RACE for 2030
RELIABLE AFFORDABLE CLEAN ENERGY

N2 Fast track

Measuring and communicating network export service quality

Final Report

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Industry Report

Measuring and communicating network export service quality

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Acknowledgement of Country

The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters and culture and pay our respects to them, their cultures and to their Elders past, present, and emerging.

What is RACE for 2030?

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

Disclaimer

Executive summary

Background

The goal of this project was to develop and test metrics for understanding and communicating the quality of network export services received by owners of rooftop solar power systems and other 'distributed energy resources' (DER).[1] This report is the primary deliverable of a research project led by UTS in partnership with SA Power Networks and Essential Energy as part of the RACE for 2030 Cooperative Research Centre.

Distribution Network Service Providers (DNSPs) are responsible for connecting solar and other DERs to the network, setting limits on the size of systems and the amount of power that can be exported to the network, and managing the upstream capacity of the network. These are referred to as 'export services.'[2] Following on from the *Access, Pricing and Incentive Arrangements for Distributed Energy Resources*[2] rule change process, DNSPs are required to consider export services as part of their core services and to integrate them into planning and regulatory proposals while the Australian Energy Regulator (AER) is tasked with exploring the viability of a 'Service Target Performance Incentive Scheme' to incentivise improvement in export service quality. To facilitate these objectives, this project developed and tested a set of proposed performance metrics for understanding and communicating the quality of export services that customers are receiving or should expect to receive.

Applications of export service quality metrics

This project identified a series of applications of export service quality metrics, commonly referred to as 'use cases' in this report. These are grouped into three main categories:

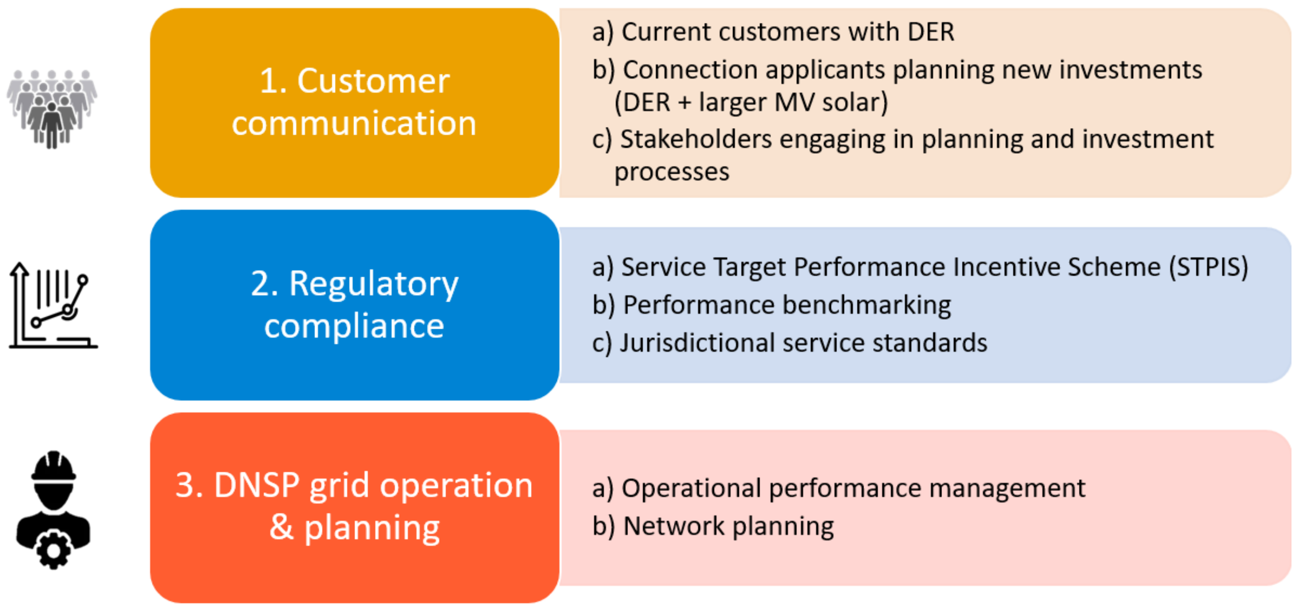
1. **Customer communication:** To allow DNSPs to engage with customers regarding the expected level of export services, network offerings and customer choices. More specific secondary categories that describe the customer or stakeholder types with different communication needs include current customers with DER, connection applicants planning new DER investments (or their industry representatives such as solar installers, retailers and aggregators) and broader stakeholder conversations regarding managing investments in export service quality.
2. **Regulatory compliance:** The Australian Energy Regulator (AER) is currently working towards monitoring, benchmarking and incentivising the quality of network export services. Metrics are required to support the setting of incentives for optimal quantity, cost, and quality of export services via a potential extension to the Service Target Performance Incentive Scheme (STPIS). Metrics are also required to:
    - bring export services into annual benchmarking reports that compare network productivity, and
    - underpin jurisdictional service standards that address inequitable customer export service outcomes.

[1] Increasingly called Customer Energy Resources (CER) in line with Energy Security Board communications. While the vast majority of metric applications considered in this report relate to rooftop solar PV, the metrics are also relevant to battery or other energy storage systems, electric vehicles and community-scale PV or other embedded generators.

