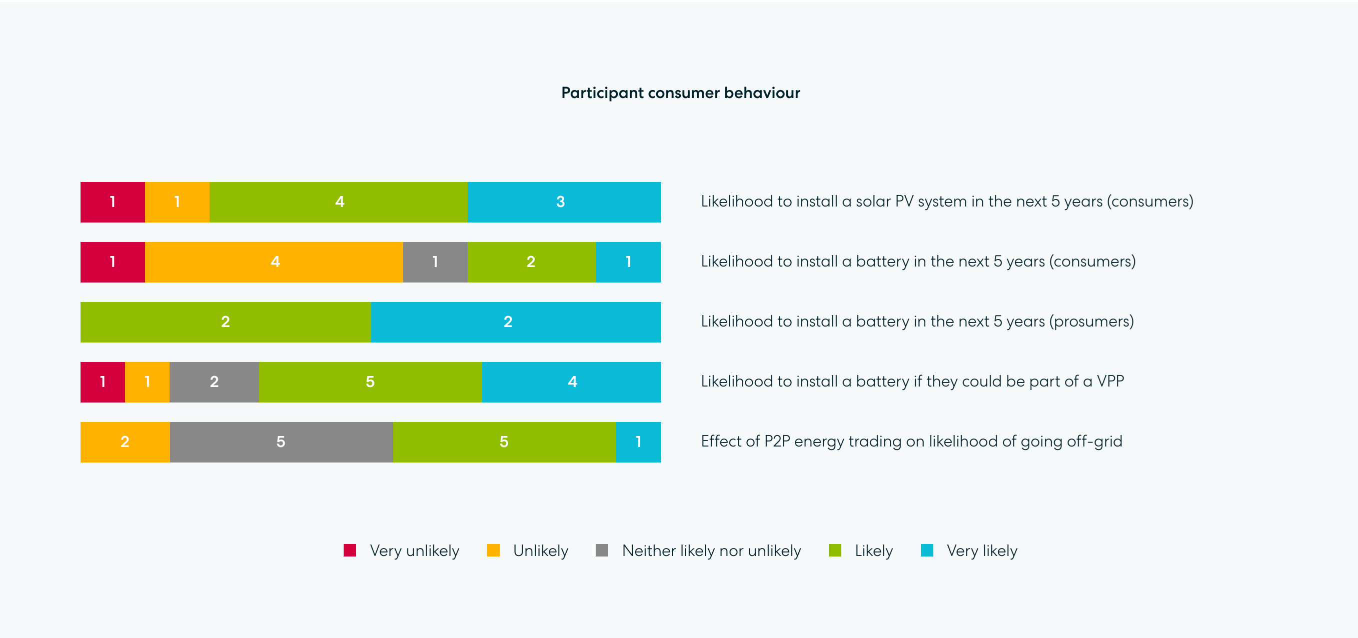


Figure 12: Participant consumer behaviour.
Participants' self-evaluations of future DER purchasing decisions.

When asked if being able to participate in P2P trading would make them more likely to stay connected to the grid, a large percentage said it would make them more likely to disconnect from the grid. This suggests a lack of understanding by participants of the effects of disconnecting from the electricity network and highlights the need for network operators and retailers to better educate the general public on the costs of operating networks and how their tariffs and bills are constructed.

Results

Loco 1

For Loco 1, a mathematical model was constructed to test typical payback times for a 10 and 15 kWh battery device in a normal household environment. This part of the trial aimed to evaluate how the payback times on household battery systems might be shortened if the batteries were included in a virtual power plant (VPP) arrangement.

Figures 13 and 14 show the results of this modelling.

Figure 13: Annual financial benefits from VPP participation.
VPP benefits for an average SWIS consumer with a 5kW solar PV system + 10kWh battery.

Results

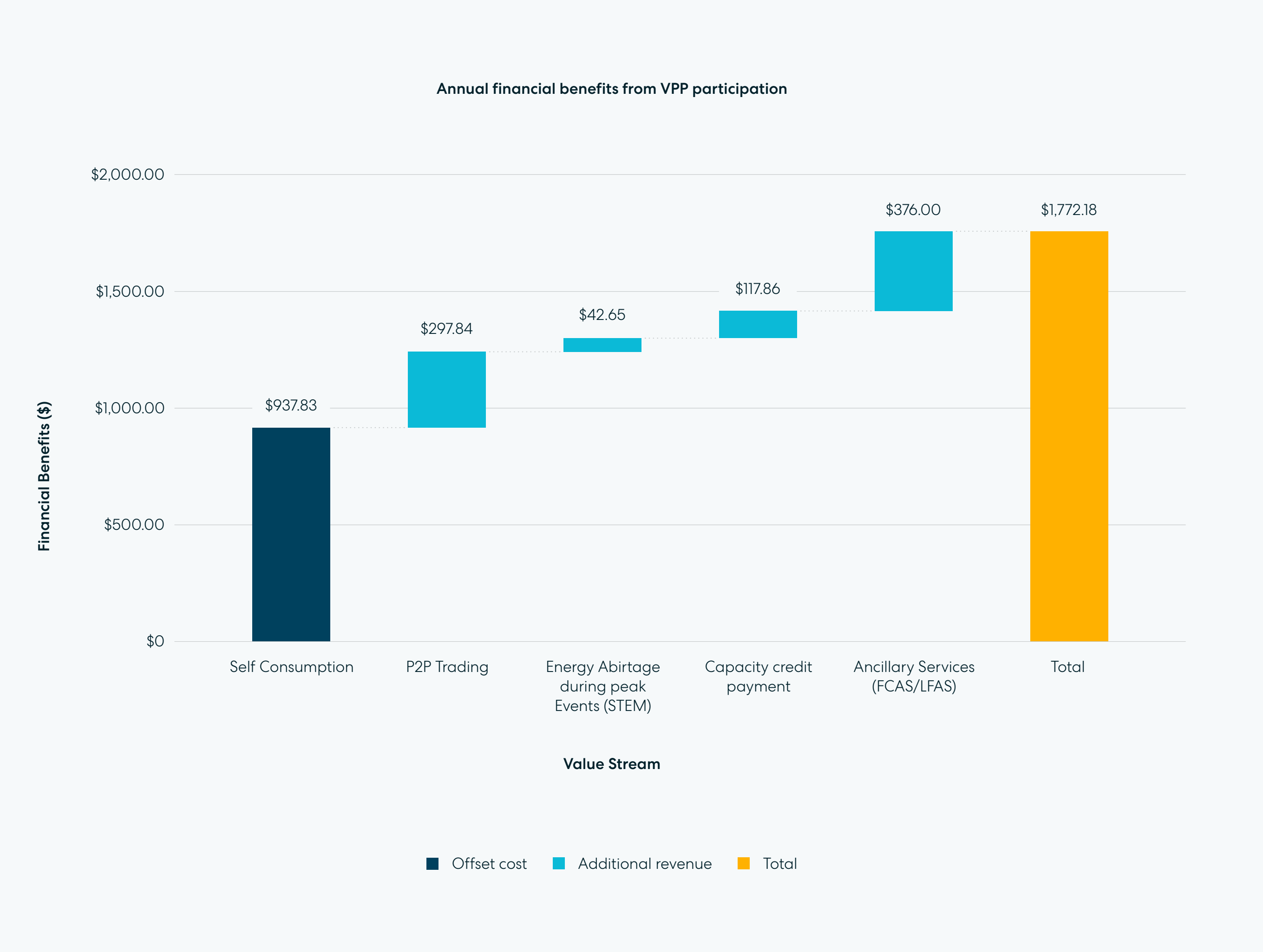


Figure 14: Annual financial benefits from VPP participation.
VPP benefits for an average SWIS consumer with a 8kW solar PV system + 15kWh battery.

