Project Symphony

Our energy future

Distribution Constraints Optimisation Algorithm Report

Work Package 4.1

31st March 2022

The PACE Research Group of the University of Western Australia

THE UNIVERSITY OF WESTERN AUSTRALIA

In partnership with:

western power · synergy · AEMO · Government of Western Australia Energy Policy WA

Project Symphony
Our energy future

Purpose

This report has been prepared for ARENA as part of Project Symphony to provide information on the network Distribution Constraints Optimisation Algorithm (DCOA) tool. The DCOA tool will enable the Distributed System Operator (DSO) to develop the appropriate level of distribution network constraint analysis and support the equitable deployment of Distributed Energy Resource (DER) in an off-market pilot to simulate aggregated DER integration into the Wholesale Electricity Market (WEM).

The purpose of this report is to describe the implementation of the network capacity forecasting function (Evolve solution) utilised within Project Symphony and provide a methodology to compare alternative DOE allocation methods (DCOA) as to their scalability and reliability, environmental impact, customer equitability and potential impact on energy buyback scheme rebates. This report should assist a DSO with deciding which allocation method is best suited under a particular scenario, or set of conditions, and the benefits of further investment in the extensive technology and equipment required to support advanced DER management techniques.

ARENA Disclaimer

Project Symphony received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.

Project Partner Disclaimer and Copyright

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1 Executive Summary

Project Symphony (the Project) is an innovative pilot where customer Distributed Energy Resources (DER) will be orchestrated as a Virtual Power Plant. The Project aims to understand how the opportunities and challenges of increasing DER can be managed to ensure a reliable, secure, and affordable electricity system, delivering the best long-term outcomes for customers. This aligns with the WA Government's DER Roadmap vision for the South West Interconnected System (SWIS) to deliver a future where DER is integral to a safe, reliable and efficient electricity system, and where the full capabilities of DER can provide benefits and value to all customers.[1]

Project Symphony will pilot a model for delivering a two-way power grid that supports better integration of DER. The model defines three key roles: Distribution Market Operator (DMO), Aggregator, and Distribution System Operator (DSO). The DSO enables the optimal use of DER within distribution networks to deliver security, sustainability, and affordability in the support of whole system optimisation. As the existing network operator in the SWIS, Western Power will assume the role of DSO.

To undertake the DSO role for the Project Symphony pilot, Western Power will develop a DSO Platform. The platform will be capable of identifying the maximum renewable energy hosting capacity of a distribution system within the Symphony Pilot area. This data will be used to estimate network capacity and publish Dynamic Operating Envelopes (DOEs) which equitably allocate the network capacity to customers. UWA's Power and Clean Energy (PACE) research group has been engaged to identify and evaluate methods to support the equitable allocation of DOEs across customers in the SWIS.

This document compares four equitable allocation methods, or Distribution Constraint Optimisation Algorithms (DCOA), proposed by PACE to support the equitable allocation of network capacity using DOEs. The DCOAs were evaluated against a baseline Static Operating Envelope (SOE) and a DOE utilising an equal capacity allocation method. The following metrics were defined to compare methods across seven different test scenarios:

1. Allocation Efficiency – the extent to which the method accurately allocates network capacity
2. Forecast Energy Supported – the proportion of forecast energy import/export supported at each NMI
3. Scalability –the computational complexity of the method
4. Reliability – the reliance of the method on input data
5. Allocation Fairness – how similar or 'fair' DOE allocations are between customers
6. Minimum Export Service Level – how well a method supports an agreed minimum capacity threshold
7. Energy Buyback Rebates – impact on energy buyback rebates for eligible customers
8. Environment Impact – impact on greenhouse gas emissions assuming annual average emission intensity

The evaluation showed the DCOA methods consistently outperformed both the baseline SOE and the DOE equal allocation methods on key metrics in scenarios where there is inadequate network capacity to support forecast import or export of energy. The benefits of the DCOA, if realised in practice, are increased utilisation of network capacity and reduced curtailment of renewable generation with commensurate benefit to energy buyback eligible customers. These benefits must be weighed against the increased complexity required to enact the methods. The evaluation also demonstrates a DOE provided little advantage over a SOE in scenarios where there is excess network capacity indicating a hybrid SOE/DOE approach may be an efficient option depending upon network conditions.

Whilst the report demonstrates there may be significant benefits to a principled approach to allocating capacity via DCOA methods, this is based upon conceptual analysis and limited modelling. The Project will include further simulation and testing of these methods to assess whether the benefits could be reliably obtained in a SWIS wide deployment.

The intended audience of this document is anyone who is interested in exploring efficient and equitable methods to allocate network capacity using Dynamic Operating Envelopes (DOEs).

2 Introduction

The overall vision for the Project is to progress toward a future where the integration and participation of DER in markets supports a safe, reliable, lower carbon and more efficient electricity system.

Project Symphony will be delivered by Western Power in collaboration with Synergy, the Australian Energy Market Operator (AEMO) and Energy Policy WA (EPWA). The Project aims to understand how the opportunities and challenges of increasing Distributed Energy Resources (DER) can be managed through orchestration of Virtual Power Plant's (VPPs) by piloting a version of the "Open Energy Networks" (OpEN) Hybrid Model[1] which defines roles and responsibilities for transitioning to a two-way power grid, allowing better integration of customer DER.

The Hybrid Model outlines three key roles that Project Symphony participants will be required to fulfill:

- Distribution System Operator (Western Power),
- Aggregator (Synergy), and
- Distribution Market Operator (AEMO).

Each party will be required to build and test separate platforms that, when integrated, will create a cohesive system for managing DER resources from end-to-end in support of a safe, reliable, and cost-effective electricity system. *Figure 1: DSO Platform in the context of the Hybrid Model* provides a conceptual view of the model and how each participant's technology platform will interact.

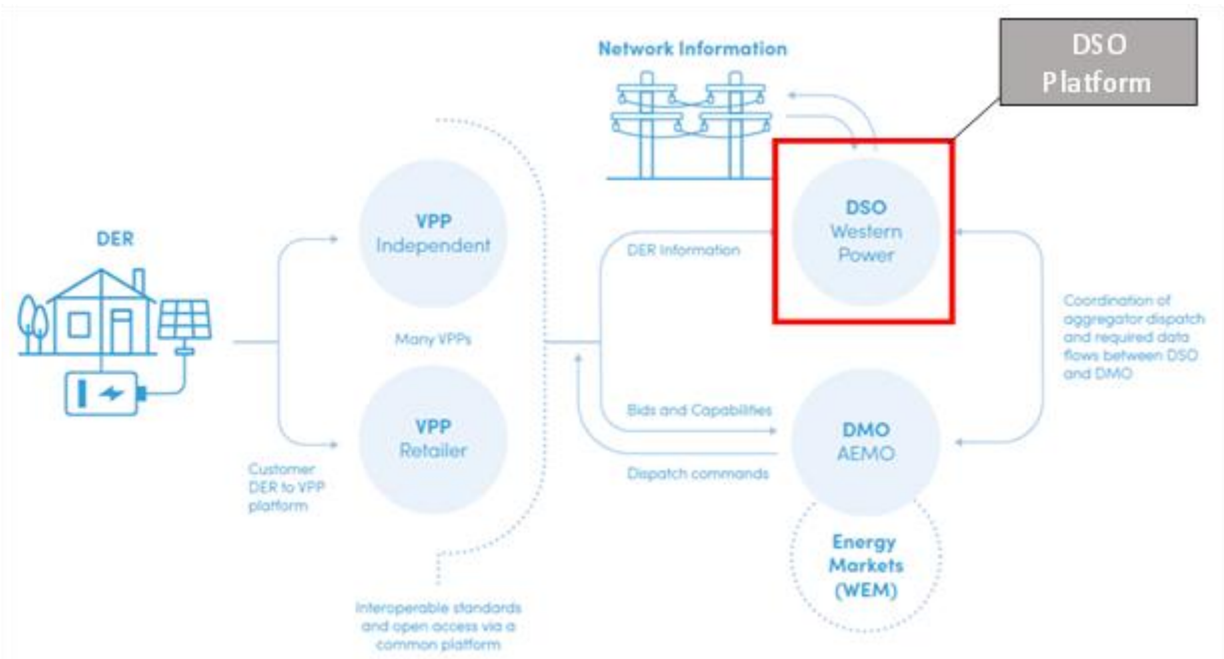

Figure 1: DSO Platform in the context of the Hybrid Model[3]

The Project aims to gain an understanding of the capabilities and technical complexity involved in managing DER within the Hybrid Model. Project learnings will be used to evolve the Hybrid Model

[1] Refer EA Technology, Open Energy Networks Report, Pg. 18. *Last accessed 09/12/2021.*

and inform future implementations. In addition, the Project will consider non-technical factors of the Hybrid Model, including customer sentiment and experience.

The Project will deliver an end-to-end solution through the design, procurement, development, implementation and testing of software based 'platforms' capable of registering, aggregating and orchestrating customer DER. Thus, the Hybrid Model is enabled by the effective integration of three platforms:

- A Market or 'DMO Platform' (AEMO),
- An 'Aggregator Platform' (Synergy), and
- A 'DSO Platform' (Western Power).

As the existing network operator in the SWIS, Western Power will assume the role of DSO. The role of the DSO is to enable access to and securely operate and develop an active distribution system comprising networks, demand, and other flexible DER[2]. The DSO is also responsible for enabling optimal use of DER within distribution networks in support of whole system optimisation.

In taking on the role of DSO for Project Symphony, Western Power will be responsible for developing a DSO Platform. The platform will include the capability to identify maximum renewable energy hosting capacity of a distribution system. This will require an ability to forecast customer generation and load on a near real time basis. This data will then be used to estimate network capacity and publish Dynamic Operating Envelopes (DOEs) which equitably allocate the network capacity to customers. The DOEs will constrain how Aggregators orchestrate the delivery of renewable energy onto the network via a VPP, ensuring operations remain within the physics-based operating constraints of the distribution network. Western Power have selected the Evolve solution developed by Zepben and the Australian National University (ANU) to implement the network capacity calculation and DOE allocation functionality as part of the Project Symphony pilot DSO Platform.

UWA's PACE Research Group[3] has been engaged to review the Evolve solution to ensure it is fit for purpose for use by the DSO to perform an appropriate level of distribution network constraint analysis, and to test alternative methods to support the equitable allocation of DOEs across customers in the SWIS. PACE have assessed the benefits of different allocation methods and developed alternative approaches centred around the support of equitable allocation policies. PACE has described their approach to equitable allocation of network capacity as a Distribution Constraint Optimisation Algorithm (DCOA) and this term will be used in this document to describe the PACE method(s). The Evolve solution and DCOA will enable the DSO to deliver key functions described in the *EA Technology Open Energy Networks Report*[4], develop the appropriate level of distribution network constraint analysis and support the equitable deployment of DER across participating VPP customers.

[2] DER Roadmap, December 2019, pg. 76. *Last accessed 09/12/2021.*
[3] UWA's Power and Clean Energy Research Group (PACE) was founded in January 2015, which is led by Professor Tyrone Fernando. In PACE, researchers carry out research work on various topics including, power systems, power electronics, grid integration of renewable energy and smart grid.
[4] Refer EA Technology, Open Energy Networks Report, Pg. 23. *Last accessed 09/12/2021.*

3 Background

3.1 Project Symphony Overview

Project Symphony is an exciting and innovative project, part-funded by the Australian Renewable Energy Agency (ARENA), where customer Distributed Energy Resources (DER) like rooftop solar, battery energy storage and other major appliances, such as air conditioning will be orchestrated as a Virtual Power Plant (VPP).

The VPP will aggregate and optimise DER, providing value to the customer, the network and energy markets, unlocking greater economic and environmental benefits for customers and the wider community. Unlocking all these benefits together will provide the greatest value to customers. As such, Project Symphony encompasses the end-to-end transactions that will enable a value chain for customer DER assets to participate in the Wholesale Electricity Market (WEM).

The rapid growth in DER, while delivering significant financial and environmental benefits for individuals owning DER, is leading to a range of emerging issues for Network Operators and challenging the traditional electricity generation and retail business models. The WA community is installing DER like rooftop solar at unprecedented rates, with one in three households in the SWIS already having a rooftop solar PV system, and around 4,000 households adding a new system each month.

High penetration of DER poses a material risk to the stability of the power system at times of low operational system demand. In 2019, the Australian Energy Market Operator (AEMO) released a report titled *Integrating Utility-scale Renewables and Distributed Energy Resources in the SWIS*[5], and an update in 2021 titled *Renewable Energy Integration – SWIS Update*[6]. The latter report found that the implementation of WA State Government reform initiatives, AEMO operational measures and Western Power initiatives have enhanced AEMO's ability to manage the stability of the power system in the South West Interconnected System (SWIS) during periods of low operational demand. However, without implementing further measures to ensure that DER is efficiently and effectively integrated into power system operations, operational conditions are likely to cause the power system to enter a zone of heightened threat[7] for periods of time before 2024.

In recognition of this risk outlined in the 2019 report, the WA State Government published a DER Roadmap for Western Australia[8] (the DER Roadmap) to support the integration of DER into the SWIS and the Wholesale Electricity Market (WEM), and to support changes to energy policy and regulation stemming from the evolution of the energy value chain. Energy Policy WA (EPWA), as the government agency responsible for the delivery of energy policy advice to the WA Minister for Energy, is responsible for supporting the delivery of the government's Energy Transformation Strategy as outlined in the DER Roadmap.

The Western Australian Government owns three corporations with active roles in the WA electricity supply chain. Two of these corporations are involved in Project Symphony: Western Power, which is solely responsible for building, maintaining, and operating the electricity transmission and distribution network within the South West Interconnected System (SWIS); and Synergy, which sells

[5] Integrating Utility-scale Renewables and Distributed Energy Resources in the SWIS, AEMO, March 2019. *Last accessed 15/12/2021.*
[6] Renewable Energy Integration – SWIS Update, AEMO, September 2021. *Last accessed 15/12/2021.*
[7] Ibid, pgs. 3-4, 52.
[8] DER Roadmap.

and generates power within the SWIS. Synergy is the sole retailer available to most small use customers (customers using less than 160MWh/year) in the SWIS. Further, retail and export tariffs are regulated and set by the State Government for small use customers using less than 50MWh/year as part of the State Budget processes and are subject to varying degrees of subsidisation.

Unlike in the electricity system supporting the National Electricity Market, the SWIS is an islanded power system that must balance all demand and generation internally without reliance on interconnectors. The independent Australian Energy Market Operator (AEMO) has the role of ensuring this balance is maintained at all times as it manages the security of the SWIS and the WEM.

Energy Networks Australia (ENA) and AEMO have jointly led the "Open Energy Networks" (OpEN) project to identify how best to transition to a two-way power grid that allows better integration of customer DER. Project Symphony will be testing a version of the Hybrid Model, a conceptual solution outlined in the OpEN project position paper[9]. A critical component of the Hybrid Model is the evolution of the responsibilities of Network Operators, retailers and the Market Operator (AEMO), as well as changing the role of customers from passive to more active participants (as consumers and generators of electricity) requiring access to energy markets.

Project Symphony will actively test the Hybrid Model on a section of the SWIS located in the Southern River area south east of Perth[10] (the pilot area). It will evaluate the model's effectiveness, as well as substantiate learnings that can be used to evolve the model and inform policy and legislative requirements to support implementation.

Project Symphony is regarded as delivering the best long-term outcomes for customers and the power system via active DER participation through market-based mechanisms. Project Symphony will lay the groundwork for enabling WA consumers to opt-in to aggregated virtual power plants and provide services to the network and WEM, including turning down (or using up) excess output, or managing demand in return for compensation. One of the Project's working hypotheses is that DER can provide cheaper, lower carbon outcomes through network and market services (e.g., load under control, generation under control, frequency, voltage) in a way that shares the most value with customers through their participation, than the alternative of significant network investment and transmission level responses.

The Project is being part-funded by ARENA and is a collaboration between Western Power, Synergy, AEMO and EPWA, working together with residential and small business electricity customers located in the pilot area of Southern River. The Project is scheduled to be completed in June 2023.

3.2 Operating Envelopes

The OpEN Hybrid Model[11] introduces the concept of dynamic or time-dependent operating envelopes to determine the DER import and export limits at a given time interval. In Symphony, the Dynamic Operating Envelope (DOE) will be applied to VPP participants and non-participants will retain their Static Operating Envelope (SOE).

[9] Interim Report: Required Capabilities and Recommended Actions, pgs. 21-22.

[10] The pilot will cover an area that includes locations in the Perth suburbs of Southern River, Piara Waters ad Harrisdale.

[11] Open Energy Networks Project, April 2020, pgs. 26-31. *Last accessed 30/12/2021.*

In addition to operating envelopes, DER incorporating inverter energy systems which connect to the SWIS are presently required to enable the following autonomous power quality controls: Volt-var mode; Volt-watt mode and power rate limit.

Thus, the expected order of dispatch or operation of network power quality controls in Symphony are:

1. Contracted Network Support Service market dispatches to avoid network forecast load exceeding equipment ratings of key infrastructure.
2. DOE curtailment of VPP participant net energy flow to avoid network forecast load exceeding equipment ratings of key and other infrastructure.
3. Autonomous power quality mode operation after voltage limits have been exceeded to avoid equipment damage or local network outage.

3.2.1 Static Operating Envelopes

Under current network connection rules, the net rate of electricity imports and export at the customer connection point is limited within a SOE. An example SOE is shown in Figure 2.

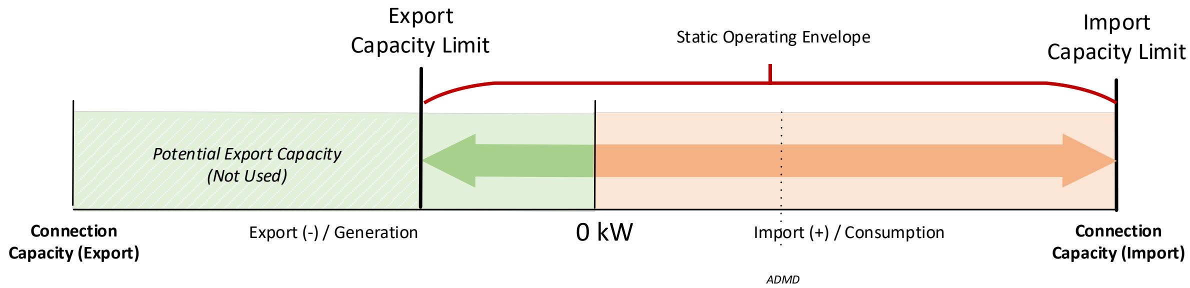

Figure 2: Static Operating Envelope for Active Power Flow

The application of SOEs presently serve to maintain safe network operation during periods of low demand by limiting the total installed PV generation capacity to avoid network issues caused by increasing penetration of DERs, particularly residential solar PV. A SOE is not time varying and has the effect of limiting renewable energy generation at times when it may pose less risk to the network and will limit the potential for customers to install new or expanded PV systems.

Despite the above limitations, SOEs will persist for some time as:

1. many inverters are not capable of management via a DOE, and
2. not all customers will choose to participate in the energy market, or be subject to inverter management, where it is not mandatory.

According to the inverter connection technical requirements document published by Western Power[12], in the SWIS network a static export limit is imposed at the customer connection point[13]. For inverters with system capacity above 5kW, or smaller systems on parts of the network categorised as "small network" (refer section 5.2.1), the export limit at the connection point is generally limited

[12] Refer Basic Embedded Generator (EG) Connection Technical Requirements, *Last accessed 19/1/2022*
[13] Static export limits, or SOEs, are also used in other jurisdictions throughout Australia.

below the inverter capacity. Moreover, the inverter capacity is usually well below the connection capacity.

3.2.2 Dynamic Operating Envelopes

A DOE is a principled[14] and time varying allocation of the available network capacity to actively participating connection points (such as those within a VPP) on a segment of an electricity distribution network. A DOE provides upper and lower bounds on the import or export power in each time interval for each connection point. The attributes of a DOE as defined in Symphony are described in Table 28.

In Symphony, DOEs will apply to customers who are pilot participants. For non-participants with a SOE the rate of export into the grid is predetermined and capped. As there is no management of PV the quantum of hosting capacity which is allocated is conservative. Therefore, this generally results in unused network capacity for most of the year.

An example of a DOE for active power flow is shown in Figure 3.

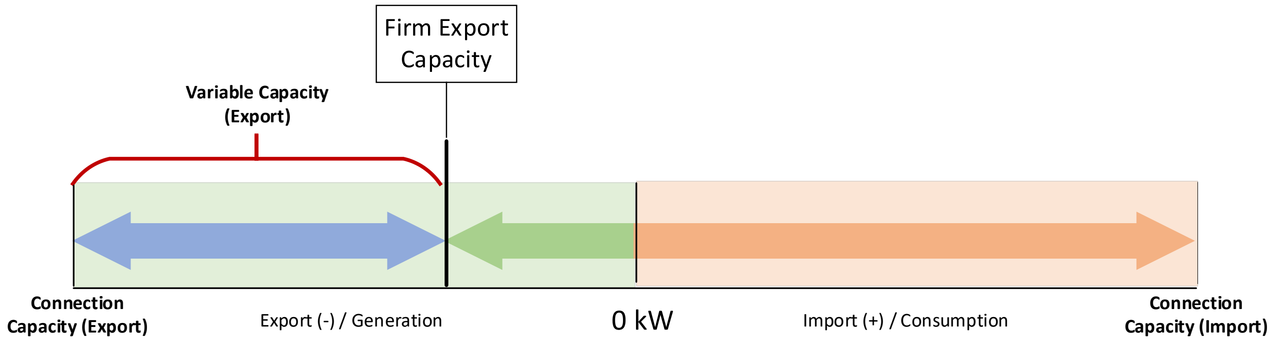

Figure 3: Dynamic Operating Envelope for Active Power Flow[15]

3.2.3 Available Network Capacity

The Available Network Capacity (ANC) is the capacity which is available to be shared amongst participant customers via the DOE after subtracting capacity which is utilised by non-participating customers.

The ANC will be dynamically calculated and will vary based upon the network configuration, load of all customers on the network (including non-participants) and the unmanaged PV generation of non-participants (participant PV generation will be managed via the DOE). The available network capacity is then allocated to participants via the DOE.

The ANC varies for both import and export scenarios. In the net import scenario, power is imported into a segment of an LV distribution network, in which case, the ANC is the maximum possible power consumption of all participating NMIs while the network remains within its technical limits. In the net export scenario, power is exported out of a segment of an LV distribution network, in which case,

[14] The term principled means the approach seeks to maximise the achievement of specified high-level objectives
[15] While DOEs theoretically can be used to vary import and export capacity, Project Symphony will be focused on using DOEs to vary export.

the ANC is the typical capacity of DER that can be connected while the network segment remains within its technical limits. In literature, the latter scenario is also referred to as the Hosting Capacity.

3.2.4 Utilising Dynamic Operating Envelopes

The Distribution System Operator (DSO) calculates DOEs to maintain the distribution network[16] within operating limits based upon an understanding of the network configuration and monitoring data. Ideally, DOEs will be calculated and published frequently based on the latest network monitoring and weather forecast data, with DER orchestration and market dispatches responding to any published changes. DOEs will need to be responsive to changes in weather (including solar irradiation), customer energy consumption/generation, and changes in network conditions (which may result from planned or unplanned outages, and temporary or permanent changes in network topology).

Under the OpEN Hybrid model DOEs are published to the Aggregator for each customer connection point identified by a National Metering Identifier (NMI). Aggregators will orchestrate the dispatch of DER assets at NMIs participating in a VPP (participating or active NMIs) within DOE import and export limits.

Conceivably, the DOE could be allocated and published by the Aggregator giving them more flexibility and potential creation of new customer products. This would require the DSO to publish to the Aggregator a DOE (effectively the ANC) at a higher level in the network (for example, at the distribution transformer). The Aggregator could then utilise a DCOA method (or other allocation method) to allocate capacity to NMIs. The DSO may then also need to publish any NMI level constraints (due to LV effects, such as voltage limits) which would need to be included in the Aggregator's allocation method. This mode of operation has not been explored in this report as it differs from the OpEN Hybrid model and is not within scope of Symphony.

There are several potential benefits of DOEs, particularly given the current maturity levels of DER deployed within the electricity system, as they can:[17]

- address challenges currently being faced by electricity distribution network operators
- work in conjunction with a variety of DER assets installed in Australian distribution networks
- be deployed progressively into different segments of a distribution network as they are needed

The figure below illustrates how a DOE is utilised within an OpEN hybrid model, such as Project Symphony.