[2] Australian Energy Market Commission (AEMC). (2021). Access, Pricing and Incentive Arrangements for Distributed Energy Resources. Rule Determination. 12 August 2021. https://www.aemc.gov.au/sites/default/files/2021-08/Final%20determination%20-%20Access%2C%20pricing%20and%20incentive%20arrangements%20for%20DER.pdf

3. **DNSP grid operation and planning:** Metrics are required to monitor and improve operational performance and to support the development of business cases for export service quality maintenance or improvement projects.

The metric applications (use cases) are summarised in the image below.



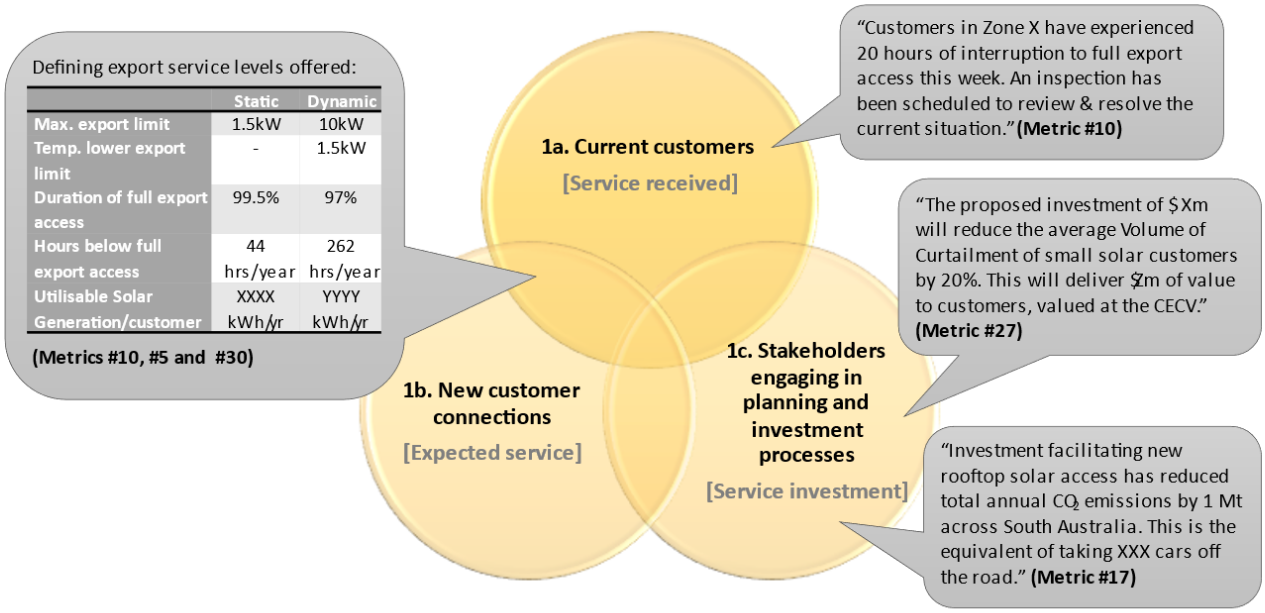
Metric examples by application

Drawing on industry and academic literature, an initial long list of 26 potential metrics was distilled via industry reference group feedback over a series of four workshops into a final shortlist of four proposed 'headline' and three 'supporting' metrics. The application of each metric was considered across a specific set of the above applications. Some metrics were applied to multiple use cases using different formats, and most use cases required several metrics to sufficiently describe export service quality for that application.

The graphics below illustrate a selection of key contextual examples covering the three primary use-case categories.

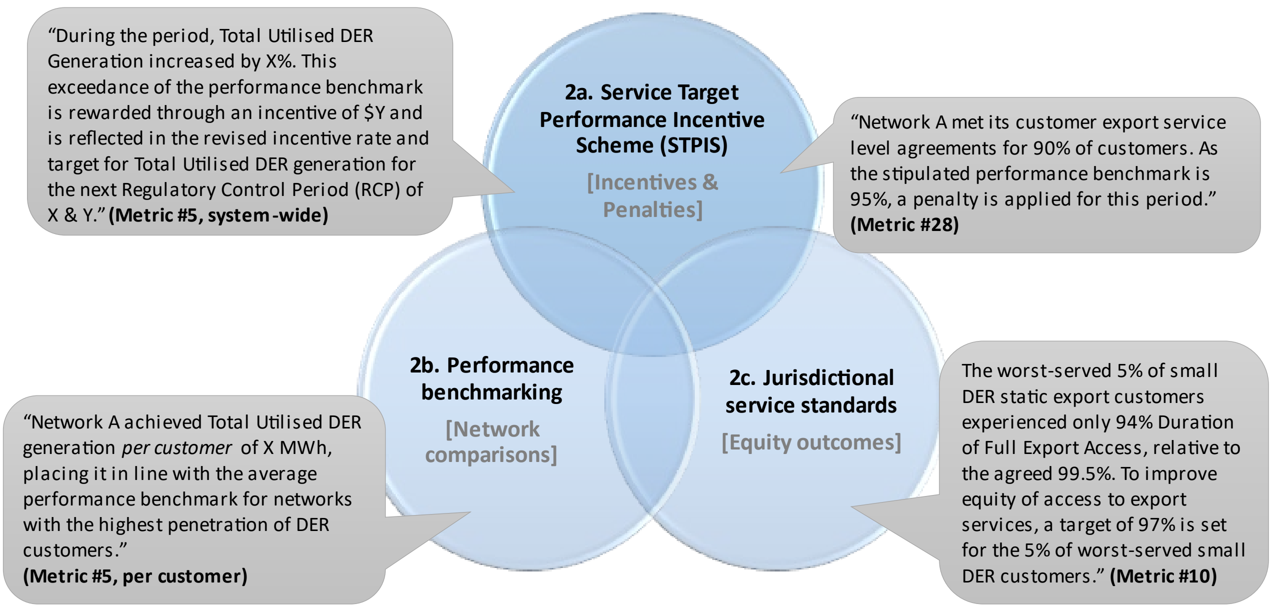
For current customers with DER, communications are mostly about the level of export service being received. This has an operational dimension in communicating the export service implications of abnormal network operating conditions and a product choice dimension. Both customers currently with DER, and customers seeking new DER connections require a clear understanding of export service options such as static versus dynamic export limits. Stakeholder engagement regarding export service investments is primarily through an understanding of the magnitude and value of improvement in volume of curtailment.