Results

This evaluation demonstrates the following:

Battery capacity	10 kWh	15 kWh
Battery cost	$11,775	$15,175
Self-consumption savings	$913.86	$937.86
P2P revenue	$110.11	$297.84
Energy arbitrage revenue (VPP)	$35.54	$42.65
Capacity Credit payment	$98.22	$117.86
LFAS revenue (VPP)	$313.00	$376.00
Total income	$1,470.73	$1,772.18
Payback period self consumption	12.88 years	16.18 years
Payback period (self consumption + VPP)	8.00 years	8.56 years

Table 2: Battery payback comparison.
Note: all fields are annualised.

From a 5kW solar PV system and 10kWh battery each consumer was able to supply 86.87% of their energy needs, with the remaining 13.13% being supplied from the grid. The results of this can be seen in Figure 15. From a 8kW solar PV system and 15kWh battery the household was able to supply 89.14% of their energy needs. The results of this can be seen in Figure 16.

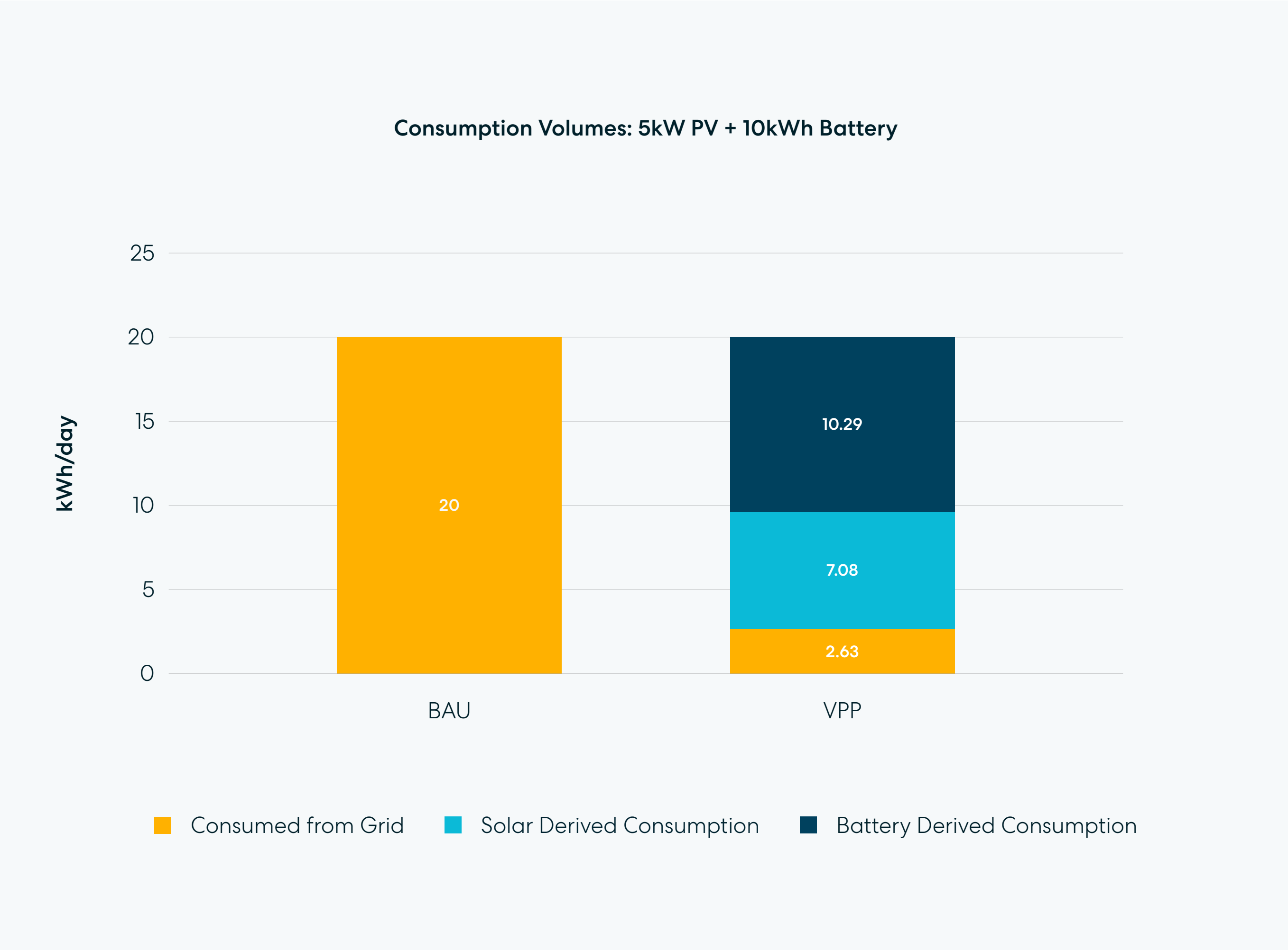


Figure 15: Consumption volumes: 5kW PV + 10 kWh battery.
Energy sources for a 20kWh/day household - BAU compared to a 5kW solar PV system and 10 kWh battery.