[16] In Symphony DOEs are used to manage network (not system) constraints, consistent with the OpEN Hybrid Model.
[17] On the calculation and use of dynamic operating envelopes, August 2020, pg. 5. *Last accessed 30/12/2021.*

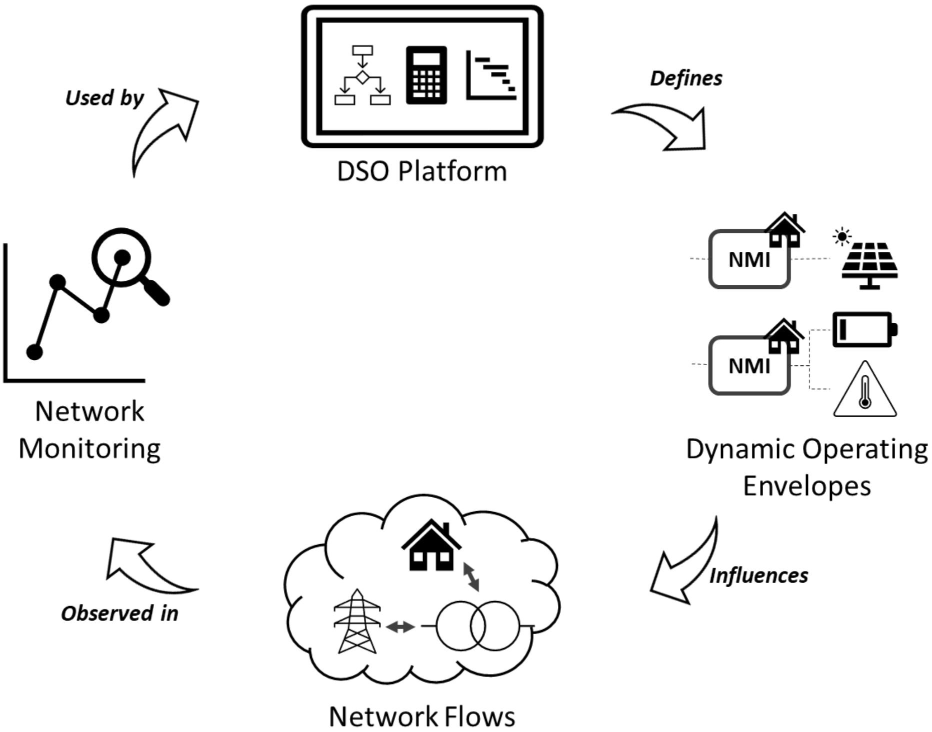

Figure 4: DSO Platform DOE Cycle

4 Literature Review

As introduced, the Australian power grid is currently undergoing a significant transformation. To address this, many projects and studies related to improving DER integration with the grid are currently underway. Some of those which have contributed to the development of network capacity estimation and DOE allocation have been reviewed here.

The following sub-sections describe methods adopted in Australian research and the findings which are relevant to this report. A summary of each project is contained in Appendix D.

4.1 Dynamic Limits DER Feasibility Study

4.1.1 DER Control Method

This study proposed a Decentralised Dynamic Limits control scheme to implement dynamic control for DER to increase the utilisation of distribution networks[18]. Overall, the DER control scheme includes four key elements which are Network Sensors, the Open Network Data Platform, DER Controllers and the Dynamic Limits Profiles. The principle of the control scheme is to coordinate among these four key elements to achieve dynamic export limits which results in the increased utilisation of the distribution network within voltage and thermal constraints.

4.1.2 Network Capacity Forecasting and Allocation Methods

Under the Decentralised Dynamic Limits control scheme, the determination of the network capacity depends on the DNSP network planners recognising the local network constraint locations in advance. Appropriate network sensors were then specified for these constrained locations, assigned unique identifiers as network data publishers, and securely communicated with the Open Network Data Platform. By using these network sensors to measure the network operating status of these pre-determined constraint locations, the published near real-time network status data was transmitted to the participant's DER controller to understand the main constraints generated by its installation.

Overall, this control strategy increases the visibility of the network and avoids the reliance on up-to-date network models. Furthermore, the data collected by network sensors and DER controllers at each site has been used to address customer equity issues among DER sites. The DER controller was able to track the curtailment levels and the exports to the network which was uploaded to the Open Network Data Platform for assessment. This function has considered the relative DER base capacity at each site and adjusted the curtailment curve that each site follows in real time. In this way, the Open Network Data Platform has facilitated timely adjustments to the use of proportional network exports and available DER hosting capacity margins, ensuring that any required curtailment was fairly shared within any single supply group. This adjustment enhanced equity.

4.1.3 Comparative Benefits and Costs

This study quantifies the benefits of using dynamic DER export limits on rural and remote networks and demonstrates its ability to increase network utilisation. The results of the study illustrated that DER utilisation increased ranging from 120% to 400% higher than that expected by applying static

[18] Dynamic Limits DER Feasibility Study, October 2021, *Last accessed 18/12/2021.*

operating envelopes and other traditional connection management methods. It also showed this increase in utilisation was achieved with minimal energy curtailment.

The Decentralised Dynamic Limits technology functions are similar to that used within Symphony but utilises direct control of DER by the DNSP with the primary goal to increase network utilisation. It doesn't rely upon the electricity retailer or VPP operator to manage customer DER and therefore doesn't directly support a market-based approach which may also benefit the system and wholesale electricity market, as is the case with Symphony.

4.2 Advanced VPP Grid Integration

4.2.1 DER Control Method

The project has demonstrated the ability to dynamically set network export limits for VPP to coordinate the operation of DER arrays, allowing participating DERs to increase their export capacity in locations where there was sufficient network hosting capacity[19]. SAPN developed a model to estimate the available hosting capacity of the network. The model generated a rolling 24-hour ahead forecasted DOE in five-minute interval for each low voltage area. The published DOE data was flexibly accessed at either NMI level or upstream asset level (i.e. LV distribution transformer). Overall, the dynamic locational limits allowed each VPP site to export more than the standard 5kW static export limit, unlocking economic value to VPP Aggregators through the increased dispatchable power.

4.2.2 Network Capacity Forecasting and Allocation Methods

SAPN has designed a constraint management system with a constraint engine as the core component to manage the export capacity provided to the VPP. The system estimated the latent network capacity available for the VPP in each network area at any given time. In other words, the constraint engine generated time-series operating envelopes for each distribution transformer, and these envelopes were transmitted to the VPP through a SAPN API.

The constraint engine contains three core components: network model, solar PV model and load model. The network model was based on a prototypical network modelling method, which has been widely used in related low-voltage network modelling work. This approach was to perform detailed modelling and monitoring on a small subset of representative network sections to estimate the hosting capacity of the entire network. To ensure customer equity, the estimated hosting capacity has been allocated equally across all participating customers below a constrained network asset (i.e. LV distribution transformer).

4.2.3 Comparative Benefits and Costs

This project quantifies the benefits of using dynamic DER export capacity in terms of average available capacity. The results have demonstrated that the DER export capacity experienced a 20% increase as a daily average from 5kW during the daylight hours to over 6kW throughout the year and up to 8kW in winter months, which equates to a 60% increase in capacity. Moreover, dynamic export limits can help unlock unused network hosting capacity and increase network utilisation.

[19] Advanced VPP Grid Integration, October 2021, *Last accessed 18/12/2021.*

This project relied upon the VPP operator (Tesla) to manage customer DER within DOEs published by SAPN which used an optimisation algorithm to determine network capacity. Tesla was also able to dispatch BESSs to provide system services, such as frequency support. The project objectives are similar to Symphony but doesn't require the establishment of a DMO.

4.3 Project Evolve

4.3.1 DER Control Method

In the Evolve project, DOEs are used to support the integration of DER without breaching the physical and operational limits of distribution networks. A DOE is allocated to each VPP participant based on the available network capacity within a segment of an LV distribution network. The high-level method for the calculation of DOEs in this work is summarised as: (1) Calculate available network capacity (2) Allocate available network capacity to participating NMIs (3) Customers' DER behaviour is constrained within the received envelope and (4) Monitor to ensure the network primary physical constraints are not breached.

4.3.2 Network Capacity Forecasting and Allocation Methods

The available network capacity is identified by first determining the initial operating state of the network due to the forecast net load (including uncontrollable demand and generation flows) of all customers connected to the distribution network. Initially, the participating sites have their power output set to zero, to determine the available network capacity which can be allocated via DOEs to participating NMIs using the forecast of non-participating sites. Then different allocation principles are designed to distribute the available network capacity. In the Evolve project, three allocation methods are described, which are (1) Proportional allocation at feeder level (2) Proportional allocation at distribution substation level and (3) Maximal allocation at NMI level. The detailed description of these allocation principles and the evaluation of their performance are shown in Section 8 and Section 9.

4.3.3 Comparative Benefits and Costs

Symphony utilises the Evolve solution to provide the DOE capability and will consider alternative capacity allocation methods which may operate in conjunction with the Evolve solution.

4.4 Project Flex

4.4.1 DER Control Method

The Flex project commits to offer a novel flexible export option as an alternative to replace the standard near-zero export limits to new and upgrading solar customers in overloaded network locations. To achieve this, the project partner organisations co-develop an end-to-end technical solution using smart inverter technology. This enables customer inverters to automatically adjust their export limits every five minutes throughout the day based on a locational, dynamic limit signal provided by the DNSP[20].

[20] SA Power Networks Flexible Exports for Solar PV Trial, May 2021, *Last accessed 18/12/2021.*

4.4.2 Network Capacity Forecasting and Allocation Methods

In the Flex project, the available network capacity depends on the network model of the selected segment of the network and customer load and generation forecasting. The DNSP runs an optimal power flow to determine the DOE which can be delivered to each new customer with small-scale PV system or the customers who are upgrading their PV system. Then SAPN offers these new and upgrading customers either a reduced static export limit of 1.5kW or a flexible export option (i.e. DOE) that allows customers to export up to 10kW per phase subject to the available hosting capacity. Based on recent network performance, SAPN demonstrates customers are able to export up to 10kW for 98 percent of the time[21].

4.4.3 Comparative Benefits and Costs

The intent of the new flexible option is to maximise export capacity for participating customers. This approach enables customers to export energy most of the time, and only reduce exports when the network is constrained. It shows that the amount of solar on the South Australian network will be doubled by adopting this technology in year 2025[22]. Moreover, the flexible limits demonstrate good scalability characteristics. The flexible option is designed for new PV customers or customers willing to update their system, thus expanded systems are easy to implement with respect to the available network capacity.

Project Flex doesn't rely upon the electricity retailer or VPP operator to manage customer DER as is the case with Symphony. It is primarily concerned with the direct management of solar PV to solve the problem of hosting capacity. In contrast, Symphony utilises a market-based approach to provide services to the network, system and wholesale electricity market. In doing so, Symphony provides the opportunity to resolve network and system issues through voluntary dispatch by other participating customers (such as dispatchable load) and to reward customers for these services.

4.5 Project EDGE

4.5.1 DER Control Method

Project EDGE develops an open-source technology solution to enable data exchange between various stakeholders in support of the OpEN Hybrid operating model.

The project demonstrates the use of DOE to better facilitate DER market participation from the 'edge' of the grid[23]. Using operating envelopes enables the DSO to ensure network integrity without having direct control of the DER. The dynamic local limits are then sent to Aggregators who will decide the most efficient customer DER portfolio.

4.5.2 Network Capacity Forecasting and Allocation Methods

In this project an optimal power flow methodology is proposed to calculate the day-ahead time-varying operating envelopes. The key inputs of the DOE calculation include an up-to-date network

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[21] https://www.energynetworks.com.au/news/energy-insider/2021-energy-insider/innovation-allows-more-sun-onto-sas-electricity-grid/, Oct 2021,
Last accessed 01/01/2022.
[22] https://www.energynetworks.com.au/news/energy-insider/2021-energy-insider/innovation-allows-more-sun-onto-sas-electricity-grid/, Oct 2021,
Last accessed 01/01/2022.
[23] https://electrical.eng.unimelb.edu.au/power-energy/projects/project-edge, *Last accessed 18/12/2021.*

model, the forecasted net demand (active power) of non-participating customers and the forecasted voltage magnitudes at head of the feeder. Then the DSO uses these sets of input data to run unbalanced three phase AC optimal power flow for each period in the day-ahead. The resulting export obtained from each optimal power flow calculation at each period is compiled to produce individual DOEs.

The objective function is based on different allocation principles. In the knowledge sharing webinar[24] of this project, two allocation methods were proposed: a) Equal Opportunity Allocation – participating customers receive the same operating envelope, and b) Maximise Services Allocation - aggregated operating envelopes or the potential volume of services is maximised.

4.5.3 Comparative Benefits and Costs

The evaluation of the two allocation methods was conducted by calculating the overall potential exports under the test feeder (the utilisation of network capacity) and the average potential export for a site at the end of the feeder.

The result demonstrates that utilisation of available capacity for Maximise Services Allocation was higher than Equal Opportunity Allocation between 12pm to 2pm but the potential export of a site at the end of the feeder was lower under Maximise Services Allocation than in Equal Opportunity Allocation.

The equal allocation method restricts the overall volume of services (utilisation of network capacity), while the maximising service allocation method penalises the participating customers at weak locations.

Symphony will also consider the equal allocation method and compare to other allocation methods which seek to increase customer equitability.

[24] Public webinar: Using operating envelopes to ensure network integrity - from concept to reality, October 2021, *Last accessed 18/12/2021.*

5 Operating Environment and Requirements

Aspects of the Wholesale Electricity Market (WEM) in Western Australia, and key regulations and technical requirements which affect connection of DER and tariffs available to customers for net export of generation, are distinct from the National Electricity Market (NEM) and other state based DNSPs.

This section describes aspects of regulation, connection requirements and energy buyback tariffs in WA and how this may inform capacity allocation principles in the SWIS.

5.1 Regulation

Western Power is required to provide access to its electricity transmission and distribution systems in accordance with the Electricity Networks Access Code 2004 (Access Code), under which Western Power must publish a set of Technical Rules, approved by the Economic Regulation Authority (ERA), detailing the technical requirements to be met by Western Power and customers (Users) who connect facilities to the distribution or transmission networks.

The Technical Rules and Access Code do not presently contemplate the issue of dynamic allocation of network capacity by Western Power, although this arrangement effectively exists with the System Operator who can direct curtailment of Users who are market generators[25]. Connection capacity is normally only assessed at the time of connection application or modification. The Technical Rules permit Western Power to prescribe the import and export limits and the customer has the freedom to operate within that limit range.

The purpose of a DOE is to communicate safe operating limits to an Aggregator. Whilst the Technical Rules make no explicit provision for requesting a User to dynamically change their import or export on demand, section 5.3 of the Technical Rules assigns responsibilities on both parties to maintain operation within safe limits.

The Network Service Provider (Western Power) must:

- operate all equipment and equipment under its control or co-ordination within the appropriate operational or emergency limits
- assess the impacts of any technical and operational constraints of all plant and equipment connected to the transmission or distribution system on the operation of the power system
- coordinate and direct any rotation of supply interruptions in the event of a major supply shortfall or disruption

A User (customer) must:

- operate its facilities and equipment in accordance with any direction given by the Network Service Provider

The ERA Approved Access Arrangement contains a Standard Electricity Transfer Access Contract (ETAC) which describes the contractual requirements on Western Power and a User. An ETAC must be in place between Western Power and a User to permit transfer of electricity on the network. There

[25] Western Power and the User must each comply with any directions given by the System Operator.

is an ETAC between Western Power and each Electricity Retailer (e.g. Synergy) covering all their connection points.

Under the ETAC, liability can arise from the Electricity Retailer (or individual Users) to Western Power for any direct damage to the network where there is a contractual default of obligations, which includes non-compliance with the Technical Rules. The orchestration of many DER has a higher potential for network damage than autonomous or individual operation of DER by customers. The transfer of liability to Aggregators, who are not Electricity Retailers, would presently need to occur via a commercial arrangement separate to the ETAC (such as a third-party agreement between the Retailer and Aggregator).

In summary, there may need to be amendments to key Legislations and Regulations (including the Access Code, Technical Rules and Standard ETAC) to support the inclusion of the requirements for the roles of Western Power as the DSO, and modified responsibilities of Electricity Retailers, Aggregators and Users.

Testing the operation and implementation of dynamic operating envelopes within Project Symphony will inform these changes and amendments.

Energy Policy WA is separately progressing a range of legislative and other reforms to better accommodate and recognise DER and the roles and responsibilities of Aggregators, the Distribution System Operator and Distribution Market Operator. Learning from Symphony is also important in informing these.

5.2 Connection Requirements

Western Power currently imposes static operating envelopes, which limit the size of solar PV systems. This is a result of the after diversity maximum demand (ADMD) approach to network planning. Removal of these limits would be expected to result in a higher average system sizing and consequently a greater rate of growth[26] in installed solar PV capacity on the SWIS.

There is already a level of customer inequality inherent in the allocation of capacity through connection guidelines, based upon the part of the network to which customers are connected or whether there are other customers with PV systems already connected.

A customer connected electrically farthest from the distribution transformer will experience greater voltage variability than a customer connected near the distribution transformer and may be limited in energy export or inverter capacity. Similarly, a customer may be unable to connect, without network upgrade, a new PV system to a network which has reached its hosting capacity limit.

Requirements for connecting inverter based embedded generators to the LV network are described in the following two documents:

1. Basic Embedded Generator (EG) Connection Technical Requirements[27], and

[26] At current market rates PV systems with high self-consumption provide an attractive return on investment to households. Network connection requirements presently provide one factor limiting the rating of installed PV systems. The removal of this limit may see an increase in average PV system sizes, notwithstanding an increase in export curtailment, as certain owners seek greater electricity tariff savings and to offset new sources of electricity use (e.g. EVs).
[27] Basic Embedded Generator (EG) Connection Technical Requirements, November 2021, *Last accessed 31/12/2021.*

2. LV Embedded Generator (EG) Connection Technical Requirements[28].

The majority of customer DER are less than 10kVA per phase and covered under the first document.

5.2.1 Basic Embedded Generator Connection Technical Requirements

The requirements for connection of embedded generators to the LV network are encompassed in Western Power's *Basic Embedded Generator (EG) Connection Technical Requirements*[29]*.* This document generally applies to AC coupled PV and BESS systems up to 30kVA and DC coupled systems up to 15kVA on three phase connections. Systems not covered by these requirements are covered under the *LV EG Connection Technical Requirements*.

Under these requirements, customers fall into two distinct categories which determine the connection limits imposed by Western Power:

1) Large networks – include all the three-phase 415V low voltage distribution networks.
2) Small networks – include LV distribution transformers less than 60 kVA; Single-phase 240 V LV networks; and Split phase 240/480V LV networks.

Table 34 and Table 35 of Appendix E summarise the maximum system capabilities for large and small networks respectively.

Under the connection requirements customers are limited to a maximum system capacity (inverter rating) and a net export limit (at the connection point) based upon the network type (small or large), connection phases and inverter type. The inverter rating and export limit are utilised in this document for the principled allocation of hosting capacity within the proposed capacity allocation methods described in section 8.2.

5.2.2 Emergency Solar Management in WA

New requirements for emergency solar management (ESM) were applied to new and upgraded rooftop solar installations from the 14 February 2022. These requirements were introduced following recommendations from AEMO to mitigate system stability risk, which were forecast to arise during periods of low operational demand from 2024[30] onward.

Under the scheme, all new and upgraded solar PV and battery installations with Synergy as the retailer and an inverter capacity of 5kW or less will need to be capable of being remotely turned down or switched off in emergency situations such as extreme low operational load levels

When ESM is triggered, it takes priority over a local DOE and customers will be required to reduce or turn off solar PV output, even if the DOE would otherwise allow exports. At the end of an ESM event, the published DOE for that customer would again apply.

It is expected that dispatch under the scheme in response to low system demand will likely coincide with times when the DOE would also curtail export at many connection points. Widespread use of DOEs to address local network issues is expected to assist with reducing the number of times that ESM is triggered.

[28] Under development at the time of writing
[29] Basic Embedded Generator (EG) Connection Technical Requirements, November 2021, pgs. 7-8. *Last accessed 16/12/2021.*
[30] Refer Integrating Utility scale Renewables and Distributed Energy Resources in the SWIS. *Last accessed 10/3/2021.*

The interaction of these two DER control schemes and operation of DOEs under non-standard system operating states will require future review and is beyond the scope of this report.

5.3 DSO Requirements

The OpEN project has identified 13 high-level functions for developing distribution level optimisation capabilities.[31] These functions, and how they relate to Project Symphony objectives and the DOE function, are summarised in Table 1.

A DSO securely operates and develops an active distribution system comprising networks, loads and other flexible DER[32]. Expanding the network planning and asset management function of a DNSP, the DSO enables the optimal use of DER within distribution networks to deliver security, sustainability, and affordability in support of whole of network optimisation. As the existing network operator in the SWIS, Western Power will assume the role of DSO[33]. In taking on this role, Western Power will be responsible for developing a DSO Platform which will include capabilities to identify the maximum demand and renewable energy hosting capacity of a distribution system.

The network capacity estimated by the DSO will be a primary input to the DCOA developed by PACE group. PACE will test several capacity allocation methods against the principles of efficiency and equity which are explored in this report.

Energy Policy WA is separately progressing work to formalise policy positions on the roles and responsibilities of the DSO, DMO and Aggregators in the context of the Western Australian energy landscape.

Table 1: DER Optimisation Functions

ID	Function[34]	Description[35]	Project Symphony Implementation	DOE Impact
1	Distribution system monitoring and planning	Network monitoring and the assimilation of wider data (e.g., weather patterns) to inform long-term forecasts, including network constraints, for the creation of long-term investment plans.	The pilot DSO Platform will store and utilise weather, solar irradiation, metering and network monitoring data collected from the pilot area distribution network. The Project will investigate how this information may be used to inform both short- and long-term network management and planning, including the cost/benefits of establishing monitoring sufficient to support DER optimisation.	Monitoring is a pre-requisite to accurate network capacity estimation.

[31] *See* Interim Report: Required Capabilities and Recommended Actions, pg. 23. Also EA Technology, Open Energy Networks Report, July 2019, p. 23. *Last accessed 15/12/2021.*

[32] DER Roadmap, December 2019, pg. 76. *Last accessed 09/12/2021.*

[33] "In the high-DER future, the Distribution System Operator is a natural evolution of Western Power's role as network service provider." DER Roadmap, pg 44.

[34] Open Energy Networks Project, pg. 23. *Last accessed 09/12/2021.*

[35] Ibid

ID	Function[34]	Description[35]	Project Symphony Implementation	DOE Impact
2	Distribution constraints development	Development of forecast network constraints into long-term static operating envelopes for network customers and, through engagement with DER, the determination of long-term requirements for network services.	The pilot DSO Platform will use available information to model and forecast network behaviour and identify constraints. The usability of this information will be assessed, including ability to inform long-term planning network policies for DER integration, and ability to identify areas of the distribution network that require/may benefit from NSS.	An accurate constraint model is a pre-requisite to accurate network capacity estimation.
3	Forecasting systems	Network monitoring and the assimilation of wider data (e.g. weather patterns) to inform short-term forecasts, including network constraints, to inform market operation	The pilot DSO Platform will use available data to develop detailed short-term forecasts, including identifying network constraints, and dynamically allocating an operating envelope per Active NMI which respects these constraints.	An accurate load forecast is a pre-requisite to NMI energy flow and spare network capacity estimation.
4	Aggregator DER bid and dispatch	Aggregators engage with DER resources to develop portfolios of customers and services, and engage with network operators and markets to submit bids and offers	Function will be performed by the Aggregator.	Aggregator dispatches will affect NMI energy flows and spare network capacity.
5	Retailer DER bid/offer and dispatch	Retailers engage with DER resources to develop portfolios of customers and services, and engage with network operators and markets to submit bids and offers	Function will be performed by the Aggregator.	Aggregator dispatches will affect NMI energy flows and spare network capacity.
6	DER optimisation at the distribution network level	Optimise operating envelopes in engagement with the markets to ensure DER bids and offers can feed into market dispatch optimisations while taking account of distribution network constraints	DSO will dynamically calculate, allocate and publish operating envelopes for the Aggregator to use in DER optimisation. The DSO will monitor compliance with published operating envelopes.	Post-requisite of DOE implementation
7	Wholesale - distributed optimisation	Receive market bids and offers and run market dispatch optimisation, integrating network constraints and/or operating envelopes into the market engine	Function will be performed by the DMO.	Post-requisite to DOE calculation

ID	Function[34]	Description[35]	Project Symphony Implementation	DOE Impact
8	Distribution network services	Procurement and use of distribution network services, such as power quality/voltage control, which can be provided by DER, either through bilateral contracts or through a market optimisation	The DSO and Aggregator will enter bi-lateral agreement(s) for NSS in line with forecast requirements. The cost/benefit of NSS will be assessed by the Project.	Distribution NSS dispatch affect NMI energy flows and should increase spare network capacity.
9	Data and settlement (network services)	Financial settlement of network support and control ancillary services at distribution and transmission level	The DSO and Aggregator will agree a process for validating and settling NSS provided under bi-lateral agreement(s).	No direct impact on DOE.
10	Data and settlement (other services)	Financial settlement of wholesale, RERT, FCAS and SRAS[36] transactions at distribution and transmission level	Function will be performed by the DMO.	No direct impact on DOE.
11	DER register	Establish, maintain and publish or share DER register data	DER registration information will be used by all parties. The pilot DSO Platform will use available information on registered DER to determine NMI capacity, which will support the forecasting of network hosting capacity and dynamic operating envelope allocation.	DER register data will be an input to some capacity allocation methodologies.
12	Connecting DER	Regulatory, technical and commercial arrangements around the connection, and active management of connections, to the distribution network	The pilot DSO Platform network monitoring, modelling and forecast capabilities will provide information that will inform technical requirements for managing DER and service connections, as well as data to monitor adherence with operating envelopes and relevant contractual agreements.	No direct impact on DOE.
13	Network and system security with DER	DER contribution to, and influence on, system security as well as contingency planning for market or network failure events.	The Project will test pilot DSO Platform outputs to ensure their application in downstream processes does not impact network safety in the pilot area. The Project will employ strategies to ensure network safety is maintained for the duration of the pilot, including in the event of market or network failure. The Project will also test and investigate services, such as NSS, that may support distribution networks in cases of incident or adverse event, such as events that require outages and/or network modifications.	No direct impact on DOE.