1. Customer Communication Use Cases

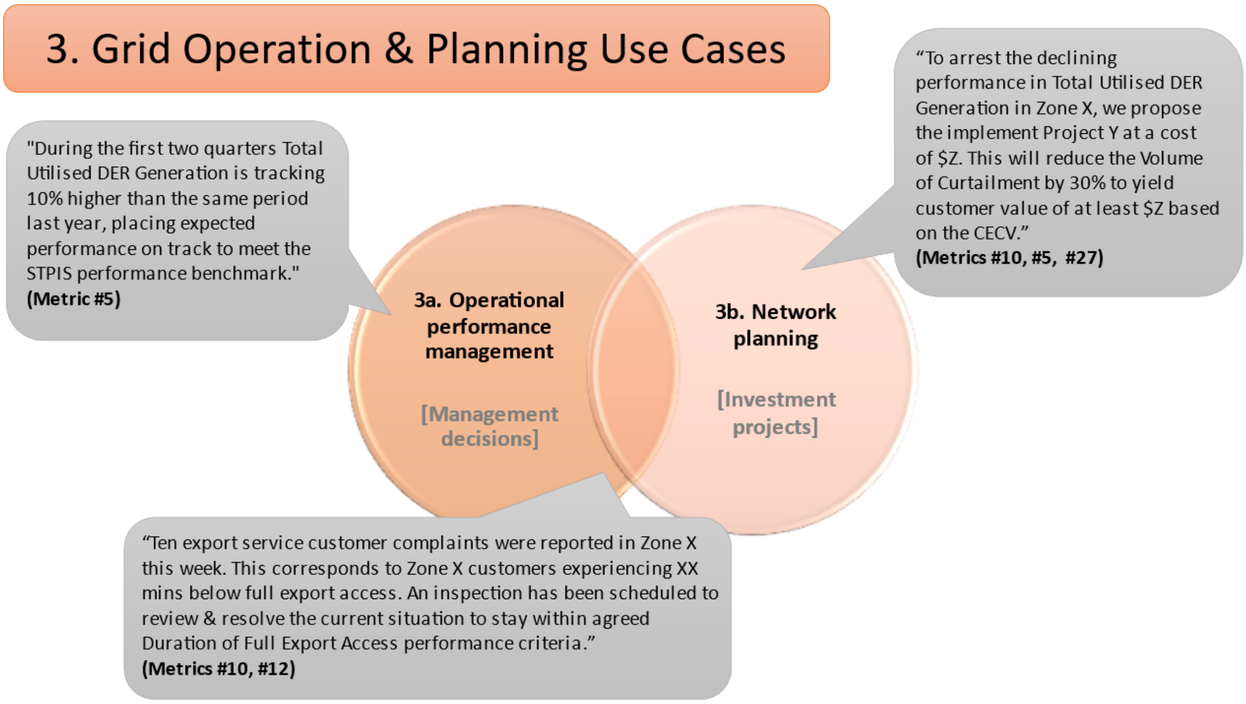


For regulatory applications, different forms of the key metric of 'Total Utilised DER Generation' seek to set incentives that integrate the consideration of the countervailing tension between the need to increase the scale of DER connections and to maintain transparent limits on curtailment from associated network congestion. Penalties and incentives could be set using benchmarks to ensure networks maintain their advertised export service commitments with customers. See the image below for key regulatory contextual examples.

2. Regulatory Compliance Use Cases



For grid operations, metrics selected are primarily more *temporally* granular versions of the regulatory metrics to ensure ongoing day-to-day compliance. These are supplemented with other metrics such as customer complaints. For network planning, metrics selected are primarily more *spatially* granular versions of the regulatory metrics to identify specific parts of the network where export service improvement is required. More work is required to adequately establish economic efficiency benchmarking measures due to challenges in comparing different network circumstances. See the image below for examples in key operations and planning contexts.