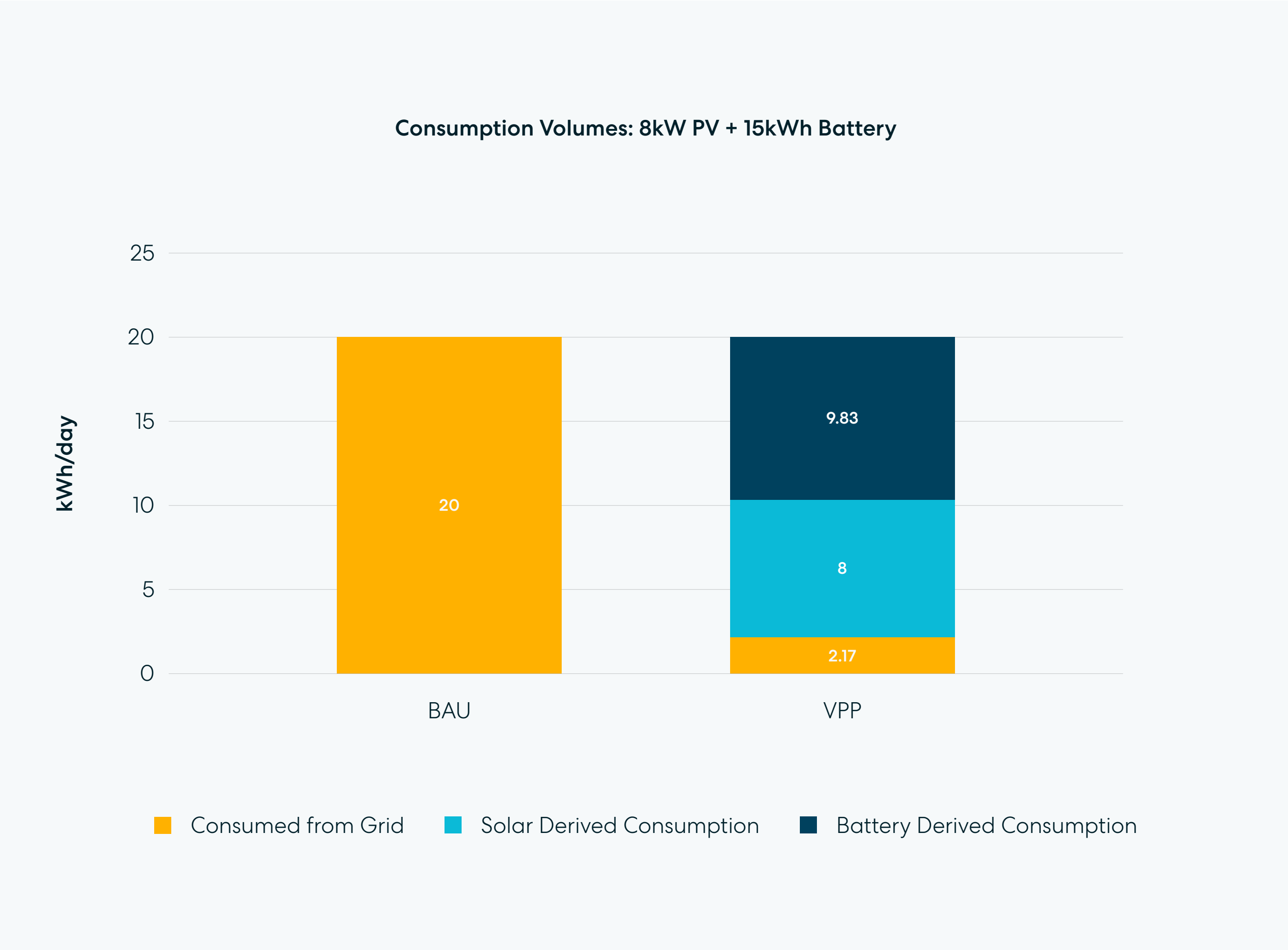


Figure 16: Consumption volumes: 8kW PV + 15 kWh battery.
Energy sources for a 20kWh/day household - BAU compared to a 8kW solar PV system and 15 kWh battery.

A primary purpose of the RENeW Nexus project was to examine the potential for localised energy markets in the SWIS and how they can contribute to the required system outcomes. For this purpose, a second set of modelling was conducted to determine the degree to which a VPP can increase localised energy markets. Specifically, to what degree can a community meet its own energy needs, measured inside a localised distribution area, on a half-hourly basis and reduce its reliance on external energy sources, and in doing so, contribute towards providing grid services in a more cost effective way.

Results

The second model used the following assumptions:

- The market consisted of 29% prosumers with a combined solar and storage system that were participating in a VPP and 71% being consumers with no solar PV or storage system. This is consistent with the overall percentage of prosumers and consumers in the SWIS of 28.8% [19].
- The results of the first model were used as electricity import and export kWh values for the prosumers.
- Consumers had a daily consumption of 13.436 kWh, which is the average consumption of a household in the SWIS [21].
- If there was a STEM high price event or FCAS dispatch opportunity, the battery would dispatch for the highest value event, otherwise all energy exported to the grid was traded P2P.
- It was assumed that there were dispatch instructions being given by the market operator using a Distributed Energy Resource Management System (DERMS) layer to match prosumer export with consumer demand.

Three scenarios were incorporated into the analysis to evaluate the potential for localised energy markets, which in this project is defined as a market within the same low-voltage distribution area downstream of the same feeder, to meet local demand. The degree to which the community can provide localised energy autonomy is defined as the percentage of local energy consumption that can be satisfied from both self-consumption (provided by the prosumer's batteries) and energy exported from the prosumer households i.e. energy traded across the grid.

The results showed that:

Scenario	Percentage of prosumers	Solar PV system size (kW)	Battery system size (kWh)	Degree of localised energy autonomy
1	29%	5	10	11%
2	29%	8	15	30%
3	50%	8	15	68%

Table 3: Results for each modelled VPP scenario.

Overall discussion of the findings

- Under scenario 2, renewable energy autonomy would sit at 30.22% due to the self-consumption provided by prosumers having a battery installed, as well as the VPP dispatching energy from their batteries to meet their neighbours energy needs. Increasing the percentage of VPP participants in the local area to 50% (i.e. scenario 3) increased local energy autonomy to 67.9%.

- The usual consumer benefit from installing a home battery system is that the prosumer consumer needs to procure less energy from the market as well as the system benefit of dealing with reverse flows of energy. By also participating in a VPP, households could sell battery sourced energy to the STEM and LFAS markets, as well as electricity from the battery to their neighbours. Providing these services could yield a 36% increase in annual financial benefit for the household with a 5kW solar PV and 10kWh battery system, decreasing the payback period from 13 to 8 years and incentivising households to install more solar PV and battery systems. This could also reduce or avoid the need for network augmentation, reducing the need for adding further costs to the network and grid tariffs.

Overall, this suggests the possibility of offering a low-cost market mechanism for trading electricity that would encourage solar and storage to be sized to contribute services to the grid, rather than just self-supply. This would need to be investigated, whether it be inclusion in the existing dual-market structure (i.e. the capacity market) or within a two-sided market structure, each could seek to resolve physical issues in the network by creating the right economic incentives for prosumers to strategically install and operate DER assets.

While the VPP modelled for this report focused on household battery systems, it should be noted that businesses with commercial scale battery systems could also participate in a VPP if they meet the requirements outlined previously.

These matters are considered further below in the Dependencies & Barriers section.

Conclusions

Conclusions

Overall perspective gained

The RENeW Nexus project was intended to look at the potential for and benefits of localised energy markets. This is defined as a market that exists within the same low-voltage distribution area downstream of the same feeder. Each market could be linked to other markets such that any net energy export from one market, caused by a net excess of solar PV energy within it, could be used to supply another local energy market linked within a section of the distribution network. This involved looking at the potential for communities to sustain more of their own consumption from local solar PV energy and battery energy via P2P trading, and the benefits that can be derived from a VPP from a grid and consumer perspective.

The Freo 48 trial results showed energy trading was a success from a technical standpoint. Participant demand for energy trading was highly dependent on price structure. Due to the trial tariff structure and the high daily fixed costs involved, participants' financial outcomes relative to the comparison rate (the default residential tariff) were largely dependent on their daily energy consumption rather than their trading volume. Participants that had a high energy consumption (>11 kWh/day) were almost always better off compared to the residential A1 tariff, since the low per-kWh rate used in the trial meant that they were penalised less for consuming more. Low consumers (<11 kWh/day) were almost always worse off since the high fixed fees meant they had a large monthly cost regardless of their consumption, whereas under the A1 tariff they paid less due to the relatively higher volumetric component.

The survey results showed participants were generally enthusiastic about the trials and energy trading, with participants from both phases wanting to be part of an innovative sustainable community project. All Phase 1 participants surveyed saw benefits in energy trading. Most surveyed participants were dissatisfied with the tariff structure, with it being cited as the main reason for withdrawing from the Phase 1 trial. 78% of participants reported (via the survey) that they would need to save greater money or not be worse off for them to continue with P2P trading. While a comparison between the trial tariff (which was designed to be roughly cost-reflective) and the A1 residential tariff isn't valid for a number of reasons (explored in the Barriers and Dependencies section below), the energy component of a SWIS consumers' bill is too small for the desired savings to be achieved via energy-only trading.

The survey results also found that some participants may not have fully understood the rationale for paying for the grid and how energy was priced. Some participants stated that P2P trading would make them more likely to disconnect from the grid, suggesting a fundamental misunderstanding of how P2P trading is carried out. This highlights the need for utilities to clearly and effectively educate the general public on any new concepts or changes that are made to the electricity system, as outlined in the WA State Government's DER Roadmap [4].

In summary, the daily tariff structure used in the Freo 48 trial was the key factor in determining the financial outcomes for participants in all studies conducted, both solar P2P and in a VPP. While the tariff was specifically designed to be cost-reflective, it removed any incentive for participants to trade energy or to shift their usage since the quantities of energy and the prices involved were so small. Under the trial tariff, participants' end financial position was largely dependent on their daily consumption levels. Exit polls showed participants were enthusiastic about energy trading but were deterred by the tariff structure and wanted to see it modified.