[36] These services will be known as Frequency Co-optimised Essential System Services in the WEM.

5.4 Energy Buyback Schemes

The energy buyback scheme in WA presently offers eligible customers a time of export payment for electricity they export to the grid, including from rooftop solar PV systems, batteries and electric vehicles. Two main energy buyback schemes currently exist in WA, the Distributed Energy Buyback Scheme (DEBS) and the Renewable Energy Buyback Scheme (REBS). As of 31st August 2020, DEBS replaced REBS for new connections and upgrades.

Solar PV system owners obtain most of their benefit from import tariff savings by avoiding grid purchase of energy. However, although a DOE will not limit generation for self-consumption, the impact of DOE curtailment on rebate eligible energy exports may be of concern and thus have been included in the assessment methodology (section 7.1.3.1).

Symphony project participants with PV systems will fall into one of three categories:

1. Customers who connected new, or modified existing, systems since 31st August 2020 and are eligible for DEBS (DEBS rate)
2. Existing customers who remain on REBS (REBS rate)
3. Customers who are ineligible for DEBS or REBS (no buyback)

Commercial customers who have bespoke buyback contracts (typically large systems) are not considered.

5.4.1 Distributed Energy Buyback Scheme (DEBS)

DEBS became the relevant buyback scheme for residential customers, schools, educational institutions and not-for-profit organisations in WA on 31 August 2020. It covers customers installing a new or upgraded eligible renewable or distributed energy system or those moving into a property with an existing system.
An eligible residential customer is someone who consumes not more than 50MWh of electricity per annum and has a PV system inverter rating between 500W and 5kW (a PV system with 6.6kW of panels and 5kW inverter is eligible). There is no eligibility limit regarding residential battery system or electric vehicle inverter ratings (applicable if the EV has vehicle to grid export capability). Synergy is only obligated to offer rebates for up to 50kWh per day per premise. The table below shows the rates available under the DEBS.

It should be noted that the DEBS rate is intended to somewhat reflect the wholesale price of energy and is subject to annual review.

Table 2: Distributed Energy Buyback Scheme (DEBS) [37]

Buyback Rate (per kWh ex GST)	
Peak (3pm to 9pm)	Off-peak (all other times)
$0.10	$0.0275

[37] Distributed Energy Buyback Scheme, August 2020, *Last accessed 16/12/2021.* Values are in Australian Dollars and exclusive of GST

5.4.2 Renewable Energy Buyback Scheme (REBS)

REBS closed to new customers on 30 August 2020 and offers a flat buyback rate of $0.07135c/kWh. Many customers with REBS eligible systems will not have VPP compliant inverters and would require an inverter upgrade, which would mean that they would be eligible for DEBS post upgrade if they meet the eligibility criteria. Those that are compliant may remain on the scheme until its end.

6 Evolve Solution Functionality

Multiple approaches can be used to forecast network capacity and allocate it to each NMI. However, it is important that capacity forecasting and allocation methods appropriately account for the physical and operational parameters of the network, which ideally include both voltage limits at customer connection points and thermal constraints of various network elements. A representation of a network capacity calculation and allocation process is shown in Figure 5 below[38].

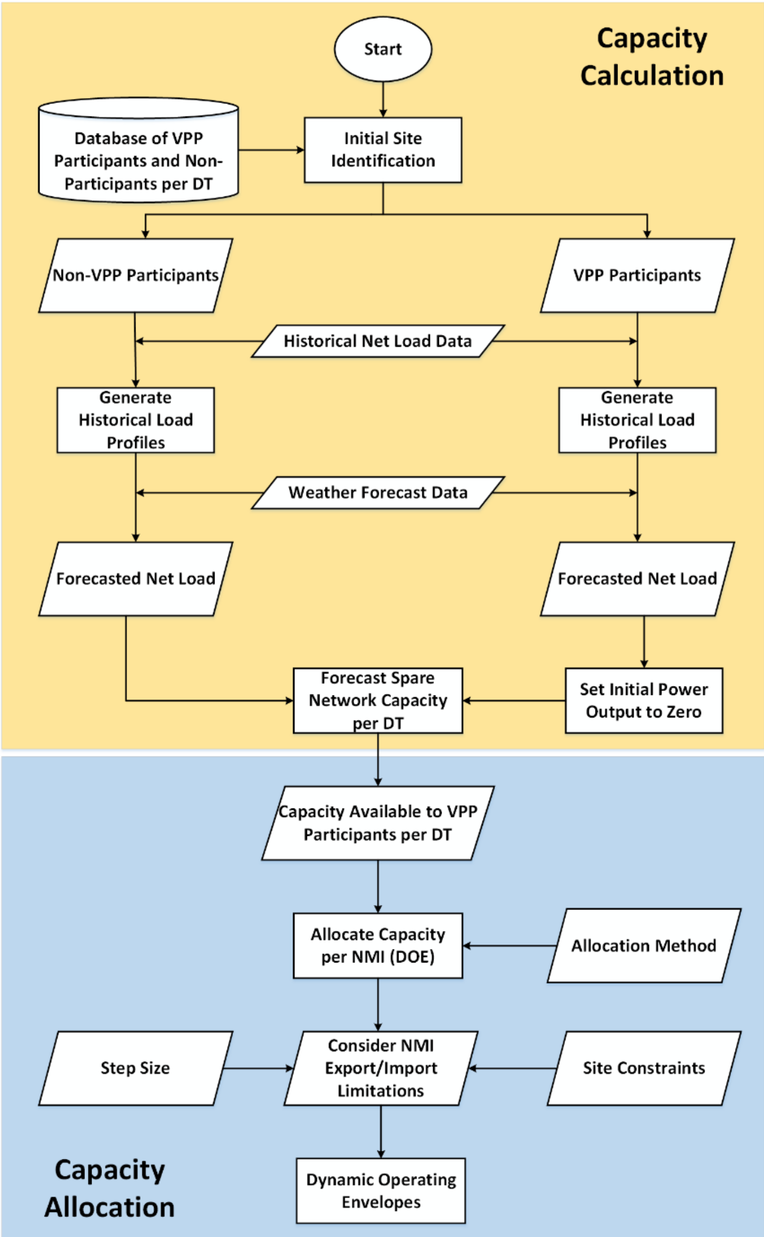

Figure 5: Diagrammatic Representation of Network Capacity Calculation and Allocation

[38] DOE initial power output is set to zero to simulate non-participant net import/export which is then used to calculate the ANC.

Whilst the Symphony project is piloting only constraining active power, the method should be extensible to efficiently and equitably manage both constraining and expanding of active and reactive power. The effectiveness of the methodology can be assessed according to its capability to accurately forecast network capacity and its performance against the allocation objectives described in section 7.1.

6.1 Evolve DOE Calculator

Project Symphony will make use of a software tool known as "The Dynamic Operating Envelope Calculator," or DOE Calculator, developed by the Evolve project team of Australian National University (ANU)[39] and Zepben.

DOEs represent a principled and time varying allocation of the available network capacity on a segment of an electricity distribution network. DOEs will be applied at the NMI level which in practice means calculating the load flow solution for the case where a combination of load and generation patterns reaches the technical limit of a network element, thermal limits for any primary assets or voltage standard limits at connection points[40].

The Evolve solution continually runs Medium Voltage (MV) and Low Voltage (LV) load-flow results to identify constraining network element(s) and network capacity limits, generating DOEs based on these results using one of three capacity calculation methods. The solution also forecasts the load at each NMI, for both VPP participants and others, for each envelope time interval.

[39] ANUs Battery Storage Grid Integration Program provided technical leadership for the Evolve solution.
[40] Voltage constraints will not be utilised in the first release of Evolve's DOE calculator.

Table 28 describes the data which defines a DOE in the Symphony project.

6.2 DOE Calculator Inputs and Operation

The DOE Calculator requires the following inputs:

- Network model
- Network monitoring data
- Metering Data
- Weather and solar data
- Configuration Settings

Data will be sourced from multiple systems, combined, and loaded into the DOE Calculator via an Ingestor. The DOE Calculator (located on a cloud based *Azure* server) will use this data to produce a hosting capacity forecast and associated NMI level DOE allocations at a given point in time. The figure below illustrates the inter-relationship of entities and data flows[41].

The following sections describe the input data and Section 8.1 of the report describes the Evolve capacity calculation and allocation methods.

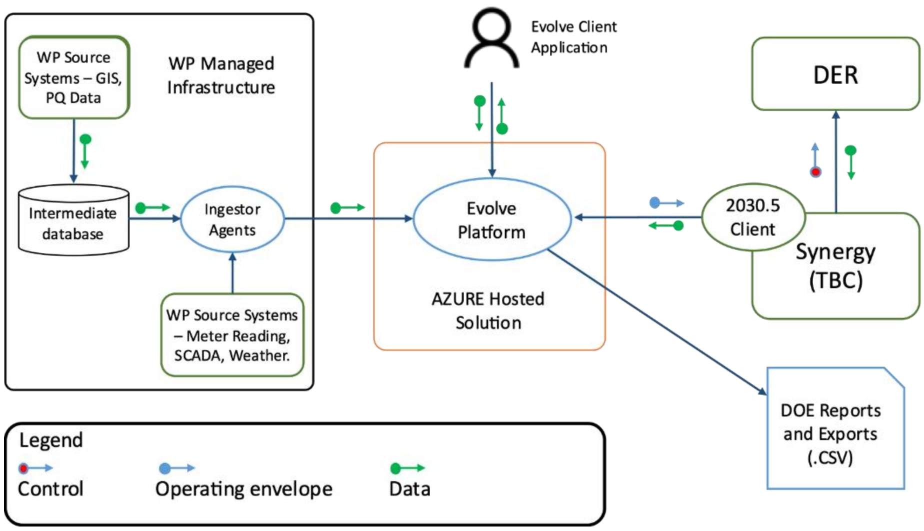

Figure 6: Evolve Dataflows, Actors and Processes (Release 2)

6.2.1 Network Model

For the purposes of the Project pilot, the DOE Calculator will require data for all network assets located downstream of Southern River distribution feeder SNR540, which is a 132kV/22kV transmission connected point (using the asset data described in Appendix A). This data will be combined with weather forecast, metering and monitoring data to produce the outputs described in Appendix A.

[41] Note that the interfaces and data flows are still in development and may change.

Network model data will be sourced from Western Power's asset database(s). The data will be loaded into the Ingestor to perform a data quality assessment, including identification of anomalous phasing, connectivity and voltage levels. The Ingestor will generate a network model that conforms to an open standard[42]. This network model will be loaded into the DOE Calculator via an Application Programming Interface (API) and made available for use by other applications.

6.2.2 Network Monitoring Data

Network monitoring data is collected from the following sources:

- Zone substation feeder and bus SCADA measurements
- Recloser and Voltage Regulator SCADA measurements (not applicable to SNR540)
- Distribution transformers via a sample of power quality meters installed for the purpose of the Project (not integrated with the SCADA network).

For the purposes of the project pilot, network monitoring data will be limited to the area of the network denoted by feeder SNR540.

[42] The Zepben implementation of the common information model is documented in a public facing URL. Refer to https://zepben.github.io/evolve/docs/cim/evolve/

Table *26* lists the data collected from these sources.

6.2.3 Metering Data

To accurately forecast network load and available hosting capacity, the DOE Calculator requires historical time series metering data for a period of two years. This will initially be loaded into the DOE Calculator as a once only load. As Advanced Meters were installed recently at customer premises on SNR540 (both participant and non-participant customers) for the purpose of the Project, two years of historical data will primarily be sourced from accumulation meters.

The Ingestor will query the metering database periodically to extract data updates from the customer revenue meter at each National Meter Identifier (NMI) and upload these to the DOE Calculator.

A summary of the energy metering data is provided in

Table 25 of Appendix A.

6.2.4 Weather and Solar Data

Weather forecasts and historical data will be sourced from WeatherZone[43] (for a single weather station located at Jandakot Airport) and solar irradiation from Proa[44] (for the Project area postcode).

Historical time series weather data for a period of two years will be uploaded in a once only load into the Evolve solution platform. The Time Series Data Ingestor will query weather forecasts periodically (every 3 hours, from 12pm noon) for the previous 24 hours of forecasts. Historical weather data will be queried daily for the previous 7 days.

6.2.5 Configuration Settings

The final major input required to run the Evolve solution platform is configuration settings data, or in other words, how the DOE calculator considers input parameters to calculate the DOEs. The configuration settings will be developed by Western Power in consultation with Evolve project team.

Ultimately the PACE allocation methods may require additional configuration settings to effect certain policy settings.

6.3 Load Forecasting

Load forecast at the NMI level (next step prior to the actual DOE calculation) is performed using the obtained load monitoring and weather data. The forecasted results will be updated based on the latest available time series data from the meters. Energy measurement and data forecasting is carried out using interval data (which is currently collected every 4 hours) for zone substation feeder load (active and reactive power per phase or amps and power factor per phase) and zone substation bus voltage (voltage per phase).

The generation of appropriate DOEs is highly contingent on accurate forecasts (particularly for the coming day).

6.3.1 DER Telemetry Data

The accumulation of real time DER telemetry data is not part of the longer-term strategy for the operation of the DOE calculator as this has many challenges. However, DER telemetry data will be used during the Project to verify and improve the accuracy of load forecasts.

6.3.2 Market Dispatch Data

Scheduled energy market dispatches have the potential to affect load forecasts and thus should be an input to the DOE calculator if the load forecasting model accuracy is to be maintained. These include the energy market dispatches being piloted within the Project:

- Futures balancing market dispatch by the Retailer (Synergy)
- Network Support Service (NSS) dispatch by the DSO (Western Power)

[43] WeatherZone provide a weather forecasting service. Refer to Home - WeatherZone
[44] Proa provide a solar irradiation forecasting service. Refer to Home - Proa

- Essential System Service (ESS) and Constrain to Zero dispatches by the DMO (AEMO)

At the time of writing these had not been included in the Evolve solution but inclusion of NSS may be explored in a future stage of the Project.

It should be noted that WEM reforms will result in ESS being reframed as frequency co-optimised essential system support services (FCESS) and non-co-optimised essential system support services (NCESS). NSS will fall under the NCESS framework.

7 Assessment Methodology

This section describes a methodology to compare the performance of different capacity allocation methods against each other, and against a base case (using a SOE). The goal of the PACE DCOA is to allocate capacity (to each NMI) by applying a principled approach using standing and forecast data to determine how network capacity should be shared between customers. The DCOA utilises as inputs selected customer attribute data and the forecast of network capacity which, in the Evolve solution, is determined using a quasi-load flow simulation.

The assessment methodology will score the method's achievement of allocation objectives (or principles) under seven different test scenarios. The results will be weighted by relative importance to calculate a single metric of performance that can be compared against the performance of a SOE and the equal allocation method (EAM) currently utilised in the Evolve solution.

7.1 Allocation Objectives

Each method for allocating capacity (SOE, EAM and DCOA) will be assessed against their achievement of the following objectives:

- Allocation efficiency
- Allocation equity
- Financial Impact (to customers and other stakeholders)
- Environmental Impact
- Network security
- Reliability
- Scalability

The objective is intended to align to the DER Roadmap vision for DER[45], which is:

The Energy Transformation Taskforce's vision for DER by 2025 is:

A future where DER is integral to a safe, reliable and efficient electricity system, and where the full capabilities of DER can provide benefits and value to all customers.

There are three parts to this vision:

1. A safe and reliable electricity system where customers can continue to connect DER and where DER supports the system in an efficient way.

2. DER capability can offer value throughout the electricity supply chain.

3. DER benefits are flowing to all customers, both with and without DER.

[45] DER Roadmap, December 2019, pg. 8. *Last accessed 04/01/2022.*

The capacity allocation method should strive for equitable allocation of available network capacity to customers. Equitable allocation does not mean equal allocation as each customer may have unique circumstances pertaining to their electricity connection, consumption and tariffs.

For example, a simple method is to allocate an equal network capacity limit to each participating customer irrespective of the circumstances (allocation equality). However, this approach may be inequitable, as PV customers with potential to export energy (those with forecast energy capacity) would be unnecessarily curtailed while other customers unable to export (those without forecast energy capacity) may not utilise their allocated capacity. Therefore, an equal allocation method is likely to lead to lower utilisation of available network capacity.

To ensure the interests of customers are addressed a reliable and workable method to define and measure equity is required which considers the circumstances of different customer classes and leads to an efficient allocation of available capacity under a host of network conditions. The method should be scalable to a large customer base and resilient to errors in, or omission of, data and remain applicable under a variety of network configurations and conditions.

This report has adopted the following definitions of efficiency and equity and in its application will seek to strike a balance between an overly simplistic method (resulting in inequity and inefficiency) and an overly complex method (which may be challenged in scale or reliability).

Definitions of efficiency and equity:

An *efficient* allocation of capacity is considered to have occurred where the total customer allocations equal or near to, but does not exceed, the available network capacity.

An *equitable* allocation of capacity is considered to have occurred where the average customer utilisation of capacity is high and, where there is insufficient capacity, the loss of benefit(s) is shared across each customer class in accordance with agreed principles.

7.1.1 Allocation Efficiency

Allocation efficiency can be readily achieved by ensuring the DCOA results in all available network capacity being allocated across the base of participating NMIs (up to the aggregate connection limit). An objective of the allocation method is to ensure there is no residual (unallocated) capacity remaining after the equitable allocation policy is applied. A second objective is to ensure the capacity is not overallocated, which may present a network security risk.

7.1.2 Allocation Equity

Allocation equity is more complex and can be determined by measuring performance against a selection of allocation principles. This report does not provide an exhaustive consideration of principles but chose to focus upon the following determinants.

7.1.2.1 Forecast Energy Flow

The energy flow (import/export) at each NMI during each interval will be forecast using AMI, solar and weather data. The proportional allocation of DOE to customers aligned with forecast energy flow will yield the highest overall utilisation of network capacity and is considered “equitable”. Allocation of capacity to customers where there is no export requirement is considered “inequitable”.

7.1.2.2 Minimum Export Service Level

The concept of a Minimum Export Service Level (MESL) has been included, whereby each customer has an equal entitlement to an agreed minimum export capacity irrespective of system size. The MESL would seek to ensure all customers were able to export the minimum of their forecast energy or the MESL.

The MESL would be applicable to customers with either single or multi-phase inverters irrespective of inverter rating or network connection type. A value of 1.5kW is consistent with export limits for inverters with rating over 5kW in Western Power’s Basic EG connection requirements, refer section 5.2.1, and has been applied in each of the DCOA allocation methods.

The MESL provides some assurance to customers who may be considering participating in a VPP, and switching from a SOE to DOE, that they would not be disadvantaged (applicable mainly to those with larger systems limited to 1.5kW export). Settings similar to the MESL have featured in other trials[46], however, there is no current or proposed WA energy policy to adopt such measures and such a measure would require additional consideration of consumer and regulatory aspects before implementation.

7.1.2.3 DER Inverter Rating

When considering available network capacity allocation, the sum of DER inverter ratings (PV and BESS) will determine the maximum capacity to export energy at each NMI[47] and thus is important when estimating export potential. The size of inverter rating is broadly indicative of customer investment and is a relevant allocation principle. PV and BESS inverter ratings will be available as DER standing data.

After the MESL and forecast energy requirements have been met, systems could be assigned a proportional export limit based on the total installed DER rating, which means larger systems may be afforded the opportunity to export more, potentially under Aggregator orchestration.

7.1.2.4 Self-Consumption

Given the network issues arising from high export of PV generation, network operators prefer customers to self-consume PV generation. This in turn supports a higher network hosting capacity. Due to this preference, self-consumption was included as an input into the DCOA methods 3 and 4 to test whether this would significantly affect capacity allocation outcomes. Whilst a high level of self-consumption may reflect an efficiently sized system and investment in capital, it has not been included as a quantifiable benefit.

[46] As part of the Flexible Exports trial, for example, new solar customers in South Australia can elect to have either a static 1.5kW export limit or a flexible 1.5-10kW constraint if they have a compatible IEEE 2030.5-capable inverter (with embedded energy management capabilities) or on-site HEMS gateway.

[47] Each NMI is presently allocated a generation limit under Western Power’s Inverter Energy System (IES) Connection Requirements (often the PV inverter rating) and this would be the SOE for non-participating NMIs.

It is important to note the DOE does not directly affect the level of self-consumption and that an increase in penetration of managed DER may in future reduce the importance of self-consumption as excess capacity can be reliably utilised or curtailed.

7.1.3 Financial Impacts

Certain participating customers with renewable generation can obtain benefits (which are in addition to self-consumption of solar PV) through existing energy buyback schemes and potentially future benefits via Aggregator orchestrated energy market services (such as retailer services), the energy balancing market (real time market), essential system services or local network support services piloted in Symphony). Different allocation methods may impact the new or existing benefits attainable by customers.

The allocation methods should, therefore, have one of its goals to strive to equitably maximise customers' collective access to new benefits and minimise erosion of existing benefits. The allocation method may also affect the Aggregator or retailer (Synergy).

The financial impact to customers is currently assessed based on current energy buyback schemes (EBS) which may not exist in the future. Moreover, the cost of energy in the wholesale market is time varying and energy Aggregators may offer different financial benefits under VPP arrangements which are currently unknown.

7.1.3.1 Energy Buyback Schemes

Existing participating customers have an opportunity to earn income or credits by selling exported energy to the retailer (Synergy) through an energy buyback scheme. There are different energy buyback rates and eligibility criteria (refer section 5.4). To be assumed eligible[48] residential customers with PV inverters of 5kW or lower rating will receive either the DEBS (new customers) or REBS (existing customers) energy buyback rate and residential customers with larger systems will be ineligible.

The DEBS payment for energy export is 2.75 cents/kWh (ex GST) except between 3pm and 9pm when it is 10 cents/kWh (ex GST), capped at 50kWh per day. The REBS payment for renewable energy export is 7.135 cents/kWh (ex GST) at all times.

As a guiding principle, this report assumes all eligible DEBS customers have an equal entitlement to benefit from the DEBS. There is no disadvantage to ineligible customers of DOE curtailment as they are not entitled to the DEBS benefit.

To collectively maximise DEBS benefits, eligible customers with inverters up to and including 5kW should be prioritised for capacity allocation to minimise financial impacts upon customers.

7.1.3.2 Energy Market Services

Project Symphony will pilot the development of platforms to enable participating customers with active DER to obtain benefits from the orchestrated (through Aggregators) provision of retailer, market, system and network services. The services may require either shifting of energy use (energy

[48] Under DEBS, eligible means a customer to whom electricity is supplied for residential purposes and who consumes not more than 50 MWh of electricity per annum or a customer that is a school, university or other educational institution or a customer that is a non-profit making organisation

balancing), a net reduction during periods of high network energy import (NSS), frequency support (ESS contingency raise) or net increase of energy import during low system demand periods (Constrain to Zero).

The benefits available to different classes of customer through the different services are not yet fully understood. As a general principal the capacity for customers to benefit from these services will depend upon the individual DER capabilities and capacities (typically via dispatch or curtailment of loads or inverter energy systems).

An expansion of customer allocated capacity provides a greater opportunity to provide market services and obtain benefits, such as BESS dispatch concurrent with PV generation. A capacity allocation amongst customers based upon inverter sizing may be equitable (as it approximately reflects the amount of investment) providing it also leads to a high utilisation of network capacity and thus maximise the customer wide potential to provide market services.