Final proposed metrics

Across the use case applications demonstrated in these examples, the four headline metrics considered to have the greatest value to monitor and manage network export service quality are:

1. **Volume of Curtailment (#27):** Expresses the amount of energy that customers could have exported to the market that was curtailed due to network constraints. The AER has developed a Customer Export Curtailment Value (CECV) to assign an economic value to this energy. This metric enables effective communication of export service quality implications in terms that are meaningful to customers. It provides transparency and allows industry parties to calculate financial implications of network export limitations and improvements.

2. **Total Utilised DER Generation (#5):** Expresses the amount of energy able to be produced by DER, taking into account energy exported to the grid and energy consumed behind the meter. This metric is considered the best overarching indicator of desirable service performance because it seeks to drive a net improvement in the productive use of DER while limiting export congestion. Ideally this metric is measured directly from customer telemetry, which is currently available for dynamic export customers in South Australia. For other customers, however, it would need to be calculated from estimated potential DER generation minus the estimated volume of curtailment.

3. **Duration of Full Export Access (#10):** Expresses the annual percentage of time customers experience unconstrained access up to the maximum export limit set in their connection agreement.

This metric accounts for periods of voltage-related curtailment[3] and dynamically signalled export limitation. Static export limitations (in cases where the customer has chosen to install a system larger than the static export limit) are not counted in this metric as the maximum agreed connection limit is being met. This metric is used to *define* and communicate the network export availability dimension of export service product offers.

4. **Export Service Levels Achieved (#28):** Measures a network's compliance with the export service levels stipulated in its customer connection agreements (defined using #10 above). Penalties could be set with this metric to ensure that networks accurately understand, communicate and deliver on their export service quality agreements with customers.

An additional three supplementary metrics are also included to support other use cases and to capture the full value customers receive from DER export services. These include **Volume of DER System Services, CO_2 Emissions Reduction** and **Customer Complaints**. Supplementary metrics are discussed in Section 3.3. Table 1 summarises which of the proposed metrics are intended for application to each use case.

Table 1. Metric application to different use cases

		Use cases							
		1) Customer communication			**2) Regulatory compliance**			**3) Grid operation and planning**	
ID	**Shortlisted metrics**	a) Current DER customers	b) Connection applicants	c) Engaging with stakeholders	a) STPIS	b) Performance benchmarking	c) Jurisdictional service	a) Operation	b) Planning
27	**Volume of Energy Curtailed**	✓	✓	✓		✓		✓	✓
5	**Total Utilised DER Generation**		✓	✓	✓	✓	✓	✓	✓
10	**Duration of Full Export Access**	✓	✓	✓		✓	✓	✓	✓
28	**Export Service Levels Achieved**				✓	✓		✓	✓
22	Volume of System Services Provided by DER		✓	✓		✓			✓
17	CO_2 Emissions Reduction			✓					
12	Customer Complaints			✓		✓	✓	✓	✓

Recommendations

Many of these metrics cannot currently be calculated across the full customer base and require more sophisticated data capture and analysis workflows to be developed over time. Ultimately a bottom-up understanding of curtailment and export service access is required. Other priority areas to support further development of export service metrics include:

- developing widely shared definitions of curtailment and export service concepts,
- establishing methods to overcome low LV data visibility and monitoring issues, and

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3 Generally includes Volt-Watt and Volt-VAr curtailment or, in occasional extreme circumstances, voltage tripping.

- improving methods to estimate voltage-related curtailment. (Specifically, the lack of availability of voltage data from existing smart meters [outside Victoria] is a key impediment arising from the contestable metering framework and must be addressed by the AEMC's ongoing review.)

While this project provides a solid foundation for export service metrics, more work is required to refine metric applications and strengthen industry experience in working with real network data applied to specific use cases, particularly regarding economic efficiency benchmarking.

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1 Introduction

1.1 Project context

Traditionally, electricity network businesses have defined Distributed Energy Resource (DER)[4] hosting capacity, which is a fixed quantity of DERs that can be connected to an area of the network without breaching network limits at any time. Once this capacity has been reached, no more DERs can be connected to that part of the network unless measures are taken to increase the hosting capacity.

However, in jurisdictions such as South Australia these static hosting capacity limits are being reached at the system, substation, and local levels. As a result, variable quality of export service is already being experienced by some customers who face inverter curtailment and disconnections owing to high voltages. Networks are starting to explore new approaches, such as dynamic operating envelopes, to continue to connect DERs beyond the static hosting capacity. While this seeks to increase energy exports, under such arrangements, customer 'export service levels' are not fixed in that the amount of energy they can export differs by time and location.

Customer and DER industry feedback on new measures to best integrate DERs into the electricity system in Australia has highlighted a need for easy-to-understand information about the quality of export service that prospective DER customers can expect to receive.[5] An increased focus on the quality of export services within distribution networks also creates the need for metrics to track and improve performance over time. In addition, the *Access, Pricing and Incentive Arrangements for Distributed Energy Resources* rule change now expects networks to invest efficiently in export capacity, which requires a means to quantify the customer value that such investments create. It also contemplates the need for export services to be tracked as part of regulatory reporting against export service standards developed in consultation with the community.