This is particularly relevant in considering overall tariff reform that would be acceptable to consumers. For example, if instead of feed in tariff subsidies, there was cheap P2P energy available, this could encourage load shifting and thereby support distribution network and reverse flow issues. This would negate the need for further subsidies to encourage greater demand for electricity when the sun is shining, i.e. solar P2P electricity priced cheaply and correctly can deal with reverse energy flows without any subsidy.

Conclusions

If coupled with the ability for prosumers with batteries to trade via a VPP, prosumers would be able to monetise their excess solar at all times of the day, without any subsidy, and also provide services to the grid (albeit with some rule changes needed) including:

1. LFAS and Spinning Reserve.
2. Reduction in Independent Reserve Capacity Requirement (IRCR).
3. Capacity market.
4. Notional cap products for retailers in the contestable market (physical hedges as cap products).
5. Network Control Services (Voltage management, Active and Reactive Power management) as proposed in the Distribution Market Operator role description in the DER Roadmap [4].
6. Black start services instead of diesel.

This could also work with grid community batteries, for consumers that opt in (as opposed to everyone paying for grid connected batteries) depending on how batteries are priced into the system. For example, if there is no FiT, or a low FiT reflective of wholesale pricing, and all participating consumers pay for a community battery network access fee (and rule changes are brought in to allow it), then prosumers could do P2P and VPP trading as well as consumers doing P2P and VPP, delivering required network services without the need for subsidy.

Therefore if users pay to participate in the community battery and switch to a community battery tariff structure, (for example the WA Government's community battery trial of $1.60/day [22]) prosumers could trade P2P and participate in a VPP. This would mean prosumers are able to monetise their excess solar without subsidy, stabilise the grid, and are economically incentivised to stay connected to the network. At the same time participating consumers, by paying $1.60/day, can purchase energy P2P cheaply and load shift to deal with the reverse flow of energy at the same time. This could provide an overall product proposition to consumers that is acceptable, whereby negative perceptions from loss of a feed in tariffs are mitigated by other benefits attainable. At the same time, government subsidies can be reduced and system benefits can be delivered to the network in a more efficient way.

Conclusions

Dependencies and barriers in the SWIS

While there are no regulatory barriers to a retailer offering their customers energy trading services (whether solar P2P trading or a VPP) within their own portfolio, several other barriers have been identified to a wide-scale deployment of energy trading in the SWIS.

Metering infrastructure

Since energy trading can be done with a regular smart meter capable of providing interval data, the network operator's remotely-read metering infrastructure is sufficient to facilitate day-behind trading. To facilitate real-time dynamic price-setting and trading by participants during the Freo 48 trial it was decided to install an additional Saturn South electricity meter at no cost to the participants. The specifics of these meters are described in the Methodology section.

While having a real-time view of participant's energy usage was considered important for the trial, the cost and disruption of installing these additional electricity meters to enable the real-time functionality was not seen, by project partners, to be justified by the benefit. Nineteen participants who initially signed up chose not to participate in Phase 2 of the trials because of problems with the installation of the additional meter - some switchboards were wholly unsuitable for connecting an additional meter due to their condition, some participants didn't have a modem/router as they had no landline internet connection (required for connecting the gateway device) and some participants were not comfortable with an additional metering device being installed in their homes. The issues that were experienced with retrofitting new meters to households to enable enhanced functionality should be considered when designing future trials.

The WA State Government, through its DER Roadmap, has highlighted that the current unavailability of advanced metering infrastructure acts as a barrier to transitioning to alternative tariff structures, but notes that the network operator is currently rolling out advanced meters to approximately 300,000 sites over the next 3 years [4]. While having a live feed of metering data is not essential to energy trading, it does provide numerous benefits to participants and the market like increased responsiveness and feedback, so the planned upgrade to the metering infrastructure in Western Australia should aim to provide this service and increase the reliability and ease of receiving live data if it is deemed economically feasible.

Tariffs

The regulated feed in tariff rate is not reflective of the true cost of energy during the time of the day that solar PV systems are generating [4]. Under these market conditions it is challenging to make a roughly cost/value reflective energy trading tariff more attractive compared to the A1 tariff and FiT rate. Furthermore, consumers are not incentivised to use energy during the day when the cost is much cheaper. Given the challenges of the existing A1 tariff and FiT arrangements, reduction of the FiT to the fair market price (for example the average Balancing Market price) coupled with a suitable Time of Use tariff structure and P2P energy trading, could create a localised energy market and in doing so deal with costly reverse flow issues. When also coupled with VPP trading, this could allow rooftop solar to be monetised for a much higher value, i.e. be attractive to households overall albeit with a reduction in the FiT.

The current tariff structure does not offer a price signal to optimise DERs nor grid services. The State Government's DER Roadmap report has outlined tariff reform as a key area it will explore, calling on the retailer and network operator to conduct trials into tariff structures that encourage efficient use of the electricity network by customers and the efficient development of network assets by the network operator [4]. The WA State Government's report into WA's transition to a DER future echoes these findings, stating that "More accurate signals would encourage more efficient asset use and development, encouraging microgrids and distributed energy resources at specific points in the network where they can deliver greatest benefit" [6].

Developing a cost-reflective tariff for energy-only trading (unbundled tariff) that is attractive to consumers is difficult as a standalone change due the current underlying economics of the energy cost stack in the SWIS. This is due to the actual cost of energy in the SWIS being relatively small compared to the fixed network costs and capacity costs. Therefore the low cost of energy in a cost-reflective tariff (4.9 c/kWh - 7.8 c/kWh as was used in the trial) means that there is small financial incentive to find a cheaper energy source or reduce energy consumption as any potential savings are limited to single digit dollar figures per month. However, when coupled with market mechanisms such as P2P and VPP, reduced subsidies can encourage load shifting and thereby support distribution network and reverse flow issues. This is discussed in further detail in the next section.

Given that distributed batteries and grid connected community batteries are likely to increase in number in the SWIS, it is prescient to look at how better price signals can be used as a key instrument to deliver the optimal system outcomes, when coupled with tariff reform.

When coupled with market mechanisms such as P2P and VPP, reduced subsidies can encourage load shifting and thereby support distribution network and reverse flow issues.

Using market incentives to shift more customer electricity demand to daylight hours could flatten the daily demand curve and prevent the system failures associated with a net grid-wide demand of less than 700MW that are predicted to begin in 2022 and also reduce network capacity constraints in certain areas [3], [4].

Dependencies and barriers for VPP

To implement and operate an energy trading system like a VPP in the SWIS, numerous regulatory challenges presently exist. Specifically, the SWIS cannot currently fully benefit from the network services that battery technologies (such as a VPP) can provide, as there are no provisions in the market rules for batteries to participate in any of the Western Australian energy markets [4], [6], [7] although the DER Roadmap signals this will change soon. Physically, batteries can dispatch into the market under similar conditions to other intermittent generation sources such as wind and solar farms where capacity payments are reflective of the batteries availability, but regulation doesn't permit this presently. The Economic Regulatory Authority (ERA), the regulator of the WEM, recommends Western Australia look at the United Kingdom as an example of battery storage integration into the electricity network due to the similarity of their markets and regulations [7]. Lessons from AEMO's recent report into their South Australian VPP program, such as methods for measuring the dispatchable capacity of the battery fleet, should be heeded and utilised in the WEM where appropriate [23]. Changes to the WEM market rules to enable batteries and aggregated DERs to participate in the WEM are one of the DER Roadmap's key recommendations [4].