All customers who are active participants in the Symphony project are allocated a DOE and others (non-participants) are not. Therefore, the report assumes all customers subject to a DOE potentially provide market services. The proposed allocation of DOE does not prioritise based upon which NMIs are scheduled to provide a market service during any interval.

7.1.3.3 Wholesale Energy Prices

Different allocation methods may also impact the cost incurred by the customer's electricity retailer and/or Aggregator. An increase in customer renewable energy curtailment may at certain times impact Synergy's energy cost due to the requirement to substitute curtailed energy with grid generated energy. The substituted energy may be supplied from other generation (which may have been displaced by unmanaged solar) and purchased at the prevailing bilateral contract or WEM price[49].

The source of substituted energy and the energy price can be highly variable, and at times negative. The financial cost (or benefit) to Synergy is the difference between the price which would otherwise be paid for the curtailed renewable energy under an energy buyback scheme (if any) and the substituted energy price[50]. The net cost or benefit is then eventually passed onto all energy consumers through electricity retail tariffs.

Due to the difficulty of accurately quantifying this macro-economic cost/benefit the methodology has not considered its impact.

7.1.4 Environmental Impact

An average increase in managed renewable power generation and export is beneficial to the environment by reducing emissions intensity of grid supplied power which in turn benefits the electricity market and society in general.

The benefit of an efficient capacity allocation method is higher utilisation of renewable energy capacity (which might otherwise be curtailed under another allocation method). Any curtailment of available renewable generation through the application of a DOE needs to be matched by generation

[49] Short Term Energy Market Bids and Offers reports, *Last accessed 6/1/2022* provide the history of WEM electricity prices
[50] Other indirect costs are also affected, such as reserve capacity, renewable energy certificates and losses

from another source. If the marginal unit that substitutes the curtailed energy is another renewable power plant, then DER curtailed energy results in no environmental impact. On the other hand, if the marginal unit is a hydrocarbon generator then there is a direct environmental impact.

The annual average emissions intensity of grid supplied energy can be quantified by the Australian Governments National Greenhouse Accounts annual average SWIS emissions intensity, 0.69 kg CO_2-e/kWh[51] (which includes average emissions across renewable and non-renewable generation).

The application of a DOE also facilitates an increase in network hosting capacity resulting in an overall increase in installed PV generation capacity and export at times when the network is not constrained.

7.1.5 Network Security

The calculation of available network capacity is based upon forecast of energy flows through the distribution transformer and feeder equipment and, as a primary objective, should ensure the distribution network is operated within thermal and voltage limits[52]. The power flowing through the branches of a distribution network must be limited by the thermal constraints of the network assets and voltage at each customer connection point cannot exceed the nominal voltage limits.

The DOE solution has two functions, to accurately forecast the maximum capacity which can be allocated (at each level of the network) and then to equitably allocate the capacity to NMIs within that part of the network. The Evolve solution has three methods of forecasting capacity and a single method of allocating capacity (equal allocation)[53].

There are two ways a DOE may adversely affect network security.

Firstly, by allocating DOE capacity exceeding the available network capacity. This can be readily avoided by ensuring the allocation method is integrated with the capacity calculation function and is quantified in the allocation efficiency measure described in section 7.2.1.

Secondly, there is a risk arising from an uneven distribution of available network capacity across the subnetwork[54]. This has the potential to cause thermal or voltage excursions above the levels forecast in the network simulation model. This risk is mitigated in the Evolve method 3 as available network capacity is calculated at the NMI by modelling the LV network. However, the Evolve methods 1, 2 and DCOA methods allocate capacity which has been calculated in aggregate at the MV level (e.g. the distribution transformer) and may be susceptible to this risk. This report will assume flexible allocation of network capacity across the population of downstream participating connection points will not result in exceedance of connection point voltage or thermal limits on parts of the LV network. Calculation of voltages and LV network flows may be assessed in a further study on the topic by PACE.

[51] National Greenhouse Accounts (NGA) Factors report, p78. L*ast accessed 6/1/2022*, provides the latest estimate of SWIS electricity grid emissions scope 2 and 3 emissions intensity as 191 kg CO2-e/GJ (0.69 kg CO2-e/kWh)
[52] There is the potential for capacity allocation to counter market dispatches, such as constraining PV export during periods of high system demand, however these concerns are considered subordinate to network requirements and the DOE will take precedence over market dispatches.

[53] Evolve solution conceptually has three methods of capacity calculation and equally allocates capacity across all NMIs below the network element. In the case of Evolve's method 3, the capacity is calculated at NMI level (and all capacity is allocated to the NMI).
[54] An example is where there is a very high penetration of solar PV systems on a lightly loaded LV segment which may be electrically distant from the distribution transformer.

7.1.6 Reliability

The reliability of the DCOA to yield consistent and accurate forecasts and allocations will be affected by several factors including quality and availability of input data, complexity and robustness of the DCOA. The DCOA allocates the capacity calculated by the Evolve solution which in turn relies upon accurate inputs, such as monitoring data, the network model and its configuration. The reliability of the platform hardware, software and communication systems are assumed to be the same between all methods.

The proposed allocation methods require enhancements to the DOE solution:

- Operational data inputs, such as NMI forecast energy and inverter rating (presently available in the input data set).
- Configurable policy limits (such as MESL).

The enhancements have the potential to increase the sensitivity of the DCOA to small variations in operational data and cause unintended effects. Some of these effects will be tested in the Symphony project (refer section 10), however, there is the remnant risk of unforeseen and untested scenarios.

A simple DCOA which achieves the allocation objectives will be preferred over a complex DCOA. Methods to simplify the application of the allocation method may in future be considered, such as classification of data into few discrete groups to map NMIs to category envelopes (rather than bespoke calculation), or utilisation of mathematical modelling techniques.

The accuracy and reliance on input data required by each allocation method has been estimated to determine the relative reliability (accuracy) of the allocation weighting.

7.1.7 Scalability

The allocation method should have the ability to deploy progressively into different segments of a distribution network and across the SWIS, supporting expansion in scale and scope.

The scalability of the method is important to assess. A method which works in the Symphony pilot may have challenges when applied at the scale of the SWIS. The scalability of the DCOA capacity allocation method will be primarily determined by the computational intensity, which can be assessed by the time it takes (time complexity) and the computational resources required (space complexity).

The time available to complete both the available network capacity (Evolve) and DCOA calculations is limited by the duration of the DOE intervals (presently 5 minutes). There are various methods for determining algorithm efficiency based upon describing a function to estimate the time and space complexity of an algorithm with an increase in data inputs. For the capacity calculation and allocation to be scalable, an increase in the number of data points (NMIs) should not require an exponential increase in computational resources and commensurate increase in cost.

In this report, the computational intensity has been estimated using a simplified process based upon the pseudo-code developed for each method. As the allocation method is likely to be hosted using cloud computing, computational resources and capacity can be readily expanded and timeframes compressed by parallel processing. Consequently, this metric has been given a low weighting in the overall evaluation.

7.2 Quantification of Benefits

The quantification of benefits of the DCOA approach are based upon allocation objectives described in section 7.1. The following definitions are utilised in quantifying the benefits.

Forecast energy flow **is the forecast power at a NMI before the application of a DOE.**

Constrained forecast energy flow **is the forecast power at a NMI after the application of a DOE.**

The DOE provides an upper limit to the power permitted at a NMI. If the DOE is lower than the forecast energy flow at a NMI, then the power at the NMI is curtailed to the DOE. If the upper limit set by a DOE is greater than the forecast energy flow (denoted FE) at a NMI then there is no curtailment of forecast energy flow. The energy flow at a NMI after the application of a DOE is denoted the constrained forecast energy (denoted CFE) and determined using the following formula:

$$CFE_i = \begin{cases} DOE_i, & DOE_i < FE_i \\ FE_i, & DOE_i \geq FE_i \end{cases}$$

Where:

DOE_i is the operating envelope in kW applied in the applicable interval at the NMI, denoted i

FE_i is the forecast energy flow of the NMI, denoted i

7.2.1 Allocation Efficiency

Allocation Efficiency (AE) is calculated for each interval as a proportion of the constrained forecast energy of participating NMIs attached to a given distribution transformer (DT) to the Maximum Forecast Energy (MFE), which is the lesser of the DT available network capacity (ANC) or the sum of individual FEs in the interval.

$$AE = \frac{\sum_{i=1}^{n} CFE_i}{MFE} \times 100\%$$

$$MFE = Min\left(ANC, \sum_{i=1}^{n} FE_i\right)$$

Where:

n is the number of NMIs attached to the network element for which the capacity is allocated

ANC is the available network capacity to be allocated on the DT (the DT capacity[55] less capacity utilised by non-participating NMIs)

Other definitions are as above

[55] DT capacity is either the thermal rating or a calculated value less than the thermal rating of DT if the feeder capacity is the constraining network element.

The table below provides an interpretation of the results of the AE metric. The interpretation depends upon whether there is sufficient or insufficient ANC to support the total forecast energy.

Table 3: Allocation Efficiency Result Interpretation

			MFE		
			= ANC	= ∑FE	
		Scenarios	insufficient capacity	surplus capacity	**AE**
∑CFE	< MFE	DOE<FE for some or all NMIs	Highest AE method has highest efficiency	Capacity hasn't been efficiently allocated	**AE<100%**
	= MFE		Method efficiently allocates capacity (DOE<FE for some or all NMIs)	Method efficiently allocates capacity (DOE = FE for all NMIs)	**AE=100%**
	> MFE	DOE>FE for some or all NMIs	Capacity is over-allocated, network security risk	Capacity is over-allocated, possible network security risk	**AE>100%**

As described earlier, allocation efficiency greater than 100% implies a network security risk.

7.2.2 Allocation Equity

The determinants of allocation equity were discussed in section 7.1.2. The following are the parameters identified to measure allocation equity.

7.2.2.1 Allocation Fairness

Allocation Fairness (AF) can be assessed as one minus the deviation of the constrained forecast energy from the forecast energy. Where the method leads to a significant deviation of allocation then the value of AF will be lower. A higher value for AF implies a fairer allocation.

$$AF = 1 - \sigma\left(\frac{CFE_i}{FE_i}\right)$$

Where:

σ is the standard deviation

Other definitions are as above

7.2.2.2 Forecast Energy Supported

The Forecast Energy Supported (FES) is the average value of the proportion of forecast energy enabled by the constrained forecast energy (CFE). If FES is 100% then the DOE equals or exceeds the forecast energy for each NMI. If FES is less than 100%, then the forecast energy was curtailed by the DOE at some or all NMIs.

$$FES = \frac{1}{n}\sum_{i=1}^{n}\frac{CFE_i}{FE_i}$$

Where:

Definitions are as above

7.2.2.3 Minimum Export Service Level

MESL Compliance (MESLC) is a measure of whether an allocated DOE exceeds the minimum export service level per NMI. If MESLC is 100% then every NMI is allocated the minimum of its forecast energy and the MESL. If MESLC is less than 100% then the DOE is less than $MESL_i$ for one or more NMIs.

MESLC should be 100% except when network capacity allocated to active participants on a network is severely limited.

$$MESLC = \frac{Min(MESL_i, DOE_i)}{MESL_i}$$

$$MESL_i = Min\ (FE_i, MESL\ )$$

Where:

MESL is the minimum export service level policy setting (set at 1.5kW for the assessment)

Other definitions are as above

7.3 Quantification of Costs

7.3.1 EBS Impact

The impact on a customer of a DOE which curtails forecast energy and results in a reduction in rebate eligible energy can be measured as the energy buyback cost (EBC). EBC impact as a percentage is evaluated as the curtailed energy divided by the forecast energy for PV systems up to 5kW. The financial impact can be quantified as the amount of energy curtailed multiplied by the EBS price. The EBS Price is the applicable DEBS or REBS rate which is a function of NMI eligibility and time of day.

EBC impact can be quantified from the following formulas for each interval[56]:

$$EBC\ Impact\ (\%) = \frac{CE_i}{FE_i}, where\ FE_i > 0$$

$$EBC\ Impact\ (\$) = CE_i \times EBS\ Price\ (i,t)$$

$$CE_i = Max\ (FE_i - DOE_i, 0\ )$$

[56] DEBS Energy buyback limit is 50kWh per day but export in excess of this is very unlikely to occur so has been omitted from the formula

$$EBS\ Price(i,t) = \begin{cases} \$0.10 & i \in DEBS\ eligible\ and\ 3pm \le t \le 9pm \\ \$0.0275 & i \in DEBS\ eligible\ and\ t < 3pm\ or\ t > 9pm \\ \$0.07135 & i \in REBS\ eligible \\ \$0.00 & otherwise \end{cases}$$

Where:

CE_i is the curtailed export in kW applied in the applicable interval at the NMI denoted i

Other definitions are as above

7.3.2 Environmental Impact

The environmental impact is quantified as the difference in utilisation of renewable generation under each allocation method quantified by multiplying the renewable energy curtailed per NMI per interval ($\mathrm{CE_i}$) by the SWIS emissions intensity provided in section 7.1.4:

$$Emissions = CE_i \times EI_{SWIS}$$

$$CE_i = Max\,(\,FE_i - DOE_i, 0\,)$$

Where:

EI_{SWIS} = 0.69 kg CO_2-e/kWh

Other definitions are as above

7.3.3 Reliability

The cost of utilising an advanced DCOA allocation method lies primarily in the complexity of the approach, which may affect the reliability and scalability of the method.

The reliability of an allocation method depends on the accuracy of the input data which includes, some or all of:

- Available network capacity at network constraint points (an output of Evolve).
- Forecast export of non-participating customers (an output of Evolve).
- Forecast export of participating customers (an output of Evolve).
- Self-consumption rate of participating customers (calculated from input data).
- Customer inverter ratings (DER standing data).
- MESL Policy setting (configured value).

A simple reliability score has been applied for each method based upon the number of inputs required to calculate the DOE and its dependency on each input[57]. The following table shows the inputs required by each method and the reliability score given.

Table 4: Reliability Score of Algorithms

Algorithm	Inputs Required	Dependence on Input	Reliability of Input	Reliability Score (0-100%)
Base Case	None	N/A	N/A	100
EAM	1. Available network capacity 2. Forecast export of non-participating customers	1. High 2. High	1. Med 2. Med	90
DCOA 1	1. Available network capacity 2. Forecast export of non-participating customers 3. Customer inverter ratings. 4. MESL setting	1. High 2. High 3. High 4. Med	1. Med 2. Med 3. High 4. High	90
DCOA 2	1. Available network capacity 2. Forecast export of non-participating customers 3. Forecast export of participating customers 4. MESL setting	1. High 2. High 3. Med 4. High	1. Med 2. Med 3. Med 4. High	70
DCOA 3	1. Available network capacity 2. Forecast export of non-participating customers 3. Self-consumption rate of participating customers 4. Customer inverter ratings 5. MESL setting	1. High 2. High 3. Low 4. Low 5. High	1. Med 2. Med 3. Med 4. High 5. High	80
DCOA 4	1. Available network capacity 2. Forecast export of non-participating customers 3. Self-consumption rate of participating customers 4. Customer inverter ratings 5. MESL setting	1. High 2. High 3. Med 4. Med 5. High	1. Med 2. Med 3. Med 4. High 5. High	70

7.3.4 Scalability

Each method was awarded a score for the scalability based on the following two criteria:

1. The number of iterations required in a method to perform a SOE/DOE calculation.
2. The number of individual calculations required under each iteration.

The pseudo-code describing each allocation method is shown in Appendix C including the determination of calculations and iterations. In scoring the scalability it was assumed that performing an extra iteration consumes ten times more computational resources than performing the calculations, due to the extraction and handling of data for each NMI. The method is not precise but should provide a relative comparison between methods.

$$Scalabiltiy\ Score\ =\ 10\ x\ Iterations + Calculations$$

The following table summarises the above information for each method and the final score. As noted in section 7.1.7, the scalability score indicates the relative computational complexity and resources

[57] Dependency on an input will be measured as either high, medium or low. For example, High is assigned if an algorithm directly uses the input value, such that the sensitivity to the input is high. Low may apply if the input is used indirectly, for example, to assign the NMI to a category with a range of values.

which may be required to support the calculation. However, a high score does not necessarily indicate the method is not scalable, as calculations can occur in parallel.

Table 5: Scalability Score of Algorithms[58]

Method	Calculations per Iteration			Total Iterations[59]	Total Calculations[60]	Scalability Score
	1	2	3			
SOE	0			0	0	0
EAM	3			1	3	13
DCOA 1	2	1		2	3	23
DCOA 2	4	1		2	5	25
DCOA 3	2	3	3	3	8	38
DCOA 4	4	4	4	3	12	42

7.4 Base Case

In the SWIS, single phase basic Embedded Generators connecting to large networks (refer section 5.2.1) are usually allocated a static export limit. A SOE with an export limit consistent with the export limit published in the Basic EG Connection Technical Requirements is regarded as a suitable base case to measure the relative benefits of applying a DOE under different scenarios.

The table below shows the SOE (export limit) to be used in the Base Case.

Table 6: Base Case SOE Assumptions

Connection Service	Inverter Rating	Export Limit
Single-phase	Less than or equal to 5kVA	5kW
Three-phase	Less than or equal to 5kVA	5kW
Three-phase	Greater than 5kVA	1.5kW

[58] A detailed review of algorithmic steps and determination of their respective iteration and calculation steps are shown in Appendix C.
[59] Number of times you need to iteratively calculate capacity for each NMI.
[60] Number of calculations performed for each NMI.

8 Capacity Allocation Methods

8.1 Evolve Allocation Methods

The Evolve allocation methods are based upon an assessment of the available network capacity, in different parts of the network, and an equal allocation of capacity to all participating NMIs below that level. The Evolve solution uses a network centric (physics based) assessment to forecast network capacity at the feeder or distribution transformer and allocates the capacity equally amongst NMIs.

The Evolve methods are summarised below.

8.1.1 Method 1 – Equal Allocation at Feeder Level

This method seeks a solution for a range of load and generation values to the point where the first constraint is reached at any point on the feeder (including distribution transformer and LV network). This method allocates the same DOE to participating NMIs and does not progress any further. The result is capacity is allocated equally to customers on the feeder, however its likely further capacity is available in some locations, so capacity utilisation is likely to be suboptimal.

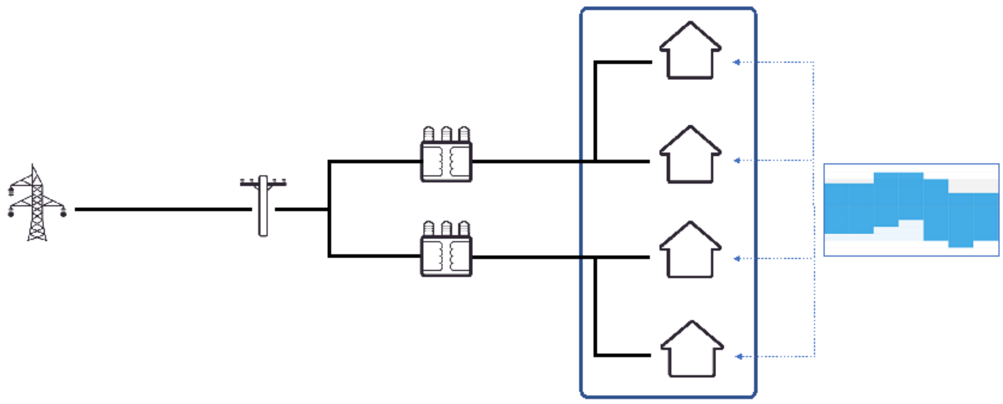

Figure 7: Evolve Equal Allocation Feeder Level

8.1.2 Method 2 – Equal Allocation at Distribution Transformer Level

This method builds on the Equal Allocation at Feeder Level (i.e. method 1) and seeks a solution that identifies a combination of constraints across the feeder and results in equal allocation to customers below a distribution transformer (customers attached to an individual transformer will experience the same limits).

The result is capacity is allocated equally to customers on the distribution transformer.

This approach will result in a higher network capacity utilisation than method 1. As it employs an equal allocation method, all customers will be allocated the same capacity, so capacity utilisation is likely to be suboptimal.

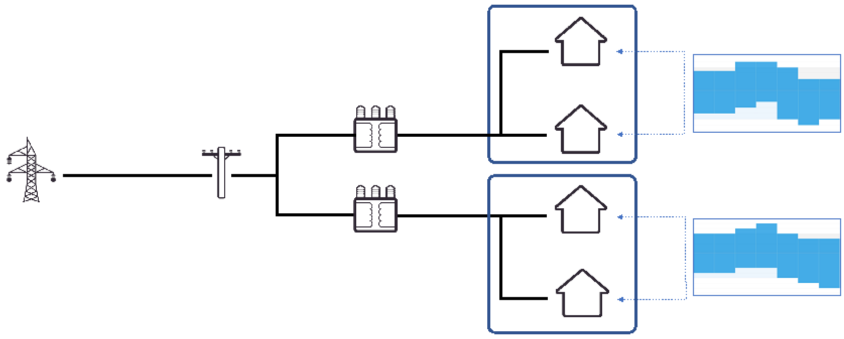

Figure 8 Equal Allocation Distribution Transformer Level

8.1.3 Method 3 – Maximal Allocation at NMI level

The maximal allocation method seeks to maximise the capacity and DOE for each NMI by allowing each NMI to have different allocations. This will result in the maximum capacity utilisation, however, will likely result in inequalities between premises depending on their electrical connection in the network. For the Symphony Pilot where the LV network is underground[61] this allocation is generally equivalent to equal allocation at the distribution transformer.

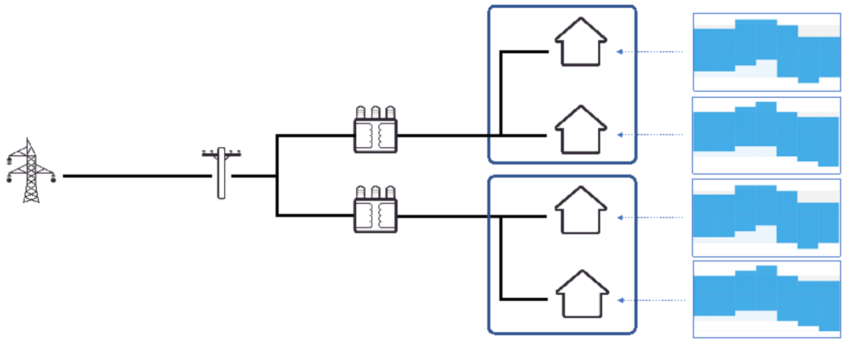

Figure 9 Maximal Allocation at NMI Level

8.2 Proposed Allocation Methods

The proposed allocation methods consider one or more customer parameters to allocate capacity equitably and achieve the objectives described in section 7.1:

- The forecast energy at each NMI, calculated using data from Evolve[62]
- The customer generation capacity (inverter rating), available from standing data
- The Minimum Export Service Level, applied as a configuration setting.

[61] Underground LV networks tend to be shorter and have lower impedance which are less susceptible to voltage constraint.
[62] The practicality of obtaining an accurate forecast of energy flow in each interval at each NMI presents a challenge. The Symphony project will assess the accuracy of forecasts and further testing and simulation will be done by PACE during Symphony to assess the reliability of the DCOA methods when using real input data.

The DCOA methods all utilise the available network capacity forecast reported in the Evolve DOE calculator, as illustrated in the figure below.

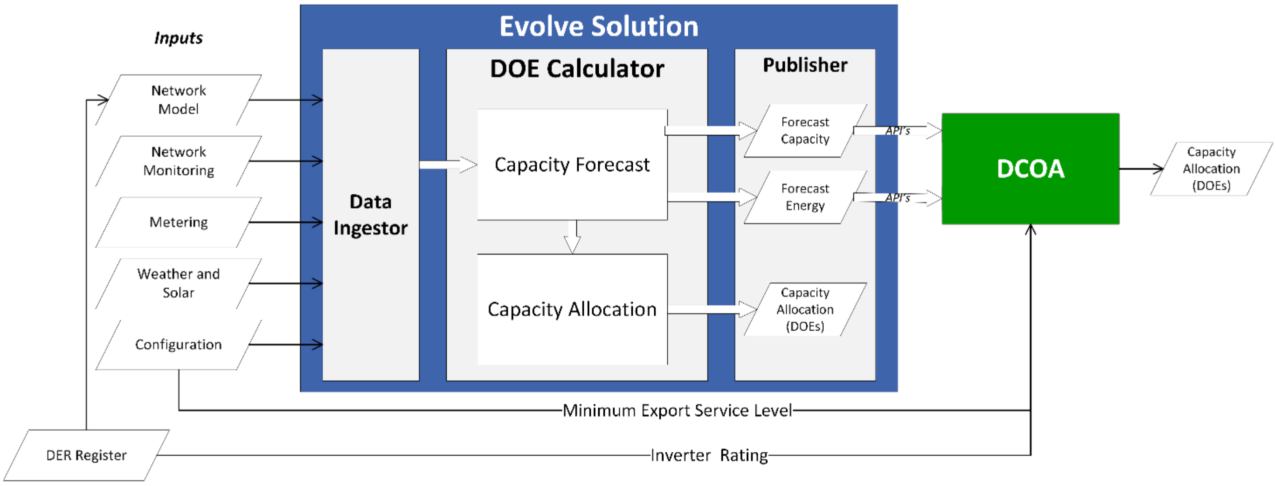

Figure 10 Calculation of the Evolve and DCOA allocation methods

8.2.1 Proposed DCOA 1 - Proportional Allocation (Inverter Rating)

In this method the inverter rating of each active participant is treated as the weighting factor to assign ANC at each NMI after MESL is allocated. The operating envelope will be the lesser of this weighted allocation and the forecast energy amount. Under this allocation method larger systems can export more energy.