This project seeks to develop and test metrics for understanding and communicating the quality of export services to begin to fill these information gaps. The outputs seek to enable networks to communicate with customers, regulators, and industry about the level of export service quality received and expected. This report is the primary deliverable of a RACE for 2030 Cooperative Research Centre project led by UTS in collaboration with SA Power Networks, Essential Energy and Energy Networks Australia. An additional component of the project also examines strategic approaches to support third party access to and/or mapping of data on network hosting capacity for DERs. The output of this project will inform future RACE support of network hosting capacity communication initiatives.

1.2 Report structure

Section 2 provides background on current and industry practices related to export service quality, including relevant concepts and industry activities, and clarifies the interplay with the evolving regulatory environment.

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4 Increasingly called Customer Energy Resources (CER), but the term DER is used across this report for current regulatory relevance. The term DER "refers to usually smaller renewable generating units located at the consumers' side of the meter at homes or businesses. The term includes technologies such as rooftop solar, residential battery storage, home energy management systems, and in the coming years, electric vehicles" Australian Energy Regulator (AER) (2022). Flexible Export Limits, Issues Paper. October 2022. In this report, DER is also used to encompass generators embedded within the distribution network, such as community-scale PV, wind or hydro power.

5 Cambridge Economic Policy Associates (CEPA). (2020). *Feasibility of export capacity obligations and incentives*. 20 July 2020. https://www.aemc.gov.au/sites/default/files/documents/cepa_report_-_feasibility_of_export_capacity_obligations_and_incentives_1.pdf

This includes recent work in relation to the AEMC's final DER access and pricing determination. Section 3 presents the shortlisting process undertaken to develop a list of proposed metrics, the success criteria applied to refine the metric selection, and a high-level view of the proposed metrics and their mapping to specific use cases. Section 4 contains a deeper analysis of calculation methods and limitations and fleshes out contextual examples of how each use case might be fulfilled by applying the suite of metrics. Section 5 presents findings regarding data availability to support the proposed metrics informed by road-testing the metrics and a survey that was circulated to all Australian DNSPs. Section 6 concludes with a list of recommendations. More detailed information is contained in appendices, including road-test results of some metrics using SAPN and Essential Energy data.

2 Background

2.1 Decentralisation of the energy sector

Changing technologies are leading to the rapid decentralisation of the energy sector. Increasing adoption of rooftop solar and other DER including battery energy storage systems (BESS), flexible appliances and electric vehicles (EVs) are further transforming our electricity system away from centralised thermal generation feeding of customers and towards decentralised generation, consumption and storage spread across the network. As of January 2022, more than 3 million rooftop photovoltaic (PV) solar systems have been installed across Australia, resulting in about 30% of Australian homes now having a rooftop PV system, the highest uptake in the world.[6] Additionally, the latest Draft Integration System Plan from AEMO[7] estimates that over half of residential customers in NEM will be able to produce and export energy to the grid by 2032, rising to 65% with 69 GW capacity by 2050.[8]

However, the rapid transformation of the energy sector is creating challenges, particularly with regards to network constraints and voltage management on low voltage (LV) distribution networks. Electricity networks were designed for one-way energy flow from large generators to end-users. While the DER uptake was relatively low, the existing electricity network infrastructure allowed some reverse power flow to manage exports from DER customers. With increasing DER penetration, however, electricity network operating, and technical limits are in some jurisdictions restricting the ability to host new DER capacity or the ability of DER to deliver services. For example, high penetration of rooftop PV is pushing up voltages across Australia's LV distribution networks, limiting DER operation through energy curtailment and these networks' ability to host additional rooftop PV systems.[9] This means that DER customers are facing growing limitations to connect and/or export power and indicates the need to explore ways to alleviate emerging network problems that arise due to the increasing DER uptake.

In this context, the obvious next questions are *How can the hosting capacity and export service quality be increased*? and *Is this worthwhile*? Thus, the concept of optimising hosting capacity refers to finding the balance between meeting customer expectations and defining an 'efficient' mix of DER and centralised resources to meet system needs. Achieving this balance must inherently weigh up the costs and benefits of DERs, network upgrades, export management strategies (e.g., static or dynamic limits), load flexibility, DER coordination or any other options to manage higher DER penetration.

2.2 Network export capabilities as a service

Harnessing the full benefits of DERs is only possible if DERs are efficiently integrated into power systems. In addition to the technical requirements, efficient integration must also consider other fundamental elements such as the regulatory framework. The regulatory framework was built on a centralised structure based on a model of large power stations and passive consumers who could not export energy to the grid. But, with the

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6 Australian Energy Market Operator (AEMO). (2022). *Draft Integration System Plan*. https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

7 Capacity and growth estimations are for the step change modelling scenario, which has been chosen as the most likely scenario by stakeholder representatives

8 Australian Energy Market Operator (AEMO. (2022). *Draft Integration System Plan*. https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

9 Yildiz, B., Adams, S., Samarakoon, S., Stringer, N., Bruce, A. & MacGill, I. (2021). CANVAS: Curtailment and network voltage analysis study project report. RACE for 2030 Fast Track project. https://issuu.com/racefor2030/docs/canvas_final_report_11.11

increasing penetration of DERs, the conventional regulatory framework needs to evolve to accommodate the prevalence of DERs as they increase. For example, one distinction necessary to unlock opportunities and address challenges is to adequately acknowledge that distribution networks provide two distinct services to customers: (i) *Consumption services*, the traditional means of supplying energy to downstream customers, and (ii) *Export services*, providing upstream energy services from DER customers to other customers or the market. Since export services were not explicitly defined in the NER, legislative and regulatory frameworks contain ambiguity about export services.