Conclusions

Best use-case scenarios for localised energy markets in the SWIS

Energy trading has many potential uses in the SWIS, some of which could yield more benefits than others. The potential best-use cases for energy trading are outlined below.

Presently due to the feed in tariff, consumers are not seeing the low price of electricity during the day, when the sun is shining, reflected in their bills. Therefore customers are not incentivised to use electricity at that time of the day. Or by removing feed in tariff subsidies, cheap solar P2P energy, when available, could encourage load shifting and thereby support distribution networks and reverse flow issues. The majority of households in the SWIS (~70%) don't have local solar PV generation. By allowing these consumers to access cheaper local solar PV energy P2P during the day, energy trading can incentivise a shift of consumption to daylight hours through cost-reflective pricing. Solar P2P energy trading could also help improve grid utilisation and deliver more efficient services to achieve grid stability as well as reducing the need for costly network augmentation in the metropolitan area [3]. Integrating an energy trading platform with distributed and community battery systems could further improve grid utilisation and improve local power quality as envisioned in the DER Roadmap [4].

Depending on market conditions energy trading could provide a bridge between group-residential, commercial and industrial (C&I) customers. In the context of the SWIS, C&I customers often receive little or no rebate for supplying excess electricity to the grid. Energy trading enables C&I customers to better monetise solar and battery assets, improving customer retention for the retailer that offers such a service.

Finally, VPP modelling demonstrated the potential for VPPs to give battery owners access to additional revenue streams for providing grid services and in doing so decrease the payback period on investment in a battery. VPP energy trading can further reduce excess solar during the day, thereby improving the resiliency of the grid, and then dispatch that electricity when the system actually needs it with households being financially better off even with a reduced feed in tariff. As an example, household income from P2P and VPP could receive between $550-830 per annum. A live trial would provide further insights. ' after the para 'retailer that offers such a service.

Blockchain specific benefits

The use of blockchain technology in electricity markets can yield numerous potential benefits:

- **Faster settlement:** In most existing electricity markets, a market operator is responsible for reconciliation and settlement of energy transactions which takes anywhere from 5 to 90 days. Typically, consumers wait 60 days for their electricity bills and any income from feed in tariffs. Blockchain technology can allow for up to near real-time settlement for transactions, and the ability to readily settle paid electricity on a more frequent basis. Pre-paid, pay as you go solutions and automated billing for consumers and distributed generators can be realised from the use of blockchains, smart contracts and smart metering.

- **Smart contracts can facilitate more complex interactions:** Examples include tokenised funds being disbursed between parties upon meeting pre-specified conditions, such as via a virtual power plant, optimising a battery for the highest value activity without any manual handling required, reducing transactional friction and providing a faster settlement process. In light of the energy system changes and market developments as described in this report, these functionalities become more critical. Smart contracts could potentially simplify and speed up switching of energy suppliers. Enhanced mobility in the market could increase competition and potentially reduce energy tariffs.

Conclusions

- **New market creation:** Blockchain-enabled distributed trading platforms can create new types of markets such as distributed, local and micro energy markets. Blockchains can provide charging solutions for sharing resources between multiple users, such as or common centralised community generation and storage assets, EVs and EV charging stations. Blockchains can assist in network monitoring and management, control and energy management systems and smart grid applications that optimise the use of flexible resources, which might otherwise lead to expensive network upgrades. Consequently, blockchains may affect revenues and tariffs for network use.

- **Cross-retailer trading:** Use of blockchain can facilitate retailers trading and settling energy with other retailers' customers, customers from different retailers trading and settling energy between themselves and also offer customers the ability to trade into the wholesale market. By using a blockchain-enabled database, consumers can trust the measurement of how much electricity is sold and that the amount they should earn will be paid, with less intermediaries, driving cost efficiencies. Using a blockchain-based register can also reduce operational costs, as the holding of registers to track transactions as well as their verification is a costly process, especially when there are issues [24].

- **Enhanced auditing:** Having market records encoded in a blockchain creates an immutable record of the transaction, providing a secure, auditable trail that will streamline disputes and complaints, as well as preventing mistakes caused by manual handling and record keeping. Cryptographic techniques provide security protections which can safeguard data confidentiality, privacy and identity management. In addition, smart grid applications can benefit from data standardisation enabled by blockchain technology. The ability to create immutable records and transparent processes on a blockchain can significantly improve auditing and provide efficiency and certainty around regulatory compliance.

- **Environmental commodity markets:** Certificates and credits derived from electricity trading, such as renewable energy certificates (RECs) and carbon credits, can benefit from the use of blockchain technology. These include the ability for there to be complete security over issuance of certificates, the inability for certificates to be traded if they are retired, or certificates to be owned by more than one party at a time. Blockchain technology can also create marketplaces that are more efficient, where trading and settlement are real time reducing transaction reconciliation and settlement costs associated with traditional processes.

Conclusions

Localised energy trading: value creation as a part of the overall solution

Energy markets around Australia, in particular the SWIS, face significant future challenges. Numerous potential solutions have been flagged by governments, regulators, market operators and network operators such as better technical standards, locational network pricing, market rule changes and increased utilisation of microgrids and SPSs. Energy trading has been proposed as a potential solution by the AEMC, to increase utilisation of the existing network's capacity. While it is not the silver bullet to fix the energy system's problems, energy trading could complement and enhance other proposed solutions to build a more efficient energy system. It is therefore important to consider how energy trading can be implemented and what value it can offer.

Retailers

Ultimately, the value for allowing customers to trade energy is that energy retailers can procure electricity and network services from its customers, providing new income streams to battery owners, while also giving participating retailers a significant point of difference to their competitors. As customers meet more of their own energy needs, the role of the retailer will change from the main supplier of electricity to providing differential power, and acting as an energy 'risk manager'. This is envisaged as the neo-retailer, 'an innovative energy retailer who supports energy trading through the effective aggregation of consumer preference and demand' [25].

Finding value in this future involves the aggregation of services, where retailers move beyond a contract for the supply of energy into providing a range of services for customers. This change is one where the traditional consumer and retailer arrangement shifts towards a dynamic consumer-centric model. As described by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), this is the rise of the prosumer [26].

Currently, in the Western Australian market, Synergy is the only retailer able to supply customers that use below 50 MWh/year. Above this level of consumption, customers are able access a choice of retailers as a part of a contestable market.

The Australian Competition and Consumer Commission (ACCC) found limited innovation by retailers relating to their underlying offer structures [27]. Trials like this involving retailers is bucking this trend by exploring P2P trading. From a competitive point of view, providing a better service to customers is the most reliable way to retain and acquire them.

Retailers stand to capture value by means of customer retention, especially for contestable customers. Under a regulated electricity market, retention is facilitated by retaining customers, engagement and new products and services that maintain profit margins.

In addition to customer retention, energy trading creates new opportunities to link C&I and residential customers. The benefit is that there are fundamentally different consumption patterns between C&I customers and residential customers, so if a retailer can utilise the solar PV generation of their residential portfolio they could then use that cheap energy to offset the load of the C&I portfolio, reducing their need to procure other sources of electricity for the daytime period.

Conclusions

Network owners and operators

Since Western Power is both the Distribution Network Service Provider (DNSP) and the Transmission Network Service Provider (TNSP) which we refer to as the 'network operator', both sides of the network are integrated and run by one organisation. The network operator is working towards similar network models as are in the NEM, as their future model of a 'modular network', outlined in their February 2019 paper 'Creating the rural network of the future' conceptualises a rural network of dynamically connected microgrids and Standalone Power Systems (SPS) interacting with a centralised electricity network. This idea implies the co-location of generation and storage in rural areas, as well as a proliferation of DERs on the edge of the grid [8]. The relevance of this is that changes such as these could provide greater relative economic incentive for customers to trade energy locally, if network pricing was more locationally or context specific.