A numerical example is provided in Appendix B and the pseudo code is shown in Appendix C.

The following formula shows the calculation of DOE for each NMI:

$$DOE_i = Min\left(FE_i, MESL_i + \frac{IR_i}{\Sigma_{i=1}^{N} IR_i} * (ANC - \Sigma_{i=1}^{N} MESL_i)\right)$$

$$i \in Participant\ NMIs, N = total\ Participant\ NMIs$$

Where:

FE is the forecast energy for each participating NMI during each interval.

IR is the customer inverter rating

ANC is the available network capacity

$MESL_i$ is the minimum export service level per NMI

8.2.2 Proposed DCOA 2 - Proportional Allocation (Forecast Energy)

In this method the forecast energy of each active participant is treated as the weighting factor to assign ANC at each NMI after MESL is allocated. The operating envelope will be the lesser of this weighted allocation and the forecast energy amount. Under this allocation method NMIs with higher forecast energy (export) can export more energy.

A numerical example is provided in Appendix B and the pseudo code is shown in Appendix C.

The following formula shows the calculation of DOE for each NMI:

$$DOE_i = Min\left(FE_i, MESL_i + \frac{FE_i - MESL_i}{\Sigma_{i=1}^{N}(FE_i - MESL_i)} * (ANC - \Sigma_{i=1}^{N} MESL_i)\right)$$

Where:

Definitions are as above.

8.2.3 Proposed DCOA 3- Weighted Allocation (Inverter Rating & Forecast Energy)

This method is based on a proportional allocation where the relevant proportional constant associated with each participating NMI is determined based on both the inverter rating and self-consumption. In this method high self-consumption and small inverter ratings are prioritised over low self-consumption and large inverter ratings.

8.2.3.1 Classification of Inverter Rating

Data on the rating of common residential PV system installations were used to classify NMIs into one of three major categories and then a weighting (of 1, 2 or 3[63]) was assigned to each category as shown in Table 7.

Rooftop PV installation data published by the "Australian Photovoltaic Institute" was used as the reference to determine the classification of inverter ratings. The following observations can be made based upon 2,871,708 roof top PV installations in the period from January 2010 to September 2021[64]:

- 47% of the total installations were lower than 4.5kW.
- 45% of the total installations were between 4.5kW and 9.5kW.
- 8% of the total installations were higher than 9.5kW.

8.2.3.2 Classification of Self-consumption

Similar to the above parameter, a separate weighting was given to each NMI depending on rate of self-consumption of renewable energy. The consumption score will be updated in every 24 hours based on the average NMI self-consumption rate (%) of the previous 24hrs.

The rationale for considering self-consumption is discussed in section 7.1.2.4.

[63] 3 is a higher weighting than 1.
[64] Australian PV Market Analysis Data, September 2021, *Last accessed 14/12/2021.*

Table 7 Weighting of Customers Based on Inverter rating and Self-consumption

Inverter Rating (kW)	Inverter Rating Weighting[63]	Self-consumption (%)	Consumption Weighting[65]
<4.5	3	0-25	1
4.5 to 9.5	2	25 to 75	2
>9.5	1	>75	3

8.2.3.3 DOE Calculation

The inverter rating and self-consumption weighting in Table 7 is used to assign the ANC at each NMI after the MESL is allocated. The operating envelope will be the lesser of this weighted allocation and the forecast energy flow.

A numerical example in provided in Appendix B and the pseudo code is shown in Appendix C.

The following formula shows the calculation of DOE for each NMI:

$$DOE_i = Min\left(FE_i, MESL_i + \frac{IR_{i\,Grading} * SC_{i\,Grading}}{\Sigma_{i=1}^{N} IR_{i\,Grading} * SC_{i\,Grading}} * (ANC - \Sigma_{i=1}^{N} MESL_i)\right)$$

Where:

> SC is the self-consumed power (of the generated renewable power) of each participating NMI during each interval[66].
>
> Other definitions are as above.

8.2.4 Proposed DCOA 4– Multistage Criteria Allocation

Allocation method 4 utilises a principled iterative allocation to allocate capacity in order of descending priority based on multiple inputs. This method is the most complex.

Iteration 1 – Minimum Capacity Allocation (MESL)

Each participating NMI has an equal entitlement to a MESL where sufficient network capacity exists. NMIs are allocated capacity up to the minimum of their forecast energy and MESL.

Iteration 2 – Forecast Energy and Self-consumption Weighted Allocation

Where there is ANC after iteration 1 then network capacity is proportionally allocated up to the forecast energy amount, weighted using a sum product of self-consumption rate and forecast shortfall[67]. Systems with higher self-consumption are thus prioritised for capacity allocation (up to their forecast energy).

Iteration 3 – Forecast Export and Inverter Rating Weighted Allocation

---

[65] 3 is a higher weighting than 1.

[66] Self-consumption is the proportion of renewable energy used onsite compared to the total renewable energy generated. Both metrics are forecast in the Evolve solution

[67] "Forecast shortfall" is defined as the difference between forecast energy and the allocated capacity in the preceding iteration.

Where there is ANC remaining after iteration 2 then network capacity is proportionally allocated up to the forecast energy amount, weighted using a sum product of inverter rating and forecast shortfall. Systems with higher inverter rating are allocated spare capacity (up to their forecast energy).

Iteration 4 – Inverter Rating Allocation

Where there is unallocated network capacity remaining after iteration 3 then remaining capacity is proportionally allocated up to the inverter rating weighted by inverter shortfall[68]. This method provides a signal to the Aggregator there is spare capacity, which may enable concurrent export to the grid from dispatchable sources (e.g. a BESS or EV).

Iteration 5 – Balance of Network Capacity Allocation for Expansion

Where there is unallocated network capacity remaining after iteration 4 then remaining capacity is equally allocated across all NMIs up to their connection limit. The connection limit is different between single phase and three phase systems (typically 15kW for single-phase and 22.5kW for three-phase). The rationale to allocate capacity in excess of current capability is that examination of the DOE history will indicate to customers if there is spare network capacity and will assist sizing for installation of upgraded systems (where permitted).

A numerical example with detailed calculation steps is provided in Appendix B. The pseudo code of DCOA 4 method is shown in Appendix C.

8.3 Reference Case

An equal allocation method, as utilised within the Evolve method 2 solution, serves as a useful reference to test the benefits and costs of alternative dynamic allocation methods. Equal allocation provides a simple DOE approach which is readily scalable and reliable.

[68] "Inverter shortfall" here is the difference between inverter rating and the allocated capacity in iteration 3.

9 Assessment

9.1 Test Scenarios and Data

Test data for each network capacity scenario comprised four hundred NMIs allocated across four transformers with a configurable allocation of participating and non-participating (in the VPP) customers and PV system penetration rates. The selection of single and three phase connections was randomised and the inverter rating and embedded load generated by randomised values within a normal distribution with defined mean and standard deviation.

Overall, the test scenarios shown in this report can be categorised as:

- Varying DT and Feeder thermal capacities, where the participating and non-participating customers are the same across all scenarios, and
- Varying VPP participation rate, which affects the available network capacity to be allocated to participating customers.

In the first category three test scenarios were studied to simulate various network constraints[69] (with 50% VPP participation rate assumed in each scenario):

1. Feeder capacity 1300kW and DT capacity 250kW each (unconstrained at DT or feeder)
2. Feeder capacity 900kW and DT capacity 250kW each (constrained by feeder)
3. Feeder capacity 600kW and DT capacity 100kW each (constrained below DT)

In the second category four test scenarios were studied to simulate increasing VPP adoption (with 600kW feeder constraint and 100kW per DT constraint assumed in each scenario):

4. VPP first mover's scenario (10% VPP participants)
5. VPP early uptake scenario (30% VPP participants)
6. VPP mainstream scenario (60% VPP participants)
7. VPP mature scenario (85% VPP participants)

The results are calculated for a single daytime interval assuming maximum PV output.

9.2 Performance by Scenario

The performance of allocation methods is quantified for each test scenario against the measures defined in section 7.2 and section 7.3. The reliability and scalability measures which are not specific to the scenarios are omitted and shown in the final evaluation, section 9.2.8. The results are tabulated in the following sections. All methods have used the same NMI dataset for the performance comparison.

9.2.1 Scenario 1 (Feeder Rating is above the sum of DT ratings) Method Performance

In scenario 1, the customer base comprised approximately 50% VPP participants and 50% non-participants with feeder level FE flow of participant NMIs of 379kW and ANC of 1058kW[70] based on

[69] These ratings are not representative of SNR540 network capacity and values selected have been used to simulate certain scenarios.

[70] ANC is the sum of network capacity (calculated at feeder and DT level) plus uncontrolled FE flow of non-participant NMIs (generally a net load which enables an increase in hosting capacity above the network capacity) which is then allocated to participant NMIs.

feeder rating of 1300kW and DT rating of 250kW each (unconstrained by DT or feeder). The sum of FE is considerably less than the ANC on each DT (there is surplus capacity).

Table 8 Scenario 1 Inputs

Network Element	Rating (kW)	Active NMIs	ANC (kW)	FE (kW)
Feeder	1300	188	1058	379
DT 1	250	46	272	97
DT 2	250	42	282	85
DT 3	250	50	245	107
DT 4	250	50	259	90

The following observations can be made based on the results in Table 9:

- The SOE and EAM resulted in AE less than 100% as these methods curtail export by some NMIs whilst allocating excess capacity to others[71]. In the base case, PV systems with inverter rating above 5kW are limited to export of 1.5kW, even when there is spare capacity. With the EAM, capacity is equally allocated to all NMIs, however, the data shows in some instances larger NMIs will still be curtailed when there is spare capacity. All DCOA methods allocated capacity so that FE was supported at all participating NMIs.
- The base case and EAM resulted in FES slightly below 100%. This is because the FES measure is closely aligned to AE when there is surplus capacity.
- The allocation fairness metric (AF) shows the deviation in export capacity assigned to NMIs compared to their forecast energy flow was lower in the base case and the EAM, as FE is not considered in these approaches. AF among the NMIs is 100% in the DCOA methods as there was surplus capacity and these methods proportionally allocate available network capacity based on inverter rating and forecast energy flow.
- All methods ensured that all the NMIs would receive the lesser of their forecast energy flow or the MESL.
- The EAM resulted in a financial loss of 0.21%, which shows that the EAM has incurred a small penalty on some EBS eligible NMIs indicating some NMIs (having a system size of less than or equal to 5kW) had DOE lower than FE. The SOE has no EBC impact as the NMIs curtailed are non-EBS eligible.
- The environmental impact calculation indicates the total energy curtailed in each method, thus the SOE has the highest impact and the EAM a minor impact while DCOA methods had no impact.

[71] In the base case, inverters with rating above 5kW are assigned a static export limit of 1.5kW which under the IES EG Connection Requirements, will be autonomously managed by an on-site power meter connected to the inverter.

Table 9 Scenario 1 Method Performance

Metric	Results					
	Base Case (SOE)	EAM (DOE Reference)	DCOA 1 (Inverter rating)	DCOA 2 (Forecast Energy)	DCOA 3 (Weighted)	DCOA 4 (Multistage)
Allocation Efficiency (AE) (refer note below)	92% (90% - 97%)	98% (95% - 100%)	100%	100%	100%	100%
Forecast Energy Supported (FES)	96%	99%	100%	100%	100%	100%
Allocation Fairness (AF)	85%	95%	100%	100%	100%	100%
MESL not met (NMIs)	0	0	0	0	0	0
Energy Buyback Cost	0	0.21%	0	0	0	0
Environmental Impact (Emissions, kgCO2-e)	4.8	1.6	0	0	0	0

Note: AE is calculated on each of the four DTs with the mean shown and the range of results in brackets. If a method results in an individual DT allocation efficiency over 100%, then this is considered a network security risk (and for that DT the AE score contributed to the final weighted evaluation will be zero).

(green)	A higher number denotes a more positive result
(orange)	A higher number denotes a more negative result

9.2.2 Scenario 2 (Feeder Rating is below the sum of DT ratings) Method Performance

In Scenario 2, the customer base is the same as scenario 1 (with feeder level FE flow of participant NMIs of 379kW) with ANC of 958kW and feeder rating of 900kW and DT rating of 250kW each (constrained by feeder). In this scenario, the sum of FE is still considerably less than the ANC on each DT (there is surplus capacity).

Table 10 Scenario 2 Inputs

Network Element	Rating (kW)	Active NMIs	ANC (kW)	FE (kW)
Feeder	900	188	958	379
DT 1	250	46	238	97
DT 2	250	42	223	85
DT 3	250	50	245	107
DT 4	250	50	252	90

The following observations can be made based on the results reported in Table 11:

- As there is surplus ANC in this scenario, the method performances are very similar to scenario 1 and the observations made of scenario 1 apply to scenario 2.

Table 11 Scenario 2 Method Performance

	Results					
Metric	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	92% (90% - 97%)	96% (95% - 97%)	100%	100%	100%	100%
Forecast Energy Supported (FES)	96%	98%	100%	100%	100%	100%
Allocation Fairness (AF)	85%	94%	100%	100%	100%	100%
MESL not met (NMIs)	0	0	0	0	0	0
Energy Buyback Cost	0	0.47%	0	0	0	0
Environmental Impact (Emissions, kgCO2-e)	4.8	2.5	0	0	0	0

9.2.3 Scenario 3 (Feeder Rating is above the sum of DT ratings) Method Performance

In Scenario 3, the customer base is the same as scenario 1 and 2 (with feeder level FE flow of participant NMIs of 379kW) but with ANC of 458kW based on feeder rating of 600kW and DT rating of 100kW each (constrained by DT). In this scenario, the sum of FE is higher than ANC on some DTs (there is inadequate capacity).

Table 12 Scenario 3 Inputs

Network Element	Rating (kW)	Active NMIs	ANC (kW)	FE (kW)
Feeder	600	188	458	379
DT 1	100	46	122	97
DT 2	100	42	132	85
DT 3	100	50	95	107
DT 4	100	50	109	90

The following observations can be made based on the results reported in Table 13:

- The EAM had the lowest average allocation efficiency as it has curtailed NMIs with higher FE.
- FES was lowest with the EAM (81%) meaning 19% curtailment of FE owing to poor allocation efficiency and a commensurately low AF score. The EBC (28%) and environmental impact (20kg CO2-e) is significant at this level of capacity constraint.
- The base case appears to perform with higher average AE than the EAM and DCOA 1, however, this is because in some scenarios the unconstrained capacity exceeds the ANC

and creates a network security risk. Due to this factor the remainder of positive impact scores can be largely ignored for this method.

- DCOA 1 had a low AE (as it prioritises capacity based on inverter rating not FE) and the FES (91%) indicates 9% curtailment of export with a significant EBC (14%) and emissions impact (10kg CO2-e).
- DCOA 2 and 4 provided similar benchmark performance with minor EBC and emissions.
- All methods ensured that all the NMIs would receive the lesser of their forecast energy flow or the MESL.

Table 13 Scenario 3 Method Performance

	Results					
Metric	Base Case (SOE)	EAM (DOE Reference)	DCOA 1 (Inverter rating)	DCOA 2 (Forecast Energy)	DCOA 3 (Weighted)	DCOA 4 (Multistage)
Allocation Efficiency (AE)	95% (90% - 109%)	72% (64% - 80%)	88% (82% - 96%)	100%	100%	100%
Forecast Energy Supported (FES)	96%	81%	91%	98%	99%	98%
Allocation Fairness (AF)	85%	77%	86%	95%	93%	93%
MESL not met (NMIs)	0	0	0	0	0	0
Energy Buyback Cost	0%	28%	14%	3.7%	3.0%	5.0%
Environmental Impact (Emissions, kgCO2-e)	4.8	20	10	2.0	2.0	2.0

9.2.4 Scenario 4 (VPP First Movers) Method Performance

In scenario 4, the customer base assumes 10% VPP participation rate (out of the 400 NMIs) with feeder level FE flow of participant NMIs of 82kW and with ANC of 505kW based on feeder rating of 600kW and DT rating of 100kW each (constrained by DT). Due to the low VPP participation the sum of FE is much lower than ANC on all DTs (there is surplus capacity).

Table 14 Scenario 4 Inputs

Network Element	Rating (kW)	Active NMIs	ANC (kW)	FE (kW)
Feeder	600	38	496	82
DT 1	100	10	121	21
DT 2	100	6	120	20
DT 3	100	10	130	22
DT 4	100	12	125	19

The following observations can be made based on the results reported in Table 15:

- All the DOE methods have an allocation efficiency (AE) of 100% and perform equally well across all metrics.
- The base case (SOE) has AE between 73% and 100% due to the incidence of participant PV systems above 5kW which are constrained to 1.5kW due to customer connection limits.

Table 15 Scenario 4 Method Performance

	Results					
Metric	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	93% (73% - 100%)	100%	100%	100%	100%	100%
Forecast Energy Supported (FES)	96%	100%	100%	100%	100%	100%
Allocation Fairness (AF)	84%	100%	100%	100%	100%	100%
MESL not met (NMIs)	0	0	0	0	0	0
Energy Buyback Cost	0%	0%	0%	0%	0%	0%
Environmental Impact (Emissions, kgCO2-e)	1	0	0	0	0	0

9.2.5 Scenario 5 (VPP Early Uptake) Method Performance

In scenario 5, the customer base assumes 30% VPP participation rate (out of the 400 NMIs) with feeder level FE flow of participant NMIs of 261kW and with ANC of 445kW based on the same feeder and DT ratings as scenario 4 (constrained by DT). Due to only moderate VPP participation the sum of FE is still lower than ANC on all DTs (there is surplus capacity).

Table 16 Scenario 5 Inputs

Network Element	Rating (kW)	Active NMIs	ANC (kW)	FE (kW)
Feeder	600	127	445	261
DT 1	100	25	132	37
DT 2	100	34	114	74
DT 3	100	40	101	89
DT 4	100	28	98	61

The following observations can be made based on the results reported in Table 17:

- Even with significant spare capacity the EAM and DCOA 1 methods curtail FE with the EAM achieving FES of only 92% (8% energy curtailed) and slight impact on the EBC and environmental metrics.
- Allocation fairness is lowest on the EAM indicating the equal allocation of capacity results in significant differences in capacity allocation between NMIs compared to their FE.
- Neither the EAM or DCOA 1 outperformed the base case (SOE) in this scenario.
- DCOA 2 to 4 methods avoided curtailment of FE and any impact on EBC or the environment.
- All methods ensured that all the NMIs would receive the lesser of their forecast energy flow or the MESL.

Table 17 Scenario 5 Method Performance

	Results					
Metric	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	96% (91% - 98%)	88% (76% - 97%)	97% (89% - 100%)	100%	100%	100%
Forecast Energy Supported (FES)	98%	92%	98%	100%	100%	100%
Allocation Fairness (AF)	90%	84%	93%	100%	100%	100%
MESL not met (NMIs)	0	0	0	0	0	0
Energy Buyback Cost	0%	8.6%	2.9%	0%	0%	0%
Environmental Impact (Emissions, kgCO2-e)	2.1	6.6	2.0	0	0	0

9.2.6 Scenario 6 (VPP Mainstream) Method Performance

In scenario 6, the customer base assumes 60% VPP participation rate (out of the 400 NMIs) with feeder level FE flow of participant NMIs of 442kW and with ANC of 444kW based on the same feeder and DT ratings as scenario 4 (constrained by DT). Due to a significant VPP participation the sum of FE is higher than ANC on two DTs (there is inadequate capacity).

Table 18 Scenario 6 Inputs

Network Element	Rating (kW)	Active NMIs	ANC (kW)	FE (kW)
Feeder	600	232	444	442
DT 1	100	60	125	97
DT 2	100	55	98	116
DT 3	100	57	92	117
DT 4	100	60	130	114

The following observations can be made based on the results reported in Table 19.

- The base case has over allocated capacity (AE>100%) this is because on some DTs the unconstrained capacity exceeds the ANC and creates a network security risk. Due to this factor the remainder of positive impact scores can be largely ignored for this method.
- The EAM has low AE (69%) resulting in FES of only 77% (23% energy curtailed) and significant impact on the EBC (41% reduction in rebate eligible energy) and environment (29 kg CO2-e).
- DCOA 2 to 4 result in an AE of 100%. This can be explained by:
    - For DTs with insufficient capacity the forecast energy flow of participating NMIs is greater than the ANC. In this situation, AE of 100% means the ANC under a DT is fully utilised by the associated participating NMIs.
    - For DTs with spare capacity the forecast energy flow of participating NMIs is lower than the ANC. In this situation, AE of 100% means all the participants have a constrained forecast energy flow equal to their forecast energy flow (i.e. no curtailment of forecast energy flow).
- Allocation fairness is lowest on the EAM indicating the equal allocation of capacity results in significant differences in capacity allocation between NMIs compared to their FE.
- DCOA 2 to 4 methods performed similarly and achieved 5% or less curtailment of FE and reduced impact on EBC and the environment.
- The EAM allocated capacity below the FE or MESL at 45 NMIs (19% of participant NMIs). All other methods ensured that all the NMIs would receive the lesser of their forecast energy flow or the MESL.

Table 19 Scenario 6 Method Performance

	Results					
Metric	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	101% (90% -115%)	69% (68% - 71%)	85% (84% - 87%)	100%	100%	100%
Forecast Energy Supported (FES)	96%	77%	87%	94%	96%	95%
Allocation Fairness (AF)	85%	74%	82%	90%	87%	86%
MESL not met (NMIs)	0	45	0	0	0	0
Energy Buyback Cost	0%	41%	24%	11%	5.0%	11%
Environmental Impact (Emissions, kgCO2-e)	7.2	29	18	7.4	7.4	7.4

9.2.7 Scenario 7 (VPP Mature) Method Performance

In scenario 7, the customer base assumes 85% VPP participation rate (out of the 400 NMIs) with feeder level FE flow of participant NMIs of 600kW and with ANC of 376kW based on the same feeder and DT ratings as scenario 4 (constrained by DT). Due to high VPP participation the sum of FE is much higher than ANC on all DTs (there is inadequate capacity).

Table 20 Scenario 7 Inputs

Network Element	Rating (kW)	Active NMIs	ANC (kW)	FE (kW)
Feeder	600	311	376	600
DT 1	100	77	107	131
DT 2	100	77	90	149
DT 3	100	83	85	166
DT 4	100	74	95	155

The following observations can be made based on the results reported in Table 21.

- The base case has over allocated capacity (AE>100%) this is because on all DTs the unconstrained capacity exceeds the ANC and creates a network security risk. Due to this factor the remainder of positive impact scores can be largely ignored for this method.
- The EAM has low AE (72%) resulting in FES of only 60% (40% energy curtailed) and major impact on the EBC (77% reduction in rebate eligible energy) and environment (57 kg CO2-e).
- DCOA 1 achieved higher AE (94%) and FES (72%) with significant impact on the EBC (54% reduction in rebate eligible energy) and environment (43 kg CO2-e).
- DCOA 2 to 4 all achieved an AE of 100%. This can be explained as per the reasons set out in scenario 6. These methods achieved the same FES (75%) with reduced impact on the EBC (46 to 51% reduction in rebate eligible energy) and environment (39 kg CO2-e). These methods also achieved similar AF scores.
- Allocation fairness is lowest on the EAM but not significantly worse than DCOA methods.
- The EAM allocated capacity below the FE or MESL at 150 NMIs (48% of participant NMIs). DCOA 2 and 4 outperformed on MESL (46 and 44 NMIs). Due to the lack of ANC, no method was able to meet the minimum MESL requirement.

Table 21 Scenario 7 Method Performance

	Results					
Metric	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	147% (116% - 176%)	72% (68% - 78%)	94% (86% - 100%)	100%	100%	100%
Forecast Energy Supported (FES)	96%	60%	72%	75%	75%	75%
Allocation Fairness (AF)	84%	71%	75%	76%	75%	75%
MESL not met (NMIs)	0	150	70	46	70	44
Energy Buyback Cost	0%	77%	54%	49%	46%	51%
Environmental Impact (Emissions, kgCO2-e)	9.3	57	43	39	39	39

9.2.8 Average Method Performance

The following general observations can be made about the performance of the different methods across a variety of scenarios from the results reported in Table 22.