Within this context, the number of DERs connected to the electricity network in Australia has grown under a regulatory framework developed for a one-way energy flow network, resulting in various interpretations and strategies to define and manage export services provided to customers. This situation creates a potential risk for DNSPs to be unable to fairly manage customers' rights to export energy to the grid, complicating network investment decisions. A wide range of stakeholders identified the need for a change through a review of access and pricing reform options to efficiently integrate more DERs that enable a two-way electricity network.[10]

2.2.1 Rule change—Access, pricing and incentive arrangements for DER

In 2019, the Distributed Energy Integration Program (DEIP) Access and Pricing Working Group was established to identify gaps and develop a suite of customer-oriented and efficient access and pricing reform options.[11] The DEIP Access and Pricing Working Group consisted of stakeholders from industry, consumer representatives, market bodies, regulators, and researchers. DEIP conducted three workshops as part of its consultation process and published an outcomes report that summarises the workshop materials and feedback from stakeholders. In particular, the outcomes report states 12 'findings' which reflect broad stakeholder views and are intended to be used as guidance to be considered when undertaking future energy access and pricing reforms in the electricity sector. The series of workshops and the outcomes report led to three submissions for rule changes in 2020: A joint submission from the Total Environment Centre and Australian Council of Social Services and individual submissions from SA Power Networks and St Vincent de Paul Society Victoria. The submissions proposed changes to the National Electricity Rules that were intended to ensure that (i) customers have the right to export energy from DERs to the grid, (ii) DNSPs invest efficiently to support the continued uptake of DERs, and (iii) costs related to supporting DERs in the network are fairly allocated. In August 2021, the AEMC published a final determination to update the National Electricity Rules and National Energy Retail Rules to integrate DERs more efficiently into the network. The final package of reforms enabled the following three key changes:

1. **Clear obligations on DNSPs to provide export services** as part of their core services, integrate export services into their planning and regulatory proposals, and recognise incentive schemes as well as the planning and investment requirements that currently apply to consumption services.
2. **Enabling new network tariff opportunities** by offering export pricing options that help promote the efficient use of the existing network infrastructure.
3. **Strengthening consumer protections and regulatory oversight,** which considers developing incentive schemes and performance monitoring for export service and develops Customer Export

[10] Australian Energy Market Commission (AEMC). (2021). *Access, Pricing and Incentive Arrangements for Distributed Energy Resources*. Rule Determination. 12 August 2021. https://www.aemc.gov.au/sites/default/files/2021-08/Final%20determination%20-%20Access%2C%20pricing%20and%20incentive%20arrangements%20for%20DER.pdf

[11] Distributed Energy Integration Program (DEIP). (2020). *Access and Pricing Reform Package—Outcomes Report*. June 2020. https://arena.gov.au/assets/2020/07/deip-access-pricing-reform-package-outcomes.pdf

Curtailment Values (CECVs) methodology to guide efficient levels of investment for exports and to support other regulatory processes.

2.3 Manage hosting capacity and improve export service quality

2.3.1 Export limits

Distribution networks designed to support consumption services have a finite capacity to accommodate the connection of DER and thereby to support export services. Within the range of techniques to manage DER hosting capacity and improve export service quality, DNSPs have started to set *export limits* at connection points to ensure that energy exports do not cause local operating network issues. While export limits may limit the full export service capability, the DER benefits of behind-the-meter consumption are not affected.[12]

Currently, export limits are defined by DNSPs and can be generally categorised into two categories—static and dynamic export limits.[13] Static limits generally apply a uniform, low level of export capacity based on maintaining integrity in all network conditions, including during worst-case scenarios such as peak net export times. In contrast, dynamic limits are technical limits that vary over time and location (based on the available capacity of the network as a whole) and provide upper and lower bounds for individual DER assets or a connection point in each time interval.[14] Dynamic limits typically allow higher export capacity on the condition that this can be actively reduced during constraint times.

2.3.2 Understanding energy curtailment

Broadly defined, curtailment occurs when the output of a DER is constrained below its theoretical 'potential' output through the imposition of some limitation. Typically, energy curtailment is caused by the inverter voltage response mode to local network operating conditions or by the imposition of an export limit. Voltage-based curtailment can impact export and behind-the-meter operation of DER. For a PV system without storage, this results in the loss of generation. For a DER system with storage (such as a battery), it effectively defers the ability to charge or discharge the system. In contrast, export limits reduce export capability at the connection point so that DER behind-the-meter services are not affected.