The AEMC has moved to further incentivise the co-location of generation with consumption, highlighting that there are various mixed incentives created by the current transmission infrastructure access model in the NEM. While the AEMC doesn't have jurisdiction over the WEM (the ERA is the regulator for the WEM), the issues they seek to address are also present in the WEM. The network operator has previously expressed support for location-based allocation of capacity credits in the WEM and has also supported investigating whether a similar locational-based pricing approach would be beneficial for the network [28], a sentiment echoed by the State Government in its report into WA's transition to a DER future [6].

Additional DERs into the electricity network is heavily dependent on the network and market operators' ability to incentivise stable rollout and management across the grid. This is why energy trading could play an important role, providing contextual pricing signals to motivate consumers to shift their consumption (or in the case of a VPP, generation) to the best time. Tariff structures are expected to change in the near future; i.e. REBS rate changed to adequately reflect the lower value for solar PV electricity in the middle of the day [29]. Market operators could also gain greater oversight over the number of DERs on the grid, their output and their potential capacity, allowing them to optimise dispatch decisions and better predict future grid load.

Conclusions

Consumers

As the energy grid decentralises, the provision of energy services will be increasingly consumer-centric.

Energy trading could give the consumers greater returns on DER investments in a future where feed in tariffs are either removed or substantially reduced [29]. In the future, the retail customer will not just solely receive energy services, but will also provide energy services. Whether it be offering demand response (where consumers deliberately curb their use to receive payment) or network support services through participation in a VPP, residential and C&I customers can be paid for the contribution they provide to the system and are therefore incentivised to invest in solar storage systems at a size that deliver system benefits. Giving battery owners access to a new source of revenue for the services they provide will encourage more people to install distributed battery systems, which can then provide a system-wide benefit through increased grid stability in addition to the financial reward for the homeowner.

In addition to being able to access cross-market benefits, consumers may be able to preference local energy generation above other energy sources, thus incentivising the construction of generation sources close to the place of consumption. This, in turn, could improve local power quality, reduce network congestion and reduce the need for network investment in the area.

Prosumers and consumers could receive instant feedback on their energy consumption and export through the instant settlement enabled by blockchain technology. In addition to better-informed market participants, the faster settlement speed results in less capital locked away waiting for settlement, making the market more responsive to changes.

In addition to the direct benefits that a localised energy market offers consumers, they also stand to benefit from its indirect effects. As outlined previously, energy trading has the potential to reduce network costs and increase grid stability, both of which are significant benefits to all consumers connected to the grid. By giving retailers the ability to purchase cheap energy from their customers, energy trading could help bring more competition to the energy wholesale market and, in turn, bring costs down for everyone.

Recommendations

Image supplied by the City of Fremantle

Recommendations

As outlined in previous sections, energy trading from solar P2P and VPP has the potential to create localised energy markets that could offer significant benefits to a number of different stakeholders in the electricity system. Various regulatory changes, tariff changes and mindset changes are required in order for energy trading to be feasible on a large scale in the SWIS. The proposed recommendations are outlined below.

Recommendation 1: Policy makers and market regulators

Developing a cost-reflective tariff for energy-only trading (unbundled tariff) that is attractive to consumers is difficult as a standalone change due the current underlying economics of the energy cost stack in the SWIS i.e the actual cost of energy being relatively small compared to the fixed network costs and capacity costs. Therefore, the low cost of energy in a cost-reflective tariff (4.9 c/kWh - 7.8 c/kWh as was used in the trial) means that as a standalone, there is small financial incentive to trade a cheaper energy source or reduce energy consumption as any potential savings are limited to single digit dollar figures per month. However, reduced FiT subsidies when coupled with market mechanisms such as P2P and VPP trading, could encourage load shifting and thereby support distribution network and reverse flow issues and be economically attractive to consumers.

Policy makers and energy market rule makers should consider modifications to FiT such as changing it to a dynamic feed-in-tariff or, if instead of feed in tariff subsidies, there was cheap P2P energy available, this could encourage load shifting and thereby support distribution network and reverse flow issues, negating the need for further subsidies to encourage greater demand for electricity when the sun is shining, i.e. solar P2P electricity priced cheaply and correctly can deal with reverse energy flows without any subsidy. [4], [6].

Policy makers and energy market rule makers should consider coupling P2P with the ability for prosumers with batteries to trade via a VPP, prosumers would be able to monetise their excess solar at all times of the day, without any subsidy, and also provide services to the grid.

Market rules should be revised to allow batteries or VPPs to be able to participate in the market and to incentivise installation of batteries that deliver network and system benefits, not just batteries facilitating self consumption.

Recommendation 2: Network and market operators

To facilitate energy trading, network operators should improve the metering infrastructure in their systems by installing advanced meters and designing systems for collecting and communicating the metering data to third parties.

Not only is the provision of individual consumer's metering data an essential part of enabling energy trading in energy markets, but it would provide significant benefits to all stakeholders in the system. Network operators would have greatly increased visibility over the network and what changes are occurring thanks to access to granular consumption data. Retailers and aggregators could use this data to make more informed commercial decisions. Third-party participants and service providers could also have access to this data, allowing them to identify areas for innovation and commercial opportunities in the residential space.

Network operators around the world could also further support trials such as the RENeW Nexus project and experiment with new technologies that could offer benefits to the stability, resilience and sustainability of their electricity grid. Such trials offer the potential for breakthrough technologies and innovation to be tested and reviewed in a live environment.

Recommendations

Australian network operators can learn from the RENEW Nexus project and should monitor the next trail, Loco 2, which will examine the East Village project. The Loco 2 trial, being run at the East Village at Knutsford development project in Fremantle, Western Australia, is another part of the RENeW Nexus project. Run jointly by DevelopmentWA, Power Ledger, Murdoch University, Curtin University, CISCO and the CSIRO, Loco 2 involves a microgrid with a large shared battery system and 36 connected prosumer households, who can trade energy with each other or store it in the battery for later use. This project was also conceptualised to look at the viability of localised energy markets, and the results will be analysed and included in an expansion of this report at a later date.

Energy network and market operators should explore alternative methods and structures of charging for network usage to more accurately reflect the reduced use of the transmission and distribution electricity network brought about by peer-to-peer trading.

Recommendation 3: Retailers

With policy support, a particular area that retailers in the SWIS could examine would be the feasibility of implementing a VPP using their customer base. Such a trial would look to test the viability (both financial and technical) of such a system by using a large cohort to identify any technical, regulatory and financial obstacles to its implementation in the short, medium and long term.

All retailers should emulate and continue this trend of innovation by conducting more trials and experiments in various markets to determine where opportunities exist for streamlining systems and improving customer outcomes.

The network operator is currently in the process of upgrading WA's metering infrastructure, aiming to install 238,000 advanced interval meters across the SWIS by 2022 [30]. Any future trial or full-scale deployment of energy trading should be focused on suburbs with advanced meters installed to enable easier metering data provision and enable a valid comparison between, baseline i.e. pre and post-trial results.

Retailers should investigate new retail models that account for the netting off of generation and consumption within their portfolios by offering new products to their customers such as peer to peer trading and VPP's.

More generally, retailers should investigate new retail models that account for the netting off of generation and consumption within their portfolios by offering new products to their customers such as peer to peer trading and VPP's.

Recommendation 4: Customers

As outlined earlier in the report, consumer behaviour is having an enormous impact on the SWIS and on energy systems more generally. Through the correct regulation and incentives, the power of the consumer can be harnessed to bring about the system changes that are needed to stabilise the grid and reduce it's overall costs. The results of this report demonstrate that educating consumers on the energy system, the changes that it's undergoing and the reasoning behind proposed reform will be a key area for governments, regulators and retailers.