- The base case appears to have a high AE (102%), however, as mentioned previously this indicates a network security risk. The other base case average performance metrics are thus somewhat misleading as it assumes utilisation of network capacity which is not available to the other methods.
- The EAM has a comparatively low AE (85%) resulting in FES of 87% (13% energy curtailed) and greater impact on the EBC (22% reduction in rebate eligible energy) and environment (17 kg CO2-e) compared to the DCOA methods.
- DCOAs 2 to 4 achieved highest AE (100%) and FES (95-96%) with least impact on the EBS rebates (8-10% reduction in rebate eligible energy) and the environment (7 kg CO2-e).
- Allocation fairness is lowest on the EAM and similar on all DCOA methods.
- MESL compliance is lowest on the EAM and similar on all DCOA methods.
- The base case is the most scalable[72] and EAM has the highest scalability among all DOE methods. The DCOA 1 and 2 methods have scored better than DCOA 3 and 4 as they require fewer iterations and calculations.
- The base case was awarded a reliability score of 100% indicating that the application of the method is highly reliable (and not sensitive to data errors). The EAM and DCOA 1 methods are similarly reliable as they rely upon standing data (number of NMIs or DER rating). The

[72] A score closer to 0 indicates a method's complexity is low. Computational complexity doesn't necessarily present a barrier to scaling of a method.

reliability of DCOA 2 to 4 are lower because of their dependency on several input parameters, some with lower accuracy.

Table 22 Average of all Scenarios Method Performance

	Results					
Metric	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	102%	85%	95%	100%	100%	100%
Forecast Energy Supported (FES)	96%	87%	93%	95%	96%	95%
Allocation Fairness (AF)	85%	85%	91%	94%	94%	93%
Reliability	100%	90%	90%	70%	80%	70%
Scalability	0	13	23	25	38	42
MESL not met	0	28	10	7	10	6
Energy Buyback Cost	0%	22%	14%	9%	8%	10%
Environmental Impact (Emissions, kgCO2-e)	5	17	10	7	7	7

9.3 Weighted Average Performance

To compare the performance of different methods across all metrics, the Weighted Average Performance (WAP) of each method was calculated by normalising the metric scores[73] in Section 9.2.

Each evaluation criterion was then provided with a weight such that the maximum WAP value of a particular method adds to 100%. The individual WAP for each scenario, metric and allocation method is provided in Appendix F.

The table below compares the normalised performance across scenarios and metrics[74].

The general observations from the below table are:

- The base case performs comparatively well against the EAM when there is surplus capacity (scenarios 1, 2, 4 and 5) as there is minimal network risk and there is only curtailment of larger PV systems[75].

[73] Non-percentage scores were converted to a percentage by comparing relative performance against the highest performing metric. Scores for allocation efficiency and reliability were not normalised as those were already expressed as a percentage.
[74] Normalised scores can exacerbate small differences in performance so should be used as a guide to overall performance only.
[75] PV systems with inverter rating above 5kW are autonomous curtailed to 1.5kW.

- The EAM underperforms the DCOA methods in all but one scenario (4, where there is spare capacity) and performance deteriorates as VPP participation increases (or capacity diminishes).
- The DCOA 1 outperforms all others in scenarios (1, 2 and 4) where there is spare capacity.
- DCOAs 2 to 4 perform similarly (and generally outperformed all other methods) of which DCOA 2 is the least complex approach.

It can be concluded that DCOA 2 and 3 have performed better than other DOE methods based upon measurement against the metrics selected, under different combinations of thermal constraints and as the PV injected into the gird increases over the time.

Table 23 Comparison of Weighted Average Performance by Scenario

	Results					
Metric	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Scenario 1	86%	82%	96%	93%	92%	91%
Scenario 2	86%	80%	96%	93%	92%	91%
Scenario 3	76%	66%	81%	90%	90%	87%
Scenario 4	86%	97%	96%	93%	92%	91%
Scenario 5	95%	71%	88%	93%	92%	91%
Scenario 6	77%	55%	78%	87%	88%	85%
Scenario 7	78%	52%	69%	71%	70%	69%
Average WAP	**83%**	**72%**	**86%**	**88%**	**88%**	**86%**

9.4 Assessment Summary

9.4.1 SOE vs DOE

The assessment shows the current SOE approach performs moderately well (reliable and scalable method with no EBC impact, minor energy curtailment and support of MESL) in scenarios where there is surplus hosting capacity. However, as the penetration of PV increases and hosting capacity is reduced this approach will either result in inadvertent over allocation of capacity (and with no means to manage PV this may cause a network security risk) or, more probably, increasingly require network upgrades or constrained connection requirements.

Another advantage of a DOE over a SOE, which has not been quantified, is the potential to use published DOEs to inform customers and other stakeholders about the time varying availability of spare capacity at each connection point. This can potentially be utilised in making efficient decisions about sizing of DER upgrades (e.g. EV, BESS and PV).

9.4.2 Energy Buyback Scheme Impact

At present, all EBS eligible customers enjoy EBS rebates for all energy exported. However, with the diminishing of hosting capacity as PV penetration increases, it may not always be possible to permit an unmanaged export limit of 5kW.

The assessment results show that VPP participants, who are subject to a DOE receive lower energy payments as compared to SOE. Given a choice for EBS eligible customer to participate in a VPP (and be subject to a DOE) or to opt out and be unmanaged with no risk to EBS rebates, some customers may choose the latter unless the VPP benefits outweigh the EBC.

9.4.3 Equal vs Equitable Allocation

The performance assessment shows there are net benefits to applying an equitable allocation method over an equal allocation method, primarily by reducing as far as possible the level of curtailment of renewable generation. The driver of forecast energy export is currently daytime export of solar PV, which are based upon embedded load and solar irradiation forecasts.

In future, an increase in battery and electric vehicle to grid (V2G) storage, coupled with incentives from Aggregators and electricity retailers, will create different energy export drivers and the NMI energy flow forecasting algorithms will need to evolve to support these DCOA methods.

10 Next Steps

This report focused upon the development by the PACE group of UWA of a set of DCOA methods to efficiently and equitably allocate capacity. The DCOA can allocate capacity which is calculated by the Evolve solution through load flow modelling and adherence to thermal operating limits at the feeder and DT level.

As described in the report, the methods are conceptual and have been assessed using test data and rely upon NMI level forecasts with uncertain accuracy.

Further study into the following areas will be conducted during Symphony:

a) The DCOA methods have been tested using randomised NMI import and export data. Testing using actual AMI and network monitoring data and an electrical load flow simulation on a section of the Southern River Distribution Network (SNR540) is to be conducted by PACE to assess whether the methods are robust.

b) The DCOA methods are highly reliant upon the forecast energy flow data provided by the Evolve solution and other standing input data. PACE will conduct sensitivity testing of the DCOA methods against variations in accuracy of these forecasts based on pilot data to test the reliability of the methods.

c) The Evolve solution method 3 can provide NMI level DOEs which, for some LV networks, will differ from method 2 DOEs. Selected DCOA methods may be adapted to incorporate the local constraints affecting NMI level DOEs and compare their performance to the Evolve method 3, where relevant LV networks exist in the Southern River Distribution Network (SNR540).

Appendix A: DCOA Input and Output data

The following data will be used/produced by the DCOA. The reference source for this data is *"Project Symphony Data Requirements, Data Sources - Network model & Time series data" EDM#56924892*

Table 24 Network Asset Data

Data field	Reporting Frequency	Units	Data Collection Period
LV, MV conductor	Once only	Conductors – Length (m) and Type/characteristics (R + jX in Ohms) Spatial locations (latitude/longitude pairs) Thermal Rating (Amps)	Current at start of project
Distribution transformer	Once only	Nominal tap setting Impedance % Spatial locations (latitude/longitude pairs) Thermal Rating (Amps)	Current at start of project
Protection devices	Once only	Over-current Pickup Settings for Feeder Breaker, all fuse/breaker nominal rating (MV and LV)	Current at start of project
Electrical connectivity model including NMI	Once only	(node and branch)	Current at start of project
Connection point nodes	Once only	NMI Spatial locations (latitude/longitude pairs)	Current at start of project
Switches	Once only	Capacity/Rating Open points state (open/closed)	Current at start of project
Source impedance for all zone substations	Once only	Max, min - R+jX	Current at start of project
Voltage regulators	Once only	Type, tap steps, set point, impedance	Current at start of project
Embedded generators and other large scale DER	Once only	Type, NMI, Capacity (kW)	Current at start of project

Table 25 Customer Data

Data field	Reporting Frequency	Units	Data Collection period
Energy data history for all connection point	Once only	kWh	Interval metering (5 minute) where available, bi-monthly elsewhere
Consumption data non-AMI	Bi-monthly	kWh	Collection time: every second month (billing cycle) Sampling time: 2 months
Consumption data AMI (net import / export)	Daily	kWh	Collection time: every 4 hours Sampling time: every 30 min
Instantaneous data AMI	4 hourly	kWh (cumulative) instantaneous: Amps, Volts, kW, Power Factor	5-minute samples
Customer connection agreement Limit	Once only	Specified Maximum Demand (kW import/export) or Standing Offer Maximum demand (kW import/export) Number of Phases	Current at start of project, updated for major Customers or Network Battery
DER information for each connection point	Once only	Solar PV capacity (kW) Battery capacity (kW and kWh)	Current at start of project
Customer class	Once only	Residential, Commercial, Industrial	Current at start of project
Historical instantaneous power and voltage readings where available	Once only	P, Q, A and/or V	up to 1-minute
Current network tariff(s) for each connection point	Once only	Tariff Code	Current at start of project
DER Customer standing data for all customers	daily	Configuration of controllable assets NMI, Lat Long, Capacity (kW, kWh) Uncontrolled DER (kW, kWh)	N/A

Table 26 Network monitoring and forecast data

Data field	Reporting Frequency	Units	Data collection period
Zone substation feeder load	Near-real-time (less than 5min lag)	P, Q per phase or Amps, pf per phase 5 min average	5 minutes
Zone Substation bus voltage	Near-real-time (less than 5min lag)	Voltage per phase, 5 min average	5 minutes
Recloser SCADA measurements	Near-real-time (less than 5min lag)	P, Q per phase or Amps, pf per phase 5 min average	5 minutes
Voltage Regulator SCADA measurements	Near-real-time (less than 5min lag)	P, Q per phase or Amps, pf per phase Voltage per phase 5 min average	5 minutes
Transformer monitor SCADA or Sensor data	Near-real-time (less than 5min lag)[76]	P, Q per phase or Amps, pf per phase Voltage per phase 5 min average	5 minutes
Weather Forecast & Solar irradiance forecast	Near-real-time (less than 5min lag)	degrees (temperature, apparent temperature) % (cloud cover, humidity, rain probability) mm/hour (rainfall) ~1 hour interval forecast	24hrs
Load Forecasts	Near-real-time (less than 5min lag)	kW Location	24hrs

Table 27 Evolve DOE output data

Data field	Reporting Frequency	Units	Data collection period
Load forecast at NMI level based on historical and forecast data such as weather, PROA.	daily	Load forecast in watts (W) for both participating and non-participating NMIs	Daily initially and more frequently after that
Constraints at asset level based on load flow analysis using the load forecast data.	daily	Constraints expressed in % of max capacity of the assets. Values include import & export limit on both unrestricted and truncated DOE. Also, only for uncontrolled & total profile.	Daily initially and more frequently after that
Dynamic operating envelope (DOE) at NMI level based on load flow analysis and allocation method	daily	DOE in watts (W) for all participating NMIs. Export & import of both unrestricted & truncated limits	Daily initially and more frequently after that

[76] At the time of writing only delayed feeder load and voltage data is available.

Table 28 Operating Envelope Parameters

Field	Units	Description
Site		Site identifier
Publish time		Publish time of envelope (represented as date-time formatted string)
Start time		Start time of envelope (represented as date-time formatted string)
Duration		Integer representing duration (in seconds) of envelope
Site import limit	W	Per-site import limit across all phases
Site export limit	W	Per-site export limit across all phases (by load convention, export limit will be negative) *
Unconstrained import limit	W	Import limit ignoring site-specific constraints (e.g. firm capacity)
Unconstrained export limit	W	Export limit ignoring site-specific constraints (e.g. firm capacity)

Appendix B: Allocation Principles

Proposed DCOA 1 - Proportional Allocation (Inverter rating)

The following example illustrates this allocation principle:

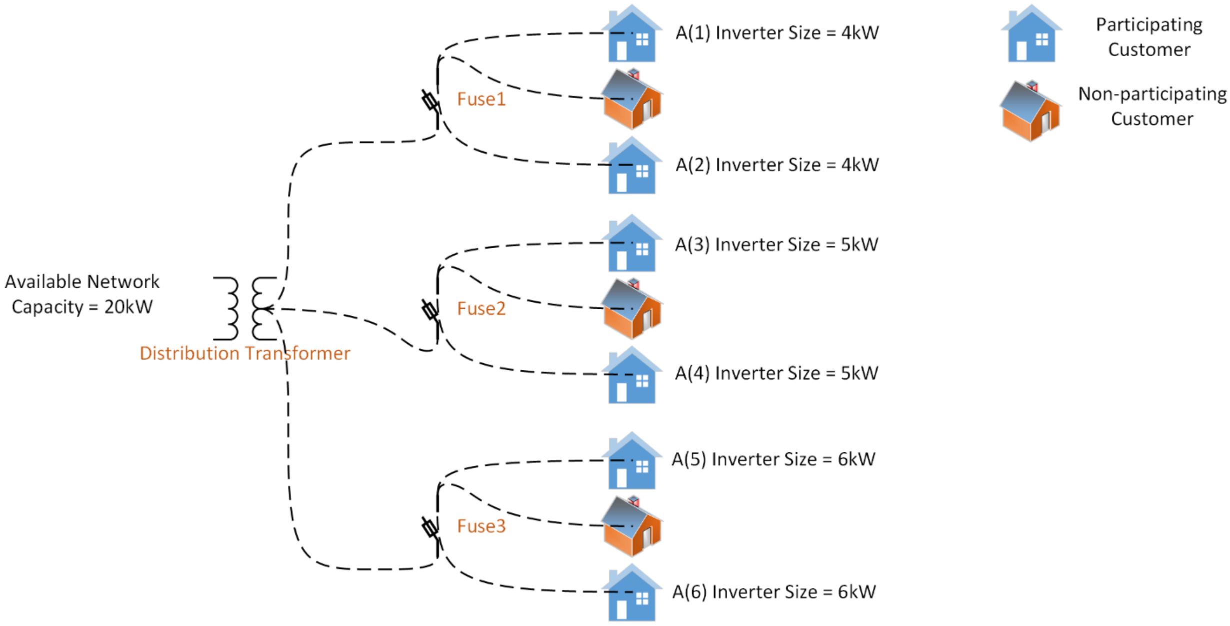

Figure 11 Proportional Allocation Based on the Inverter rating

Note: The values used in the example are arbitrary values that were considered by the authors.

Per Figure 11 there is an available network capacity of 20kW at the distribution transformer. First, each customer would receive the minimum capacity allocation of 1.5kW and then any remaining network capacity would be allocated proportionally based on their respective inverter ratings.

Allocating 1.5kW to each participating customer will utilise 9kW out of the 20kW available network capacity. The remaining 11kW (20-1.5kW*6) is allocated based on customer inverter rating. The overall capacity allocation process is shown in Table 29:

Table 29 Capacity Allocation Process of DCOA 1

Customer	Inverter Rating (kW)	Minimum Capacity Allocation (MCA) (kW)	Proportional Allocation Based on Inverter Rating (kW)	Final DOE (kW)
A1	4	1.5	$\frac{4}{30} * 11 = 1.47$	$1.5 + 1.47 = 2.97$
A2	4	1.5	$\frac{4}{30} * 11 = 1.47$	$1.5 + 1.47 = 2.97$
A3	5	1.5	$\frac{5}{30} * 11 = 1.83$	$1.5 + 1.83 = 3.33$
A4	5	1.5	$\frac{5}{30} * 11 = 1.83$	$1.5 + 1.83 = 3.33$
A5	6	1.5	$\frac{6}{30} * 11 = 2.2$	$1.5 + 2.2 = 3.7$
A6	6	1.5	$\frac{6}{30} * 11 = 2.2$	$1.5 + 2.2 = 3.7$

Proportion of allocation has been treated based on the size of inverter each customer has installed.

Proposed DCOA 2 - Proportional Allocation (Forecast Energy)

The following example illustrates this allocation principle:

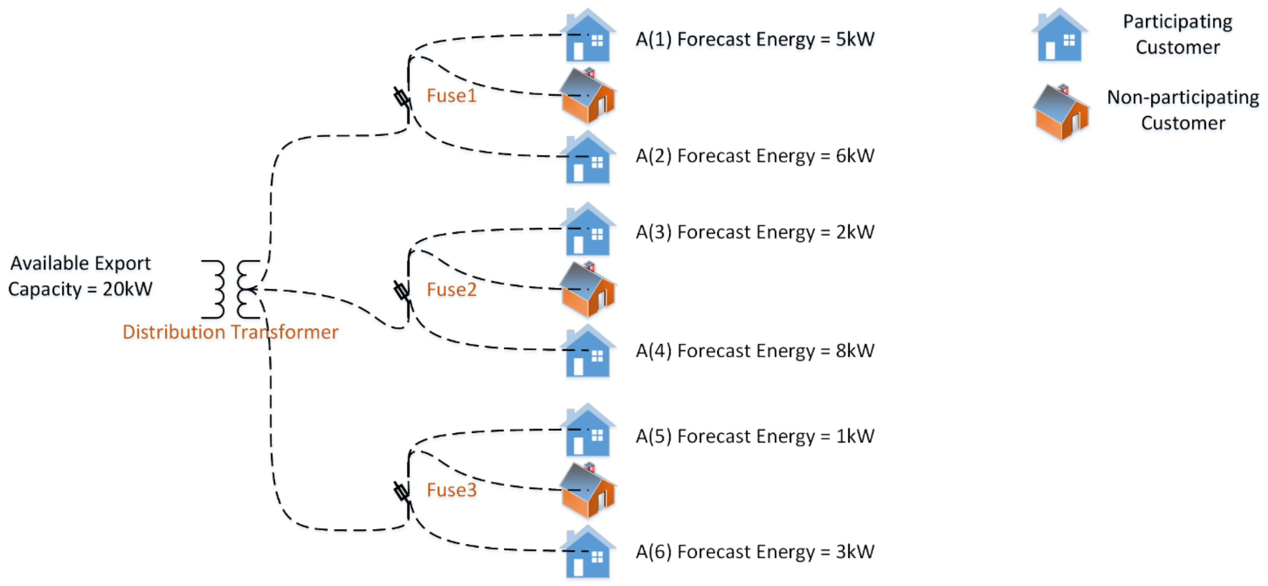

Figure 12 Proportional Allocation Based on the Forecast Export

Per Figure 12 there is an available network capacity of 20kW at the distribution transformer. First, each customer would receive the minimum between 1.5kW and their forecast energy as the minimum allocation capacity. Then the remaining network capacity (if remaining) would be allocated proportionally based on their respective forecast energy shortfall.

In this example, customer A5 can only receive capacity up to its forecast energy which is 1kW. Thus, the remaining network capacity after minimum capacity allocation is 11.5kW (20-1.5kW*5-1kW). The overall capacity allocation process is shown in Table 30:

Table 30 Capacity Allocation Process of DCOA 2

Customer	Forecast Export (FE, kW)	MCA (kW)	Forecast Shortfall (FS, kW)	Proportional Allocation Based on FS (kW)	Final DOE (kW)
A1	5	$\min(1.5, 5) = 1.5$	3.5	$\frac{3.5}{16.5} * 11.5 = 2.44$	$1.5 + 2.44 = 3.94$
A2	6	$\min(1.5, 6) = 1.5$	4.5	$\frac{4.5}{16.5} * 11.5 = 3.14$	$1.5 + 3.14 = 4.64$
A3	2	$\min(1.5, 2) = 1.5$	0.5	$\frac{0.5}{16{,}5} * 11.5 = 0.35$	$1.5 + 0.35 = 1.85$
A4	8	$\min(1.5, 8) = 1.5$	6.5	$\frac{6.5}{16.5} * 11.5 = 4.53$	$1.5 + 4.53 = 6.03$
A5	1	$\min(1.5, 1) = 1$	0	0	1
A6	3	$\min(1.5, 3) = 1.5$	1.5	$\frac{1.5}{16.5} * 11.5 = 1.05$	$1.5 + 1.05 = 2.55$

Proportion of allocation has been treated based on the customer forecast energy.

Proposed DCOA 3 - Weighted Allocation (Inverter Rating & Forecast Energy)

The following example illustrates this allocation principle:

In this example, three participating active customers (A1, A2 and A3) have been considered and the available network capacity at the distribution transformer was assumed to be 10kW. It is assumed that minimum capacity allocation (MCA) per customer is 1.5kW.

Table 31 Weighted Grading Allocation Example Iteration 1 and 2

Customer	Inverter rating (kW)	Self-Consumption (%)	Forecast Export (FE, kW)	Iteration 1 Allocation [Min (MCA, FE)]	Remaining FE	Final Score (1)	Iteration 2 Allocation (kW)
A1	3.5	80	0.7	0.7=min (0.7,1.5)	0	3*3=9	0
A2	8	40	4.8	1.5=min (4.8,1.5)	3.3	2*2=4	$\frac{4}{4+1} * 6.3 = 5.04$
A3	10	20	8	1.5=min (8,1.5)	6.5	1*1=1	$\frac{1}{4+1} * 6.3 = 1.26$

Notes to table: Final Score = Inverter Score * Self-Consumption Score (Table 7)

Iteration 1

At the beginning each customer would allocate the minimum of their forecast energy or the minimum export service level (i.e. 1.5kW).

At the end of first iteration following observations can be made referring to the above table:

- Customer A1 would fully utilise its forecast energy.
- Both A2 and A3 will have available export capacity of 3.3kW and 6.5kW respectively.
- Remaining network capacity will be 6.3kW (10kW-0.7kW-1.5kW-1.5kW)

Iteration 2

- Based on the Iteration 2, A1 did not receive any DOE allocation since it fully utilised its forecast energy during Iteration 1.
- A2 and A3 received 5.04kW and 1.26kW as their respective DOEs, however, A2 is only able to export up to 3.3kW (remaining forecast energy). This carried forward spare 1.74kW (5.04kW-3.3kW) to the next iteration.
- A3 was able to fully utilise the allocated 1.26kW since it still has a remaining forecast energy of 6.5kW.
- At the end of Iteration 2, both A1 and A2 have fully utilised their respective forecast energy. However, A3 is still left with forecast energy of 5.24kW (6.5kW-1.26kW) that can be further utilised in the next Iteration.

Iteration 3

- The spare network capacity of 1.74kW at the end of iteration 2 is allocated to A3 in Iteration 3. This ensured that available network capacity has been fully utilised at the end of 3 Iterations.

Observations at the end of each iteration are summarised in the following table:

Table 32 Weighted Grading Allocation Example Stage 2

Iteration	Customer	Calculated DOE (kW)	Forecast Export[1] (kW)		Spare capacity not addressed[2] (kW)
			Start of Iteration	End of Iteration	
1	A1	0.7	0.7	0	6.3
	A2	1.5	4.8	3.3	
	A3	1.5	8	6.5	
2	A2	5.04	3.3	0	1.74
	A3	1.26	6.5	5.24	
3	A3	1.74	5.24	3.5	0

Notes to table:

1) Positive value indicates customer is left with unutilised forecast energy (that could be exported to the grid)
2) Positive value indicates the network capacity of the grid (10kW) is not fully utilised

It can be concluded that in this method all the participating customers have been treated equally, where, both customer A1 and A2 were allowed to export up to their forecast energy. On the other hand, customer A3 was initially penalised for having a PV system greater than 10kW and only self-consuming 20% of the generation. At the end of the calculations A3 enjoyed total exports of 4.5kW. This shows that considering both the system capacity size and the self-consumption allows full utilisation of the available network capacity.

Proposed DCOA 4 - Multistage Criteria Allocation

Under this arrangement the available network capacity is allocated to participating customers in the order of: (1) up to the minimum capacity allocation (2) allocate up to the forecast energy (prioritise based on individual self-consumption rates) (3) allocate up to the forecast energy (prioritise based on individual inverter sizes) (4) up to the inverter size and (5) expansion above inverter capacity.

The following example details how this allocation principle works:

In this example, three participating active customers (A1, A2 and A3) have been considered and the available network capacity at the distribution transformer was assumed to be 10kW.