Although limits on system sizes, or reductions in the numbers of systems being connected to a network because of consumer responses to export limits might be considered a constraint on the growth of DER, in this study, curtailment was considered as the output of *installed DER* being constrained in response to:

- a *static export limit* (which only includes customers with a static limit that is *lower* than their DER capacity)
- a flexible or dynamic export limit, or
- *network voltage conditions*, which generally includes *Volt-Watt and V-VAr curtailment* as DER output is dictated by network-prescribed inverter settings to prevent excessive voltage rise on the local

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[12] Note that in the absence of export limits, customer inverters may be ramped down or trip-off in a network with high DER penetration, reducing the potential benefits of export services and self-consumption.

[13] Distributed Energy Integration Program (DEIP). (2020). *Access and Pricing Reform Package—Outcomes Report*. June 2020. https://arena.gov.au/assets/2020/07/deip-access-pricing-reform-package-outcomes.pdf

[14] Braslavsky, J., Graham, P., Havas, L., Sherman, J., Spak, B., Dwyer, S., Langham, E., Nagrath, K., Orbe, J. G., Khorasany, M., Razzaghi, R., Heslop, S., Hossain, J., Ibrahim, I., & Amin, R. (2021). *N2 opportunity assessment: low voltage network visibility and optimising DER hosting capacity: final report December 2021*. The Reliable Affordable Clean Energy for 2030 Cooperative Research Centre (RACE for 2030 CRC). https://www.racefor2030.com.au/opportunity-assessment-reports/

network during times of excess generation, or occasionally in extreme circumstances, the inverter being disconnected from the grid (referred to as '*tripping*').

There is not yet a well-accepted definition of curtailment within the Australian energy industry, but different types of curtailment can be classified based on how the technical limit is defined and the potential impact[15], as shown in Table 2 below.

Table 2. Types of energy curtailment and customer impacts

		Potential energy customer impacts	
	Type of curtailment	**Reduce BTM consumption**	**Reduce exports**
Voltage response modes	Tripping	✓	✓
	Volt-Watt	✓	✓
	Volt-VAr	✓	✓
Export limits	Static limits	×	✓
	Dynamic limits	×	✓

The amount of potential DER generation lost to curtailment depends on whether the inverter is ramped down to meet the export limit or switched off completely. This is indicated by the ticks and crosses in Table 1 above. Behind-the-meter (BTM) energy, which is used to serve real-time customer loads, has a higher value to system owners than exported energy as it offsets retail energy rates (at, say, 30 ¢/kWh), while exports tend to receive a lower Feed-in-Tariff (roughly 0–12 ¢/Wh).

2.4 Use case applications of export service quality metrics

Considering export services as part of the fundamental services provided by DNSPs and the underlying operating, planning and regulatory implications raise the need to develop a systematic approach to estimate, benchmark and communicate the level of export services that DNSPs are providing to customers.

This project identified three primary and a series of secondary categories of applications of export service quality metrics, commonly referred to as 'use cases' in this report. These use cases are shown in Figure 1 below.

15 Yildiz, B., Adams, S., Samarakoon, S., Stringer, N., Bruce, A. & MacGill, I. (2021). CANVAS: Curtailment and network voltage analysis study project report. RACE for 2030 Fast Track project. https://issuu.com/racefor2030/docs/canvas_final_report_11.11