The results of this report demonstrate that educating consumers on the energy system, the changes that it's undergoing and the reasoning behind proposed reform will need to be a key area of focus for governments, regulators and retailers.

Governments and regulators should look into the changes that would need to be made to make P2P and VPP energy trading attractive to consumers to deliver optimal system benefits so that consumers can be the driving force behind the energy transition and clean, lowest cost and resilient energy.

Recommendation 5: Live trial

A live trial of a localised energy community (created through a community of consumers and prosumers on the same substation-level distribution network trading via P2P and a VPP) be conducted in the SWIS to determine whether it can provide the hypothesised benefits to the wider electricity system and determine the extent of any economic benefits to the various stakeholders involved.

As outlined in the DER Roadmap, a live trial of orchestrated DER assets (also known as a VPP) should be undertaken in the SWIS. The live VPP trial should aim to identify whether a VPP can provide the electricity system benefits outlined previously in this report as well the financial benefits for any stakeholders involved. These stakeholders might be the household, the network operator, retailer and the surrounding community.

Such a trial should aim to incorporate the learnings derived from this study. In particular, it should:

1. Be conducted in an area that contains a high penetration of solar PV systems that has had interval-capable smart meters installed to facilitate the trial and also quantify any changes in baseline household energy consumption behaviour.

2. Minimise consumer interaction with the VPP and trial onboarding process as much as possible. A major learning from this study was that the inconvenience associated with being onboarded to the trial led to some participants electing not to take part.

3. Ensure thorough education of participating consumers to ensure complete understanding of the trial, the VPP itself, the consequences of participating and the households' obligations in participating. The survey results from this trial suggest a lack of participant understanding around energy trading and the way it is carried out.

4. Be conducted closely with relevant stakeholders such as the network operator, AEMO and the retailer involved to identify the physical and financial impact of a VPP in the SWIS.

5. Cohort size should ideally be greater than 1-2MW and 1,000 household minimum size.

References, Glossary & Appendices

References

1 AEMO, 'AEMO Microgrid and Associated Technologies', Apr. 2018.

2 AEMO, '2019 Electricity Statement of Opportunities', Jun. 2019.

3 AEMO, 'Integrating Utility-scale Renewables and Distributed Energy Resources in the SWIS', Mar. 2019.

4 Energy Transformation Taskforce, 'Distributed Energy Resources Roadmap', Apr. 2020.

5 Department of Treasury, Government of Western Australia, 'Energy Transformation Strategy', 2019. Available: https://www.wa.gov.au/sites/default/files/2019-08/Energy-Transformation-Strategy.pdf

6 Economics and Industry Standing Committee, 'Taking Charge: Western Australia's Transition to a Distributed Energy Future', Feb. 2020., Available: https://www.parliament.wa.gov.au/Parliament/commit.nsf/(Report+Lookup+by+Com+ID)/444FE5266D8EDEA14825851300106DCD/$file/EISC%20Report%208%20for%20web%20FINAL%20REPORT.pdfhttps://www.wa.gov.au/sites/default/files/2019-08/Energy-Transformation-Strategy.pdf.

7 ERA, 'Report to the Minister for Energy on the Effectiveness of the Wholesale Electricity Market 2018, Apr. 2019. [Online] Available: https://www.parliament.wa.gov.au/publications/tabledpapers.nsf/displaypaper/4012365ae79dcabf169e53fd482583d90005d956/$file/2365.pdf

8 Western Power, 'Creating the rural network of the future', 2019.

9 AEMC, 'Integrating Distributed Energy Resources for the Grid of the Future', Sep. 2019.

10 J. Pierce and A. Pearson, 'AEMC Annual Report 2018-19', p. 148, Sep. 2019.

11 Wen, W., Quezada, G., Schleiger, E., Bratanova, A., Graham, P., Spak, B., 'The Future of Peer-To-Peer Trading of Distributed Renewable Energy.' CSIRO & Data61, 2019.

12 Junko Movellan, 'End of the Residential FIT in Japan. Post FIT RECs go to RE100 Companies', Renewable Energy World. [Online]. Available: https://www.renewableenergyworld.com/2019/11/19/end-of-the-residential-fit-in-japan-post-fit-recs-go-to-re100-companies/#gref.

13 Andy Colthorpe, ''Repowering' Japan: Reporting from PV Expo in Tokyo, Part 2', PV Tech, [Online]. Available: https://www.pv-tech.org/editors-blog/repowering-japan-reporting-from-pv-expo-in-tokyo-part-2.

14 R. D. and C. Department of Infrastructure, 'Smart Cities and Suburbs', Infrastructure, Regional Development and Cities. [Online]. Available: https://infrastructure.gov.au/cities/smart-cities/index.aspx. [Accessed: 20-Sep-2019].

15 Energy Transformation Taskforce, 'DER Roadmap: DER Project Stocktake', Dec. 2019. Available: https://www.wa.gov.au/sites/default/files/2020-04/DER%20Roadmap%20-%20Attachement%20B%20-%20DER%20Project%20Stocktake.pdf

16 WA Government, 'Household electricity pricing', 2006. [Online]. Available: https://www.wa.gov.au/organisation/energy-policy-wa/household-electricity-pricing. [Accessed: 12-Dec-2019].

17 Synergy, 'Standard Electricity Prices Brochure'. 01-Jul-2019.

18 Government of Western Australia, 'Electricity Industry (Licence Conditions) Regulations 2005', June. 2019. Available: https://www.legislation.wa.gov.au/legislation/statutes.nsf/main_mrtitle_1347_homepage.html

References

19 Australian PV Institute, ‘Mapping Australian Photovoltaic Installations’, Sep. 2019. Available: https://pv-map.apvi.org.au/historical.

20 Wilkinson, S., Hojčková, K., Eon, C., Morrison, G. M., & Sandén, B. , ‘Is peer-to-peer electricity trading empowering users? Evidence on motivations and roles in a prosumer business model trial in Australia’, Energy Research & Social Science, Aug. 2020.

21 Australian Energy Market Commission, ‘Residential Electricity Price Trends 2019’, Dec. 2019.

22 Government of Western Australia, ‘State Government rolls out first community battery in Perth’, Feb. 2020. Available: https://www.mediastatements.wa.gov.au/Pages/McGowan/2020/02/State-Government-rolls-out-first-community-battery-in-Perth.aspx.

23 AEMO, ‘AEMO Virtual Power Plant Demonstration’, 2020. [Online]. Available: https://aemo.com.au/-/media/files/electricity/nem/der/2019/vpp-demonstrations/aemo-knowledge-sharing-stage-1-report.pdf?la=en&hash=50B02E668A57A9B5257951537F431134.

24 Matt Levine, ‘Dole Food Had Too Many Shares’, Feb. 2017. [Online]. Available: https://www.bloomberg.com/opinion/articles/2017-02-17/dole-food-had-too-many-shares

25 Power Ledger, ‘Power Ledger Whitepaper’, Perth, White Paper, 2019.

26 CSIRO, ‘Change and choice - The Future Grid Forum’s analysis of Australia’s potential electricity pathways to 2050’, p. 80.

27 ACCC, ‘Retail Electricity Inquiry - Preliminary report’, 13-Nov-2017. [Online]. Available: https://www.accc.gov.au/system/files/Retail%20Electricity%20Inquiry%20-%20Preliminary%20report%20-%2013%20November%202017.pdf. [Accessed: 07-Oct-2019].