Table 33 Multistage Criteria Allocation Example

Customer	Inverter rating (kW)	Self-Consumption (%)	Export (%)	Forecast Export (kW)
A1	3.5	80	20	0.7
A2	8	40	60	4.8
A3	10	20	80	8

Iteration 1
As per the introduced in Section 7.1.2.2, minimum export service level is set to 1.5kW irrespective of customer inverter rating and phase. Calculate DOE-1 for each participating customer:

$$DOE(1)_{A1} = \text{Min}(0.7, 1.5) = 0.7\text{kW}$$
$$DOE(1)_{A2} = \text{Min}(4.8, 1.5) = 1.5\text{kW}$$
$$DOE(1)_{A3} = \text{Min}(8, 1.5) = 1.5\text{kW}$$

After iteration 1, A1 fully utilised its forecast energy (0.7kW), A2 and A3 are still left with 3.3kW (4.8-1.5=3.3kW) and 6.5kW (8-1.5=6.5kW) that can be exported to the grid. The remaining network capacity after iteration 1 is 6.3kW (10-0.7-1.5-1.5=6.3kW) which will be allocated afterwards.

Iteration 2
The weighted allocation based on forecast energy and self-consumption rate is used to assign the unallocated network capacity (6.3kW) in this stage. Calculate DOE-2 for each participating customer:

$$DOE(2)_{A1} = \text{Min}\left(0.7, 0.7 + \frac{0 \times 80\%}{0 \times 80\% + 3.3 \times 40\% + 6.5 \times 20\%} \times 6.3\right) = 0.7\text{kW}$$
$$DOE(2)_{A2} = \text{Min}\left(4.8, 1.5 + \frac{3.3 \times 40\%}{0 \times 80\% + 3.3 \times 40\% + 6.5 \times 20\%} \times 6.3\right) = 4.7\text{kW}$$
$$DOE(2)_{A3} = \text{Min}\left(8, 1.5 + \frac{6.5 \times 20\%}{0 \times 80\% + 3.3 \times 40\% + 6.5 \times 20\%} \times 6.3\right) = 4.6\text{kW}$$

No further capacity is allocated to customer A1, A2 and A3 can export another 3.2kW (4.7-1.5=3.2kW) and 3.1kW (4.6-1.5=3.1kW) respectively. After iteration 2, three customers are left with 0kW, 0.1kW (4.8-4.7=0.1kW) and 3.4kW (8-4.6=3.4kW) that can be exported. The overall available network capacity (10kW) is fully allocated after iteration 2.

Iteration 3

Although there is no network capacity left in this case, to demonstrate the versatility of the allocation method, we will continue to elaborate on other criteria. In criteria 3, a weighted allocation method which considers forecast energy and inverter rating is utilised. Calculate DOE-3 for each participating customer:

$$DOE(3)_{A1} = \text{Min}\left(0.7{,}0.7 + \frac{0 \times 3.5}{0 \times 3.5 + 0.1 \times 8 + 3.4 \times 10} \times 0\right) = 0.7\text{kW}$$
$$DOE(3)_{A2} = \text{Min}\left(4.8{,}4.7 + \frac{0.1 \times 8}{0 \times 3.5 + 0.1 \times 8 + 3.4 \times 10} \times 0\right) = 4.7\text{kW}$$
$$DOE(3)_{A3} = \text{Min}\left(8{,}4.6 + \frac{3.4 \times 10}{0 \times 3.5 + 0.1 \times 8 + 3.4 \times 10} \times 0\right) = 4.6\text{kW}$$

Iteration 4

If there is remaining network capacity after the first three iterations, the capacity will be allocated up to the inverter capacity weighted by inverter shortfall. Calculate DOE-4 for each participating customer:

$$DOE(4)_{A1} = \text{Min}\left(3.5{,}0.7 + \frac{3.5 - 0.7}{(3.5 - 0.7) \times (8 - 4.7) \times (10 - 4.6)} \times 0\right) = 0.7\text{kW}$$
$$DOE(4)_{A2} = \text{Min}\left(8{,}4.7 + \frac{8 - 4.7}{(3.5 - 0.7) \times (8 - 4.7) \times (10 - 4.6)} \times 0\right) = 4.7\text{kW}$$

$$DOE(4)_{A3} = \text{Min}\left(10{,}4.6 + \frac{10 - 4.6}{(3.5 - 0.7) \times (8 - 4.7) \times (10 - 4.6)} \times 0\right) = 4.6\text{kW}$$

Iteration 5

If there is still network capacity spare after iteration 4, the remaining capacity will be equally allocated to all customers up to the maximum capacity allocation, set to 15kW in this case. Calculate DOE-5 for each participating customer:

$$DOE(5)_{A1} = \text{Min}\left(15{,}0.7 + \frac{0}{3}\right) = 0.7\text{kW}$$
$$DOE(5)_{A2} = \text{Min}\left(15{,}4.7 + \frac{0}{3}\right) = 4.7\text{kW}$$
$$DOE(5)_{A3} = \text{Min}\left(15{,}4.6 + \frac{0}{3}\right) = 4.6\text{kW}$$

Overall, in this example, the available network capacity (10kW) is fully allocated within the first two iterations. This means the allocation procedure will stop after running iteration 2. Nonetheless, it is worth noting that when the network capacity increases, such as 12kW, the capacity allocation will run up to iteration 3. Furthermore, the main aim of iteration 4 is to provide a signal to Aggregators there is spare capacity which will enable concurrent export from other DER sources (such as BESS or EV) to the grid. In addition, iteration 5 will provide a signal for customers to assist sizing for installation of upgraded systems if there is network capacity left. In summary, this allocation method supports the operator to manage the effect of different factors on capacity allocation.

Appendix C: Pseudo Codes for DCOA Algorithms

The following definitions are applicable for the pseudo codes introduced for all four DCOA methods.

Term	Definition
AC	Active Customers
ACFS	Active Customers Forecast Shortfall
DTNC	Distribution Transformer Network Capacity
FE	Forecast Export
FS	Forecast Shortfall
FSIS	Forecast Shortfall and Inverting Sizing (Weighted Allocation)
FSSC	Forecast Shortfall and Self-consumption (Weighted Allocation)
IS	Inverter Size
MEC(1P)	Maximum Export Capacity of Single Phase NMI
MEC(3P)	Maximum Export Capacity of Three Phase NMI
MESL	Minimum Export Service Level
PC	Passive Customers
PCFE	Passive Customers Forecast Export
PR	Phase Ratio
PSS	PV Size Shortfall
SC	Self-consumption
SNC	Spare Network Capacity
TFESCA	Total Allocation Capacity based on Forecast Export and Self-consumption
TFSISA	Total Allocation Capacity based on Forecast Shortfall and Inverter Sizing
TICA	Total Allocation Capacity based on Inverter Capacity
TMCA	Total Minimum Capacity Allocation under DT

The determination of the number of iterations and number of calculations required under each iteration is based on the following assumptions:

1. The coding is assumed to be most efficient.
2. The calculations only need to be calculated periodically are excluded. For example, the grading score in DCOA 3 would only calculate once periodically, not calculating at each interval when DOE is calculated.
3. The calculations for passive NMIs are excluded. This is because the calculation process for non-participating NMIs is necessary for each DOE method. Thus, the impact of the calculation on scalability can be neglected when comparing methods.
4. It is assumed that DCOA3 can fully allocate the available network capacity within three iterations, this assumption is based on the test cases presented in this report. If required, the number of iterations can be adjusted based on the actual scale of the network.
5. For DCOA 4, it is assumed that the iteration will run up to three times as well. This is based on the test cases presented in this report.

Proposed DCOA 1 - Proportional Allocation (Inverter rating)

Line	Statement	NMI Iteration	Active NMI Calculation
	%Zero Variables		
1	PCFE = 0		
2	Total_IS = 0		
3	TCMA = 0		
4	for each DT		
5	for each NMI under a DT		
6	if non-participating_NMI	1	
	%Total forecast energy of passive customers		
8	PCFE = PCFE + FE of NMI		
9	elseif participating NMI		
	%Summation of active customer PV inverter sizes		
10	Total_IS = Total_IS + IS of NMI		
	%Minimum capacity allocation		
11	DOE_Initial = min[FE,MESL]		1
12	TMCA = TMCA + DOE_Initial(NMI)		1
13	end		
14	end		
	%Spare network capacity for each DT		
15	SNC = [DTNC - (PCFE + TMCA)]		
	%Spare network capacity allocated to each NMI		
16	if SNC > 0		
17	for each NMI under a DT		
18	if participating NMI	1	
19	DOE_Updated = DOE_Initial + SNC*(IS of NMI/Total_IS)		1
20	end		
21	end		
22	end		
23	end		
Summation		**2**	**3**

Proposed DCOA 2 - Proportional Allocation (Forecast Energy)

Line	Statement	NMI Iteration	Active NMI Calculation
	%Zero Variables		
1	PCFE = 0		
2	Total_IS = 0		
3	TCMA = 0		
4	ACFS = 0		
5	for each DT		
6	for each NMI under a DT		
7	if non-participating_NMI	1	
	%Total forecast energy of passive customers		
8	PCFE = PCFE + FE of NMI		
9	elseif participating NMI		
	%Minimum capacity allocation		
11	DOE_Initial = min[FE,MESL]		1
12	TMCA = TMCA + DOE_Initial(NMI)		1
	FS = FE - DOE_Initial		1
	ACFS = ACFS + FS		1
13	end		
14	end		
	%Spare network capacity allocated to each NMI		
12	SNC = DTNC - (PCFE + TMCA)		
	%Spare network capacity allocated to each NMI		
	if SNC > 0	1	
	for each NMI under a DT		
13	if participating NMI		
14	DOE_Updated = DOE_Initial + [(FS of NMI/ACFS)*SNC]		1
	end		
	end		
18	end		
19	end		
Summation		**2**	**5**

Proposed DCOA 3 - Weighted Allocation (Inverter Rating & Forecast Energy)

Line	Statement	NMI Iteration	Active NMI Calculation
	%Zero Variables		
1	PCFE = 0		
2	Total_IS = 0		
3	TCMA = 0		
4	SUM_GT = 0		
5	for each DT		
6	for each NMI under a DT		
7	if non-participating_NMI	**1**	
	%Total forecast energy of passive customers		
8	PCFE = PCFE + FE of NMI		
9	elseif participating NMI		
	%Minimum capacity allocation		
10	DOE_Initial = min[FE,MESL]		**1**
11	DOE_Updated = DOE_Initial		
12	TMCA = TMCA + DOE_Initial(NMI)		**1**
13	G1 = Define NMI score based on inverter sizing		
14	G2 = Define NMI score based on forecast energy		
15	GT = G1*G2		
16	SUM_GT = SUM_GT + GT		
17	end		
18	end		
	%Spare network capacity allocation		
19	SNC = DTNC - (PCFE + TMCA)		
	% Spare network capacity allocated to each NMI		
20	While SNC > 0 Loop	**2**	
22	for each NMI under a DT		
23	if participating NMI AND [FE for NMI- (DOE_Updated)]>0		**2**
25	DOE_Updated = DOE_Initial + SNC * (GT / Sum_GT)		**2**
26	SNC = SNC - [SNC * (GT/Sum_GT)]		**2**
27	else		
28	DOE_Updated = DOE_Initial		
29	end		
30	end		
31	end		
32	end		
Summation		**3**	**8**

Notes to pseudo code table:
1) The number 2 in the "NMI iteration" column implies that the second iteration starting at line 20 will run twice.
2) The active NMI calculations in lines 23 to 25 are doubled because the second iteration starting at line 20 will run twice.

Proposed DCOA 4 - Multistage Criteria Allocation

Line	Statement	NMI Iteration	Active NMI Calculation
	%Zero Variables		
1	PCFE = 0		
2	Total_IS = 0		
3	TMCA = 0		
4	TFESCA = 0		
5	TFSISA = 0		
6	TICA = 0		
7	SNC = 0		
8	SUM_FSSC = 0		
9	SUM_FSIS = 0		
10	SUM_PSS = 0		
11	for each DT		
12	for each NMI under a DT	**1**	
13	if non-participating_NMI		
	%Total forecast energy of passive customers		
14	PCFE = PCFE + FE of NMI		
15	elseif participating NMI		
	%Minimum capacity allocation (criteria 1)		
16	DOE_criteria1 = min[FE,MESL]		**1**
17	TMCA = TMCA + DOE_criteria1		**1**
	%Complete required calcs for next 'round'		
18	FS = FE - DOE_criteria1		**1**
19	FSSC = FS*SC		**1**
20	SUM_FSSC = SUM_FSSC+ FSSC		
21	end		
22	end		
	%Spare network capacity calculation		
23	SNC = DTNC - (PCFE + TMCA)		
	%Allocation Criteria 2		
24	if SNC > 0		
25	for each NMI under a DT	**1**	
26	if participating NMI		
27	DOE_criteria2 = min(FE,DOE_criteria1+[FSSC for NMI/SUM_(FSSC)]*SNC)		**1**
28	TFESCA = TFESCA + DOE_criteria2		**1**
	%Complete required calcs for next 'round'		
29	FS = FE - DOE_criteria2		**1**
30	FSIS = FS * IS		**1**

Line	Statement	NMI Iteration	Active NMI Calculation
31	SUM_FSIS = SUM_FSIS + FSIS		
32	end		
33	end		
34	else		
35	DOE_criteria2 = DOE_criteria1		
36	end		
	%Spare network capacity calculation		
37	SNC = DTNC - (PCFE + TFESCA)		
	%Allocation Criteria 3		
38	if SNC > 0		
39	for each NMI under a DT	1	
40	if participating NMI		
41	DOE_criteria3 = min(FE,DOE_criteria2 + ([FSIS for NMI/SUM_FSIS]*SNC)		1
42	TFSISA = TFSISA + DOE_criteria3		1
43	Calculate PSS		1
44	SUM_PSS = SUM_PSS + PSS for NMI		1
45	end		
46	end		
47	else		
48	DOE_criteria3 = DOE_criteria2		
49	end		
	%Spare network capacity allocation		
50	SNC = DTNC - (PCFE + TFSISA)		
	%Allocation Criteria 4		
51	if SNC > 0		
52	for each NMI under a DT	1	
53	if participating NMI		
54	DOE_criteria4=min(IS,DOE_criteria3+PSS for NMI/SUM_PSS*SNC)		1
55	TICA = TICA + DOE_criteria4		1
56	end		
57	end		
58	else		
59	DOE_criteria4 = DOE_criteria3		

Line	Statement	NMI Iteration	Active NMI Calculation
60	end		
	%Spare network capacity allocation		
61	SNC = DTNC - (PCFE + TICA)		
	%Allocation Criteria 5		
62	if SNC > 0		
63	for each NMI under a DT	1	
64	if participating NMI		
65	if NMI 1 Phase		
66	DOE_criteria5=min(MEC(1P),DOE_criteria4+PR/SUM(PR)* SNC)		1
67	else		
68	DOE_criteria5=min(MEC(3P),DOE_criteira4+PR/SUM(PR)* SNC)		
69	End		
70	End		
71	Else		
72	DOE_criteria5 = DOE_criteria4		
73	end		
74	end		
Summation		**3**	**12**

Notes to pseudo code table:

1) The summation of NMI iteration equals to 3 is because we assumed DCOA 4 will run for 3 iterations.
2) The active NMI calculations are limited to three iterations (since the algorithm only runs for three iterations).

Appendix D: Literature Review

Dynamic Limits DER Feasibility Study

Project Name	Dynamic Limits DER Feasibility Study
Partner Organisations	Dynamic Limits Pty Ltd, UniSA, SAGE Automation, Opto22
Status & Key Dates	Project Duration: 12/2018 - 08/2021
Locations	New South Wales, South Australia
Objectives	The purpose of the study is to investigate the feasibility of implementing dynamic DER export limits to increase the network hosting capacity and better manage voltage and thermal constraints on the distribution network.
Description	Currently, to prevent capacity limits from being exceeded, static limits, network augmentation and power quality response modes are normally adopted to constrain the energy exports from customer DERs. However, this will prevent the maximisation of renewable energy exports and as a result lower utilisation of network capacity. In this study, a Decentralised Dynamics Limit control scheme is proposed to support the concept of dynamic export limits, which would allow better management of thermal and voltage constraints of the distribution network.
Key findings	The Decentralised Dynamic Limits control scheme can provide a range of benefits for rural and remote networks, but not dense metropolitan networks. The use of network sensors and DER controllers to collect individual customer data can improve network visibility of DER behaviour and remove the reliance on network model. Customer equity issues are identified and addressed by adjusting the assigned Dynamic Limits Profile. The study demonstrates the control scheme could unlock more hosting capacity of the distribution networks.
References	https://arena.gov.au/projects/dynamic-limits-der-feasibility-study/ https://arena.gov.au/assets/2020/09/dynamic-limits-der-report.pdf

Advanced VPP Grid Integration

Project Name	Advanced VPP Grid Integration
Partner Organisations	SA Power Networks, Tesla Motors Australia, CSIRO
Status & Key Dates	Project Duration: 01/2019 - 06/2021
Locations	South Australia
Objectives	Design and build DSO-VPP interface and operating model for dynamic operating envelops. Develop a new hosting capacity forecasting system to generate DOE. Test the method in the real world and quantify the values.
Description	South Australia Power Networks (SAPN) recognised that Tesla's South Australia VPP project has presented a unique opportunity to integrate VPPs with the distribution network. This has enabled Tesla VPP sites to register electronically with SAPN, provide telemetry data, and receive dynamic export limits that reflect the actual export capacity available at their location as it varies over time. This project investigates how higher levels of dynamic DER exports can be enabled and compared with the static export limits.
Key findings	SAPN and Tesla have co-designed an Application Programming Interface (API) to support the data transmission between DSO and Aggregators. This project is the first of its kind to demonstrate how a real VPP actively participate in the market. The dynamic capacity profiles demonstrates that dynamic constraint management enables significant increases in average DER export capacity compared to the static limit of 5kW. The network capacity constraint estimates indicate that the DER hosting capacity is unlocked by adopting dynamic locational network limits.
References	https://arena.gov.au/?s=advanced+VPP+Grid+integration https://arena.gov.au/assets/2021/05/advanced-vpp-grid-integration-final-report.pdf https://arena.gov.au/assets/2021/01/analysis-of-the-vpp-dynamic-network-constraint-management.pdf

Project Evolve

Project Name	Evolve DER Project
Partner Organisations	Zeppelin Bend Pty Ltd, The ANU, Energy Queensland, Ergon Energy, Energex, Essential Energy, Endeavour Energy, Ausgrid, Reposit Power, Evergen, Redback Technologies, SwitchDIn, NSW Government
Status & Key Dates	Project Start: 02/2019
Locations	Australian Capital Territory, New South Wales, Queensland
Objectives	The aim of the Evolve DER Project is to increase the network hosting capacity of DERs by maximizing their participation in markets for energy, ancillary and network services. This is by ensuring the physical and operational limits of distribution networks are not violated.
Description	The evolve DER project focuses on the development of working software systems that will be integrated with the DOE calculation technologies used by DSO, and the systems used by Aggregators to determine the optimum operation of controllable DERs. In other words, the project will develop new algorithms and functions to identify and alleviate congestion in the distribution network. This is achieved by developing a calculation engine for operating envelops and investigating different allocation principles.
Key findings	The project demonstrates that more participating DER capacity can connect to the distribution network, which results in flexible DER export limits compared to the current static connection limits. The operating envelops can be updated and published as needed with respect to different operational use cases. The operating envelops can be deployed progressively into different segments of a distribution network. The operating envelops is easy to implement, and do not require the use of complicated local optimisation and control system.
References	https://arena.gov.au/projects/evolve-der-project/ https://arena.gov.au/assets/2020/10/using-the-cim-for-electrical-network-model-exchange.pdf https://arena.gov.au/assets/2020/09/on-the-calculation-and-use-of-dynamic-operating-envelopes.pdf

Project Flex

Project Name	SA Power Networks Flexible Exports for Solar PV Trial – Flex Project
Partner Organisations	SA Power Networks, AusNet Services, SwitchDin, Fronius, SMA, SolarEdge
Status & Key Dates	Project Start: 07/2020
Locations	Richmond, South Australia
Objectives	The aim of the Flex Project is to provide a flexible connection option for solar PV systems; thus, customers don't have to limit their systems with a permanent zero or near-zero export limits which required by Distribution Network Service Provider (DNSP) in congested networks.
Description	Currently, to avoid exceeding network technical limits, energy networks impose zero or near-zero energy export limits on new solar systems in congested areas. However, as more and more households install rooftop solar and network constraints increase, the number of new customers that face limits will keep increasing. This would result in an unfair treatment to the new customers compared to the early adopters of rooftop solar. This project introduces a new flexible option based on smart inverter technology, which allow the customers to export energy most of the time, and only reduce exports during specific periods when the network is constrained, thus maximising export capacity for everyone.
Key findings	The flexible exports remove the need for permanent zero or near-zero export settings, increasing the amount of renewable energy available to the market. The designed system will enable customers' inverters to automatically adjust their export limits every five minutes based on a locational, dynamic limit signal provided by DNSP. This work speeds up the process of integration of DERs into the network without costly network upgrades. The result demonstrates that the amount of renewable energy which can be accommodated to the distribution network could double.
References	https://arena.gov.au/projects/sa-power-networks-flexible-exports-for-solar-pv-trial/ https://arena.gov.au/assets/2021/01/flexible-exports-for-solar-pv-lessons-learnt-1.pdf

Project EDGE

Project Name	Victorian Distributed Energy Resources Marketplace Trial - EDGE Project
Partner Organisations	AEMO, Ausnet Electricity Services, Mondo Power, University of Melbourne
Status & Key Dates	Project Start: 08/2020
Locations	Melbourne, Victoria
Objectives	Demonstrate how aggregated DERs can participate in the existing and future wholesale market and operate within distribution network constraints. Demonstrate different ways to consider distribution network limits in the wholesale dispatch process. Demonstrate an efficient, secure, and scalable way to exchange data among project participants to support delivery of distributed energy service. Develop a detailed understanding of roles and specific responsibilities that each industry actor should play.
Description	"Energy Demand & Generation Exchange" (EDGE) project aims to demonstrate an off-market proof-of-concept DER marketplace for DER services. In here, consumers with DERs are facilitated to provide both wholesale and local network services within the distribution network constraints. In project EDGE a marketplace is created for DERs to be dispatched and traded as part of the National Electricity Market (NEM). Aggregators will utilise the customer's DERs to deliver electricity services within DER marketplace and provide incentives to the customers.
Key findings	Project EDGE is testing a DER marketplace concept that facilitates three core functions: wholesale integration of DER, data exchange and local services exchange. Project EDGE has a focus on operating envelope design which includes the design of digital architecture, the DOE calculation engine, and the allocation principles to be tested. The dynamic limits help DSOs ensure the network integrity while allowing participating customers to make the most of their DER assets.
References	https://arena.gov.au/projects/victorian-distributed-energy-resources-marketplace-trial/ https://arena.gov.au/assets/2021/05/project-edge-lessons-learned-report-1.pdf https://aemo.com.au/-/media/files/initiatives/der/2021/edge-factsheet.pdf?la=en

Appendix E: System Capacities for Basic Embedded Generators

The following tables are excerpts from Table 4.1 and 4.2 of the *Basic EG Connection Technical Requirements*

Table 34 Maximum System Capacities for Large Network Category

Connection Service	Basic EG System Phase	Maximum Basic EG System Capacity			Export Limit (3)(4)
		Single Energy Source	DC Coupled with BESS (1)	AC Coupled with BESS (2)	
Single-phase	Single-phase	5kVA	5kVA	5kVA PV (or other energy source IES) and 5kVA BESS IES	5kW
Three-phase	Single-phase	3kVA	5kVA	3kVA PV (or other energy source IES) and 5kVA BESS IES	5kW
Three-phase	Three-phase	15KVA	15kVA	15kVA PV (or other energy source IES) and 15kVA BESS IES (up to 5kVA per phase)	1.5kW except where PV (or other energy source IES) capacity ≤ 5kVA then 5kW export limit

Table 35 Maximum System Capacities for Small Network Category

Connection Service	Basic EG System Phase	Maximum Basic EG System Capacity			Export Limit (3)(4)(5)
		Single Energy Source	DC Coupled with BESS (1)	AC Coupled with BESS (2)	
Single-phase rural	Single-phase	5kVA	5kVA	5kVA PV (or other energy source IES) and 5kVA BESS IES	3kW
Two-phase rural	Single-phase	1.5kVA	5kVA	1.5kVA PV (or other energy source IES) and 5kVA BESS IES	1.5kW
Two-phase rural (≤ 10kVA transformers)	Two-phase (two single-phase inverters)	6kVA (3kVA per phase)	6kVA (3kVA per phase)	6kVA PV (or other energy source IES) and 6kVA BESS IES (3kVA per phase)	1.5kW
Three-phase	Single-phase	3kVA	5kVA	3kVA PV (or other energy source IES) and 5kVA BESS IES	3kW
Three-phase rural	Three-phase	10KVA	10kVA	10kVA PV (or other energy source IES) and 10kVA BESS IES (up to 5kVA per phase)	1.5kW except where PV (or other energy source IES) capacity ≤ 3kVA then 3kW export limit

Notes to table:

1. DC coupled refers to multiple energy sources (including Energy Storage systems) into a single inverter on the DC side of the inverter.
2. AC coupled refers to systems with multiple Inverters for various energy sources (commonly PV) and energy storage systems. AC coupled systems may also have generation limit control requirements.
3. For systems where export limit is equal to or greater than the system capacity no control based on external measurement is required
4. Listed Export limits are based on the most common small network connection arrangements, for example single-phase and two-phase rural are typically connected to 10 kVA transformers. For these small networks the export limit may be decreased/increased as a result of the technical studies
5. Where a User does not have an off-take agreement with their energy retailer their basic EG system shall have an export limit setting of no more than 1.5kW.