28 Western Power, ‘Proposed approach to implement constrained network access’, Nov. 2018. Available: https://www.wa.gov.au/sites/default/files/2019-08/Consultation-Paper-Two-Improving-access-to-the-Western-Power-Network_0.pdf

29 S. Vorrath, ‘WA govt considers home battery incentives, in solar tariff review’, RenewEconomy, 01-Aug-2018. [Online]. Available: https://reneweconomy.com.au/wa-govt-considers-home-battery-incentives-solar-tariff-review-36744/. [Accessed: 11-Dec-2019].

30 Western Power, ‘Advanced meters puts the power in your hands’, 2020. Available: https://westernpower.com.au/energy-solutions/projects-and-trials/advanced-meters-puts-the-power-in-your-hands/?gclid=EAIaIQobChMI6tiGwIzB6AIVxBwrCh03awPxEAAYASAAEgJsavD_BwE.

Glossary

ACCC	Australian Competition and Consumer Commission
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
API	Application Programming Interface
BAU	Business as Usual
C&I	Commercial and Industrial
COAG	Council of Australia Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Distributed Energy Resources
DNSP	Distribution Network Service Provider
ERA	Economic Regulatory Authority
FCAS	Frequency Control Ancillary Service
GW	Gigawatt
kW	Kilowatt
kWh	Kilowatt-hour
LFAS	Load Following Ancillary Service
MW	Megawatt
MWh	Megwatt-hour
NEM	National Electricity Market
P2P	Peer-to-peer
PV	Photovoltaic
REBS	Renewable Energy Buyback Scheme

Glossary

SPS	Standalone Power System
STEM	Short Term Energy Market
SWIS	South West Interconnected System
ToU	Time of Use
TNSP	Transmission Network Service Provider
UK	United Kingdom
VPP	Virtual Power Plant
WA	Western Australia
WEM	Wholesale Energy Market
WOSP	Whole of System Plan

Appendices

Appendix A: Comparison of trial tariffs and typical flat rate WA residential tariff

Rate	Time	Phase 1 Price	Phase 2 Price	Typical flat rate WA residential tariff*
Retailer Everyday Peak Rate	3:00pm - 9:00pm	9.90 c/kWh	7.80 c/kWh	28.8229 c/kWh
Retailer Everyday Off-peak Rate	All other times	5.72 c/kWh	4.90 c/kWh	28.8229 c/kWh
Retailer Buyback Rate	Daily	4.00 c/kWh	3.50 c/kWh	7.135 c/kWh
RENeW Nexus P2P Energy Rate	Any time	Set by participants	Set by participants	N/A
Power Ledger Transaction Fee	Any time	0.50 c/kWh	0.50 c/kWh	N/A
Retailer Capacity Charge	Daily	$1.10 / day	$1.10 / day	N/A
Network Operator Network Charge	Daily	$2.20 / day	$2.20 / day	N/A
Supply Charge	Daily	N/A	N/A	$1.033263 / day

Note: Prices include GST, except for the Buyback Rate on which there is no GST payable.

**Synergy's A1 tariff is used which is the most common flat rate residential tariff in WA.*

Appendix B: Phase 1 participant kWh trade volume, categorised by trade type

Meter ID	Bought from grid	Bought P2P	Total imported	Sold to grid	Sold P2P	Total exported
RNX_0021	2,085.84	255.88	2,341.72	4,417.78	338.51	4,756.29
RNX_0059	773.98	111.51	885.48	1,487.41	41.78	1,529.19
RNX_0060	2,167.62	180.20	2,347.82	4,542.72	449.95	4,992.67
RNX_0072	2,124.89	194.38	2,319.27	3,562.40	416.58	3,978.97
RNX_0081	1,325.63	307.62	1,633.25	939.20	56.45	995.65
RNX_0083	904.69	296.64	1,201.33	314.84	2,256.25	2,571.09
RNX_0084	5,801.00	398.81	6,199.82	5,677.68	401.46	6,079.14
RNX_0094	1,372.55	302.09	1,674.63	1,966.53	330.38	2,296.90
RNX_0102	1,415.86	373.14	1,789.00	753.49	52.60	806.09
RNX_0108	1,465.64	453.97	1,919.61	246.69	1.05	247.75
RNX_0184	1,580.76	92.25	1,673.01	4,658.44	289.44	4,947.89
RNX_0232	898.59	459.53	1,358.12	-	-	-
RNX_0238	744.55	607.67	1,352.22	-	-	-
RNX_0244	921.80	644.34	1,566.14	-	-	-
RNX_0250	1,440.52	617.89	2,058.40	-	-	-
RNX_0256	1,113.30	751.60	1,864.89	-	-	-
RNX_0418	1,570.17	177.70	1,747.87	2,796.37	2,266.90	5,063.27
RNX_0436	1,187.55	676.15	1,863.69	-	-	-
Totals	28,894.93	6,901.36	35,796.28	31,363.56	6,901.36	38,264.92
Average	1,605.27	383.41	1,988.68	1,742.42	383.41	2,125.83

Appendix C: Phase 2 participant kWh trade volume, categorised by trade type

Meter ID	Bought from grid	Bought P2P	Total imported	Sold to grid	Sold P2P	Total exported
RNP2-C3	826.91	283.90	1,110.81	-	-	-
RNP2-C4	867.19	714.18	1,581.37	-	-	-
RNP2-C5	1234.88	-	1,243.88	-	-	-
RNP2-C7	620.87	263.54	884.41	-	-	-
RNP2-C12	787.82	466.68	1,254.51	-	-	-
RNP2-C13	1,431.32	-	1,431.32	-	-	-
RNP2-C17	1,055.55	407.64	1,463.18	-	-	-
RNP2-C18	2,190.27	-	2,190.27	-	-	-
RNP2-C20	1,596.81	-	1,596.81	-	-	-
RNP2-C21	883.11	-	883.11	-	-	-
RNP2-C22	1,892.82	619.81	2,512.63	-	-	-
RNP2-C27	693.73	1,072.81	1,766.54	-	-	-
RNP2-C30	1,120.32	-	1,120.32	-	-	-
RNP2-C32	849.78	407.30	1,257.08	-	-	-
RNP2-C33	1,313.12	619.58	1,932.71	-	-	-
RNP2-C38	1,216.03	463.87	1,679.90	-	-	-
RNP2-C40	810.05	157.67	967.72	165.43	433.24	598.67
RNP2-C42	619.41	458.48	1,077.89	-	-	-
RNP2-C44	986.23	392.41	1,378.65	-	-	-
RNP2-C45	1,001.70	230.36	1,232.06	-	-	-
RNP2-P1	1,022.54	87.57	1,110.11	831.60	973.75	1,805.35
RNP2-P2	1,316.67	270.67	1,587.34	872.62	2,154.33	3,026.94
RNP2-P3	1,237.72	97.47	1,335.20	2,116.49	158.13	2,274.62
RNP2-P4	1,249.96	185.35	1,435.31	698.13	1,842.36	2,540.49
RNP2-P5	1,170.35	371.29	1,541.64	493.36	956.83	1,450.18
RNP2-P8	1,124.59	93.60	1,218.20	423.16	474.06	897.22
RNP2-P10	1,217.00	-	1,217.00	2,460.36	-	2,460.36
RNP2-P11	1,008.81	582.86	1,537.67	780.81	479.65	1,260.46
RNP2-P12	1,272.55	-	1,272.55	3,024.31	113.15	3,137.46
RNP2-P13	312.33	31.73	344.07	1,085.38	639.29	1,724.68
Totals	32,939.46	8,224.78	41,164.24	12,951.64	8,224.78	21,176.43
Average	1,097.98	274.16	1,372.14	431.72	274.16	705.88