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Appendix F: Performance by Scenario

Scenario 1 (Feeder Rating is above the sum of DT ratings) Method Performance

Table 36 Scenario 1 Method Performance (Normalisation of required parameters)

			Results					
Metric	**Beneath a DT or Feeder**	**Weight**	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	DT 1	5%	90%	98%	100%	100%	100%	100%
	DT 2	5%	92%	100%	100%	100%	100%	100%
	DT 3	5%	97%	95%	100%	100%	100%	100%
	DT 4	5%	91%	98%	100%	100%	100%	100%
Forecast Energy Supported (FES)	Feeder	20%	96%	99%	100%	100%	100%	100%
Scalability	Feeder	5%	100%	69%	45%	40%	10%	0%
Reliability	Feeder	15%	100%	90%	90%	70%	80%	70%
Allocation Fairness (AF)	Feeder	10%	85%	95%	100%	100%	100%	100%
MESL not met (NMIs)	Feeder	10%	0%	0%	0%	0%	0%	0%
Energy Buyback Cost	Feeder	10%	0%	100%	0%	0%	0%	0%
Environmental Impact (Emissions, kgCO2-e)	Feeder	10%	100%	33%	0%	0%	0%	0%
Weighted Average Performance (WAP)		**100%**	**86%**	**82%**	**96%**	**93%**	**92%**	**91%**

Scenario 2 (Feeder Rating is below the sum of DT ratings) Method Performance

Table 37 Scenario 2 Method Performance (Normalisation of required parameters)

Metric	Beneath a DT or Feeder	Weight	Results						
			Base Case (SOE)	EAM (DOE Reference)	DCOA 1 (Inverter rating)	DCOA 2 (Forecast Energy)	DCOA 3 (Weighted)	DCOA 4 (Multistage)
Allocation Efficiency (AE)	DT 1	5%	90%	95%	100%	100%	100%	100%
	DT 2	5%	92%	97%	100%	100%	100%	100%
	DT 3	5%	97%	95%	100%	100%	100%	100%
	DT 4	5%	91%	97%	100%	100%	100%	100%
Forecast Energy Supported (FES)	Feeder	20%	96%	98%	100%	100%	100%	100%
Scalability	Feeder	5%	100%	69%	45%	40%	10%	0%
Reliability	Feeder	15%	100%	90%	90%	70%	80%	70%
Allocation Fairness (AF)	Feeder	10%	85%	94%	100%	100%	100%	100%
MESL not met (NMIs)	Feeder	10%	0%	0%	0%	0%	0%	0%
Energy Buyback Cost	Feeder	10%	0%	100%	0%	0%	0%	0%
Environmental Impact (Emissions, kgCO2-e)	Feeder	10%	100%	52%	0%	0%	0%	0%
WAP		**100%**	**86%**	**80%**	**96%**	**93%**	**92%**	**91%**

Scenario 3 (Feeder Rating is equal to the sum of DT ratings) Method Performance

Table 38 Scenario 3 Method Performance (Normalisation of required parameters)

Metric	Beneath a DT or Feeder	Weight	Results: Base Case (SOE)	EAM (DOE Reference)	DCOA 1 (Inverter rating)	DCOA 2 (Forecast Energy)	DCOA 3 (Weighted)	DCOA 4 (Multistage)
Allocation Efficiency (AE)	DT 1	5%	90%	76%	90%	100%	100%	100%
	DT 2	5%	92%	80%	96%	100%	100%	100%
	DT 3	5%	109%	69%	82%	100%	100%	100%
	DT 4	5%	91%	64%	85%	100%	100%	100%
Forecast Energy Supported (FES)	Feeder	20%	98%	83%	93%	99%	100%	100%
Scalability	Feeder	5%	100%	69%	45%	40%	10%	0%
Reliability	Feeder	15%	100%	90%	90%	70%	80%	70%
Allocation Fairness (AF)	Feeder	10%	90%	81%	90%	100%	97%	97%
MESL not met (NMIs)	Feeder	10%	0%	0%	0%	0%	0%	0%
Energy Buyback Cost	Feeder	10%	0%	100%	51%	13%	11%	18%
Environmental Impact (Emissions, kgCO2-e)	Feeder	10%	25%	100%	49%	10%	10%	10%
WAP		**100%**	**90%**	**66%**	**81%**	**90%**	**90%**	**87%**

Scenario 4 (VPP First Movers) Method Performance

Table 39 Scenario 4 Method Performance (Normalisation of required parameters)

			Results						
Metric	**Beneath a DT or Feeder**	**Weight**	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	DT 1	5%	100%	100%	100%	100%	100%	100%
	DT 2	5%	73%	100%	100%	100%	100%	100%
	DT 3	5%	100%	100%	100%	100%	100%	100%
	DT 4	5%	100%	100%	100%	100%	100%	100%
Forecast Energy Supported (FES)	Feeder	20%	96%	100%	100%	100%	100%	100%
Scalability	Feeder	5%	100%	69%	45%	40%	10%	0%
Reliability	Feeder	15%	100%	90%	90%	70%	80%	70%
Allocation Fairness (AF)	Feeder	10%	84%	100%	100%	100%	100%	100%
MESL not met (NMIs)	Feeder	10%	0%	0%	0%	0%	0%	0%
Energy Buyback Cost	Feeder	10%	0%	0%	0%	0%	0%	0%
Environmental Impact (Emissions, kgCO2-e)	Feeder	10%	100%	0%	0%	0%	0%	0%
WAP		**100%**	**86%**	**97%**	**96%**	**93%**	**92%**	**91%**

Scenario 5 (VPP Early Uptake) Method Performance

Table 40 Scenario 5 Method Performance (Normalisation of required parameters)

			Results					
Metric	**Beneath a DT or Feeder**	**Weight**	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	DT 1	5%	97%	97%	100%	100%	100%	100%
	DT 2	5%	97%	84%	98%	100%	100%	100%
	DT 3	5%	91%	76%	89%	100%	100%	100%
	DT 4	5%	98%	93%	100%	100%	100%	100%
Forecast Energy Supported (FES)	Feeder	20%	98%	92%	98%	100%	100%	100%
Scalability	Feeder	5%	100%	69%	45%	40%	10%	0%
Reliability	Feeder	15%	100%	90%	90%	70%	80%	70%
Allocation Fairness (AF)	Feeder	10%	90%	84%	93%	100%	100%	100%
MESL not met (NMIs)	Feeder	10%	0%	0%	0%	0%	0%	0%
Energy Buyback Cost	Feeder	10%	0%	100%	33%	0%	0%	0%
Environmental Impact (Emissions, kgCO2-e)	Feeder	10%	31%	100%	30%	0%	0%	0%
WAP	**N/A**	**100%**	**95%**	**71%**	**88%**	**93%**	**92%**	**91%**

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Scenario 6 (VPP Mainstream) Method Performance

Table 41 Scenario 6 Method Performance (Normalisation of required parameters)

Metric	Beneath a DT or Feeder	Weight	Results: Base Case (SOE)	EAM (DOE Reference)	DCOA 1 (Inverter rating)	DCOA 2 (Forecast Energy)	DCOA 3 (Weighted)	DCOA 4 (Multistage)
Allocation Efficiency (AE)	DT 1	5%	90%	67%	85%	100%	100%	100%
	DT 2	5%	109%	68%	84%	100%	100%	100%
	DT 3	5%	115%	70%	87%	100%	100%	100%
	DT 4	5%	90%	71%	85%	100%	100%	100%
Forecast Energy Supported (FES)	Feeder	20%	100%	81%	91%	98%	100%	99%
Scalability	Feeder	5%	100%	69%	45%	40%	10%	0%
Reliability	Feeder	15%	100%	90%	90%	70%	80%	70%
Allocation Fairness (AF)	Feeder	10%	94%	82%	91%	100%	96%	96%
MESL not met (NMIs)	Feeder	10%	0%	100%	0%	0%	0%	0%
Energy Buyback Cost	Feeder	10%	0%	100%	60%	28%	12%	26%
Environmental Impact (Emissions, kgCO2-e)	Feeder	10%	25%	100%	62%	26%	26%	26%
WAP	**N/A**	**100%**	**86%**	**55%**	**78%**	**87%**	**88%**	**85%**

Scenario 7 (VPP Mature) Method Performance

Table 42 Scenario 7 Method Performance (Normalisation of required parameters)

			Results					
Metric	**Beneath a DT or Feeder**	**Weight**	**Base Case (SOE)**	**EAM (DOE Reference)**	**DCOA 1 (Inverter rating)**	**DCOA 2 (Forecast Energy)**	**DCOA 3 (Weighted)**	**DCOA 4 (Multistage)**
Allocation Efficiency (AE)	DT 1	5%	116%	68%	86%	100%	100%	100%
	DT 2	5%	154%	70%	94%	100%	100%	100%
	DT 3	5%	176%	78%	100%	100%	100%	100%
	DT 4	5%	142%	73%	94%	100%	100%	100%
Forecast Energy Supported (FES)	Feeder	20%	100%	62%	75%	78%	79%	79%
Scalability	Feeder	5%	100%	69%	45%	40%	10%	0%
Reliability	Feeder	15%	100%	90%	90%	70%	80%	70%
Allocation Fairness (AF)	Feeder	10%	100%	85%	90%	91%	90%	89%
MESL not met (NMIs)	Feeder	10%	0%	100%	47%	31%	47%	29%
Energy Buyback Cost	Feeder	10%	0%	100%	70%	63%	59%	66%
Environmental Impact (Emissions, kgCO2-e)	Feeder	10%	16%	100%	76%	68%	68%	68%
WAP	**N/A**	**100%**	**78%**	**52%**	**69%**	**71%**	**70%**	**69%**

Appendix G: Glossary of Terms

Abbreviations and Terms

Abbreviations used in this report are notated in UPPERCASE and their unabbreviated meaning is provided in the List of Abbreviations below. Words with specific meaning are Capitalised.

Term	Definition
Active NMI	A meter identified by its unique *National Metering Identifier* that has been recruited by the *Aggregator* to participate in *Project Symphony* as part of an approved *Facility*. The import and export of power from an Active NMIs may be constrained via a *Dynamic Operating Envelope*.
AC	Alternating Current
Active Customer	See *Active NMI*
Active Power	The actual power that is consumed or utilised within an AC Circuit. This is also known as real power and is measured in kilowatts (kW) or megawatts (MW).
Advanced Metering Infrastructure	Advanced Metering Infrastructure (AMI) typically includes smart meters (that measure bidirectional energy flows in shorter time intervals), upgraded communications networks (to transmit large volumes of data), and requisite data management systems.
AEMO	See *Australian Energy Market Operator*
AF	Allocation Fairness
AFEU	Average Forecast Energy Utilisation
Aggregator	A party which facilitates the grouping of DER to act as a single entity when engaging in power system markets (both wholesale and retail) or selling services to the system operator(s).
Aggregator Platform	The platform that will be developed by the *Aggregator* under *Project Symphony* to support *Aggregator* operations and processes.
AMI	See *Advanced Metering Infrastructure*
ANU	Australian National University
API	Application Programming Interface
ARENA	See *Australian Renewable Energy Agency*
Australian Energy Market Operator	AEMO manages Australia's electricity and gas markets including operating the systems for energy transmission, and the energy financial markets. Note: AEMO manages the WEM separately to the NEM, under different rules, funding, and governance structures. Australian Energy Market Operator will be undertaking the role of the *Distribution Market Operator* in *Project Symphony* and, as such, is responsible for development and delivery of the *DMO Platform*.
Australian Renewable Energy Agency	The Australian Government-funded agency whose purpose is to improve the competitiveness of renewable energy technologies and increase the supply of renewable energy through innovation that benefits Australian consumers and businesses.[77]
BESS	Battery Energy Storage System
BMO	See *Balancing Market Offer*

[77] About ARENA - Australian Renewable Energy Agency (ARENA), Australian Renewable Energy Agency website. *Last accessed 15/12/2012.*

Term	Definition
Business Requirement	High-level requirement based on a business need, the specification of which is solution agnostic. Business Requirements, once analysed and understood, can be refined into lower-level stakeholder and solution requirements.
CE	Curtailed Energy
CFE	Constrained Forecast Energy
Connection Capacity	The maximum amount of energy that can be safely consumed or generated at a Connection Point.
Connection Point	Network location which is electrically connected into the electricity system. A connection point may be metered (i.e., *Service Connection*) or unmetered (i.e., streetlight, traffic light etc.)
CSIRO	Commonwealth Science and Industry Research Organisation
DCOA	See *Distribution Constraints Optimisation Algorithm*
DER	See *Distributed Energy Resource*
Dispatch	Dispatch refers to the instructions from AEMO to generators delivering power to the system. Dispatch instructions are provided in the form of generation, timing, and ramp rate information. AEMO dispatches generation with consideration for the prices offered by generators, network limitations, and system requirements.
DCOA	See *Distributed Constraints Optimisation Algorithm*
DEBS	Distributed Energy Buyback Scheme
Distribution Constraints Optimisation Algorithm	The calculation of available network capacity that enables the publishing of the dynamic operating envelope in a given time interval for a given location within a segment of an electricity distribution network utilising a number of capacity allocation principles.
Distributed Energy Resource	Distributed Energy Resources or DER are smaller–scale devices that can use, generate, or store electricity and form a part of the local distribution system, which serves homes and businesses. DER can include renewable generation, energy storage, electric vehicles (EVs), and technology to manage load at the premises. These resources operate for the purpose of supplying all or a portion of the customer's electric load and may also be capable of supplying power into the system or alternatively providing a load management service for customers.[78]
Distribution Market Operator	The Distribution Market Operator (DMO) is a Market Operator that is equipped to operate a market that includes small-scale devices aggregated and able to be dispatched at appropriate scale.[79] The term is interchangeable with Market Platform.
Distribution Network Service Provider	Distributed Network Service Providers are the organisations that own and control the hardware of the distributed energy network such as power poles, wires, transformers, and substations that move electricity around the grid.
Distribution System Operator	A Distribution System Operator (DSO) enables access to the network, and securely operates and develops an active distribution system comprising networks, demand, and other flexible DER. Expanding the network planning and asset management function of a DNSP, the DSO

[78] Issues Paper - DER Roadmap: Distributed Energy Resources Orchestration Roles and Responsibilities, pg. 39.
[79] Ibid, pg. 39.

Term	Definition
	enables the optimal use of DER in *Distribution Networks* to deliver security, sustainability, and affordability in the support of whole system optimisation.[80]
Distribution Network	The parts of the electricity network that transport electricity at lower voltages to end-use customer *Connection Points* and *Service Connections*.
Distribution Transformer	A physical asset connected to the network for the purpose of transforming voltage prior to its distribution to downstream *Connection Points*.
DMO	See *Distribution Market Operator*
DMO Platform	The platform that will be developed by the *Distribution Market Operator* under *Project Symphony* to support *Distribution Market Operator* operations and processes.
DNSP	See *Distribution Network Service Provider*
DOE	See *Dynamic Operating Envelope*
DOE Calculator	A component of the *DSO Platform* that will be used to forecast load and allocate DOEs for *Active NMIs* based on network load analysis and forecasted *Network Constraints*.
DSO	See *Distribution System Operator*
DSO Platform	The platform that will be developed by the *Distribution System Operator* under *Project Symphony* to support *Distribution System Operator* operations and processes. The *Requirements* in this document describe the required capabilities of the *DSO Platform* sufficient to conduct the *Project Symphony Pilot*.
DT	See *Distribution Transformer*
Dynamic Operating Envelope	A Dynamic Operating Envelope (DOE) is a principled allocation of the available hosting capacity to individual or aggregate DER or connection points within a segment of an electricity distribution network in each time interval. A Dynamic Operating Envelope essentially provides upper and lower bounds on the import or export power in a given time interval for either individual DER assets or a connection point and may also apply at an upstream *Distribution Network* node.
EAM	Equal Allocation Method
EBC	Energy Buyback Cost
EDGE	Energy Demand and Generation Exchange
EG	Embedded Generator
Engineering Power Flow Data	Instantaneous measurement data collected at defined position on the network at a particular point in time that describes energy flow including the following variables: • Consumption (cumulative kWh) • Real power (kW) • Current (Amps) • Power Factor

[80] Ibid, pg.40

Term	Definition
	• Voltage This data can be used for both NMI level load forecasting as well as validating the DOEs dispatched to Aggregators. In the context of Project Symphony this will be referred to as PQ Data.
EPWA	Energy Policy WA
ESS	See *Essential System Service*
Essential System Service	A range of services designed to address or respond to deviations in system frequency.
ETAC	Energy Transfer Access Contract
EV	Means Electric Vehicle, cars or other vehicles with motors that are powered by electricity rather than liquid fuels.
Evolve	The ANU Battery Storage Grid Integration Program (BSGIP) has been contracted by Western Power to provide a Dynamic Operating Envelope (DOE) Solution as part of the broad Project Symphony program.
EWB	Energy Work Bench
FE	Forecast Energy
Feeder	A circuit emanating from a Zone Substation that is energised at Medium Voltage.
FEU	Forecast Energy Utilisation
Flex	Flexible Exports for Solar PV project
Hosting Capacity	DER hosting capacity is defined as the typical amount of DER that can be connected to a *Distribution Network* without requiring network augmentation while the network remains within its technical limits.
LV	Means Low Voltage. Distribution level 415V three-phase and 240V single-phase.
Market Platform	See *Distribution Market Operator*
Market Service	Services provided by a *Facility* and *Dispatched* under instruction from the DMO. Market Services include BMO electricity storage and generation, *Network Support Services* (NSS), and *Essential System Services* (ESS).
MCA	Minimum Capacity Allocation
MESL	Minimum Export Service Level
MESLC	Minimum Export Service Level Compliance
MV	Means Medium Voltage. Distribution level 33kV, 22kV, 11kV and 6.6kV.
National Electricity Market	A wholesale market through which generators and retailers trade electricity in Australia's six eastern and southern states and territories (not Western Australia and the Northern Territory), and the power system that interconnects these regions. The NEM delivers around 80% of all electricity consumption in Australia.
National Metering Identifier	The National Metering Identifier (NMI) is a unique 10- or 11-digit number used to identify an electricity network connection point in Australia.
NEM	See *National Electricity Market*
Network Constraint	When a section of an electricity network approaches its technical limits.

Term	Definition
Network Model	A data representation of objects, their relationships, and any distinguishing feature. For Project Symphony, the Network Model will represent the MV and LV electricity network downstream of the *Feeder* identified as SNR540.
Network Support Service	A contracted service provided by a generator / retailer / demand side program / DER *Aggregator* to help manage network limitations on the LV network. Services relieving *Transmission Network Constraints* are provided under the Non-Co-optimised *Essential System Services* framework.
NSS	See *Network Support Service*
NMI	See *National Metering Identifier*
NMI Status	The NMI Status determines whether a NMI is participating in *Project Symphony* and, thus, may be allocated a *Dynamic Operating Envelope*, or if the NMI is a non-participant and therefore is operating within a predetermined, defined operating envelope (currently set at 5kW generation and 15kW import).
OpEN	Means Open Energy Network, a joint consultation launched by *the Australian Energy Market Operator* and Energy Networks Australia seeking stakeholder input on how best to integrate *Distributed Energy Resources* into the electricity grid.
Operating Envelope	An Operating Envelope is the DER or Connection Point power transfer that can be accommodated before electrical limits of a Distribution Network are at risk of being breached. See also *Dynamic Operating Envelope.*
Operating Authority	The division or group responsible for a part of a network. Only one Operating Authority can be accountable for the operation of a network. This includes alarm management, real-time intervention, authorising access, and interaction with authorised personnel. The Network Operations team of *Western Power* is the Operating Authority for the electricity network encompassing the *Pilot Area*.
Outage	A network or localised issue that resulted in one or more Service Connections being unable to access the network. An Outage may either be planned or unplanned, and relate to the past, present and (in the case of planned outages) the future.
PACE	Power and Clean Energy
Passive NMI	A meter that is uniquely identified via a *National Metering Identifier* that is within the *Project Symphony Pilot Area* but which has not been recruited by an *Aggregator* and, thus, whose operations will not be managed using a *Dynamic Operating Envelope*. The operation of these NMIs will be as per the rules when the service was connected, which normally means a *Static Operating Envelope* with a 5kW generation and a 15kW consumption limit.
Photovoltaic	A photovoltaic (PV) cell, commonly called a solar cell, is a nonmechanical device that converts sunlight directly into electricity.
Pilot	The pilot project is an initial small-scale implementation that is used to prove the viability of a project idea. This could involve either the exploration of a novel new approach or idea or the application of a standard approach recommended by outside parties, but which is new to the organisation.

Term	Definition
	The pilot study will confirm viability and scalability and enable proposed processes and procedures to be tested. It will confirm the appropriateness and safety of any tools proposed and also confirms that any working practices are safe and comply with organisational/statutory standards. It also enables the benefits to be tested and a more reliable investment appraisal to be created for the Project
(the) Project	See *Project Symphony*
Project Symphony	A project where customer *Distributed Energy Resources* will be orchestrated as a *Virtual Power Plant*.
PV	See *Photovoltaic*
REBS	Renewable Energy Buyback Scheme
Requirement(s)	Describes specific aspects, characteristics, capabilities, functions and services that may form part of a solution. Requirement statements contained in this document relate to the *DSO Platform*.
SAPN	South Australia Power Networks
Service Connection	A metered *Connection Point* that provides energy services to a customer. A *Connection Point* is uniquely identified by a *National Metering Number*.
SNR540	Refers to a specific Feeder located in the Southern River area near Perth, Western Australia. The Feeder identified as SNR540 will be used to define the boundaries of the *Pilot Area* for *Project Symphony*, with the *Distribution Transformer*, *NMI* and *DER* infrastructure that is connected downstream of SNR540 and the customers that use it with the scope of the Pilot.
SOE	See *Static Operating Envelope*
South West Interconnected System	South West Interconnected System (SWIS) is an electricity grid in the southwestern part of Western Australia. It extends to the coast in the south and west, to Kalbarri in the north and Kalgoorlie in the east.
Static Operating Envelope	A Static Operating Envelope is an allocation of the available hosting capacity to individual or aggregate DER or connection points within a segment of an electricity distribution network that is applies at any time and in any conditions. As such, it differs from a *Dynamic Operating Envelope*, in that is provides upper and lower bounds on the import or export power at any time, rather than for a prescribed time interval.
SWIS	See *South West Interconnected System*
Synergy	A provider of electricity and gas that supplies residential, business and industrial customers across Perth and Western Australia. Synergy will be undertaking the role of the *Aggregator* in *Project Symphony* and, as such, is responsible for the development and delivery of the *Aggregator Platform*.
Telemetry Data	The automated recording and transmission of data from remote sources into a central system in support of monitoring and analysis.
UWA	University of Western Australia
Virtual Power Plant	A Virtual Power Plant (VPP) broadly refers to an aggregation of distributed energy resources (such as decentralised generation, storage, and controllable loads) coordinated to deliver services for power system operations and electricity markets.

Term	Definition
VPP	See *Virtual Power Plant*
WEM	See *Wholesale Electricity Market*
Western Power	Western Power will be undertaking the role of the Distributed System Operator in Project Symphony and, as such, is responsible for development and delivery of the *DSO Platform*. Western Power will additionally be responsible for the installation and maintenance of a Grid Connected BESS to be used by *Project Symphony*. Western Power is also acting as the lead organisation accountable for the overall delivery of *Project Symphony*
Wholesale Electricity Market	Supplies electricity to the south-west of Western Australia via the South West Interconnected System.

Project Symphony
Our energy future

Appendix H: List of Tables and Figures

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