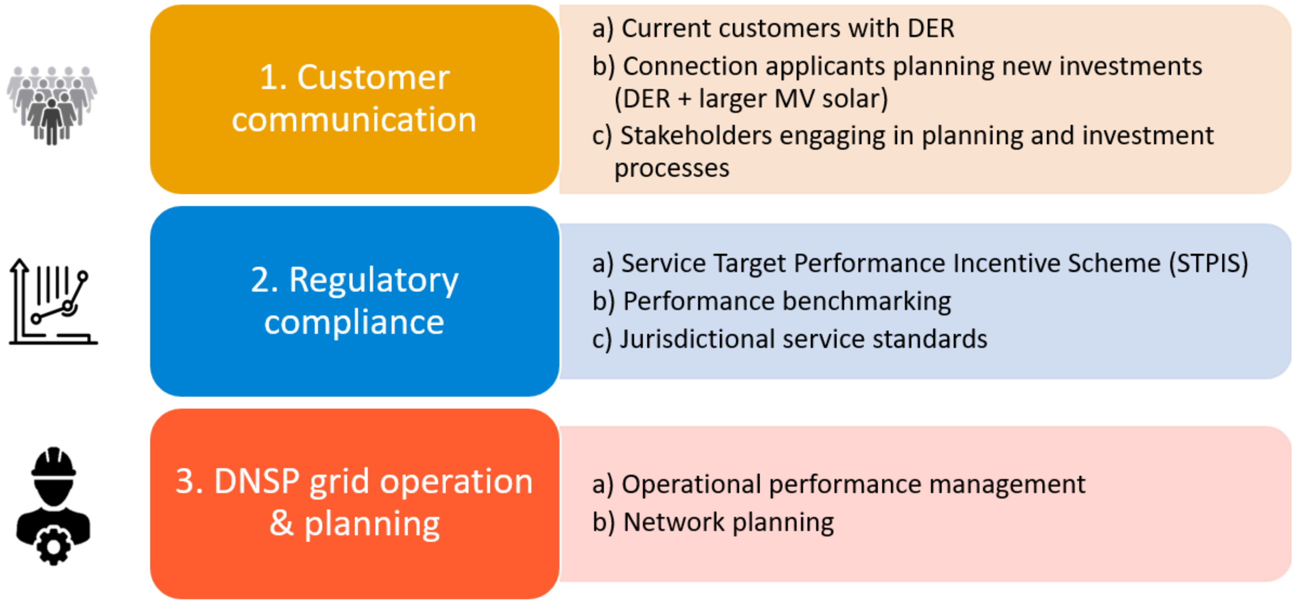

Figure 1. Metric use cases

2.4.1 1. Customer communication use cases

Metrics are required to allow DNSPs converse with their customers and other stakeholders regarding expected levels of network export service, network offerings and customer choices. Three specific customer communication use cases were identified:

a) **Current customers with DER**

b) **Connection applicants**[16] (or their industry representatives) planning new investments in

- Small-scale DER
- Larger embedded generation (connected at medium voltage)

c) **Stakeholders engaging in planning and investment processes**, such as prioritising investment approaches to making material improvements to export service quality.

2.4.2 2. Regulatory compliance use cases

Following the access and pricing rule change process, the AER is working towards monitoring, benchmarking and incentivising the quality of network export services.[17] Metrics can service three specific regulatory use cases:

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16 Connection applicants include those who have already submitted their application and those who may be looking to adopt DER.

17 The AER has been exploring several options for incentivising DNSPs to provide export services. In addition to a financial incentive mechanism such as STPIS, AER is exploring (i) an allowance/margin mechanism and (ii) reputational incentives as proposed in their consultation paper on incentivising and measuring export service performance. Allowance/margin mechanisms could provide DNSPs with specific funding arrangements for projects that are associated with improving export capacity. Reputational incentives

1. **Service Target Performance Incentive Scheme (STPIS):** Metrics may reflect relevant desirable attributes of export services that can be tracked on a daily, weekly or monthly basis and be robust enough to form the basis of financial incentives for DNSPs within an extended STPIS. These incentives will be used to inform DNSP operational and planning decisions regarding investments in maintaining and improving export service quality over time.
2. **Performance benchmarking:** Metrics may inform the preparation and publishing of annual reports, benchmarking network export service performance to enhance transparency and support regulatory policy decisions by government agencies and investment and operating decisions by customers and DER installers.
3. **Jurisdictional service standards:** Metrics may be used to inform monitoring to track network compliance with potential state-based minimum export service performance standards. Similar to reliability measures, jurisdictional standards may take the form of geographical, region-based service standards to address inequitable customer outcomes, Guaranteed Service Level (GSL)-style approaches to account for worst-served customers, or to protect against major plant failures that affect export service quality.

2.4.3 3. DNSP grid operation and planning use cases

The two internal (DNSP) metric use case applications are:

1. **Operational performance management**: Metrics to support performance tracking on a daily/weekly/monthly basis and troubleshooting issues or constraints that are resolvable through ongoing maintenance and management decisions without substantial planning and financial investment. It is highly desirable that operational performance metrics are identical to STPIS measures (performance benchmarking use-case #2a, above).
2. **Network planning**: Metrics that support the creation of business cases by quantifying the costs and benefits of export service quality maintenance or improvement projects with longer lead times or greater financial investment.

A wide net was cast to source potential data sources and metrics that could plausibly form part of a suite of metrics that represent export service quality. We anticipated that multiple metrics would be needed for each use case as data availability and quality are variable and most metrics have some limitations on their usefulness for different purposes.

do not consider a financial reward or penalty but would require DNSPs to publish metrics on their export service performance to improve transparency for stakeholders and to facilitate comparison between DNSPs (i.e., communication use cases and performance benchmarking use case in this report). As the AER's consultation paper is a preliminary paper that was realised near the final stage of this project, this document refers to all incentive options within the STPIS context. Allowance/margin mechanisms or reputational incentives are not explicitly included in this report, but they are suggested as part of future work.

3 Developed metrics and rationale

This section presents the results of the metric development process and the associated rationale. After clarifying the metric use cases, a four-step process was undertaken. A scan of relevant industry and academic documents informed the creation of an initial **metric long list** and the subsequent development of a set of **metric assessment criteria. These were** then used to produce a **shortlist** of metrics that were **matched to a set of use cases**.

Note that, to support this process, the shortlist was road-tested with SAPN and Essential Energy data and emerging outputs of each core task were shared and refined with key stakeholders through a series of workshops with an industry reference group and other stakeholders. For a fuller description of the methodology see Appendix A.

3.1 Long list of metrics

The design and implementation of performance metrics is not an easy task as this process needs to take into account many relevant impacts such as unintended consequences or perverse service outcomes. Therefore, it was important to define a list of promising metrics and then assess them against criteria that incorporate these relevant elements.

The existing literature on metrics to measure network performance to deliver downstream services is extensive and widely recognised; for example, existing regulatory arrangements account for planning and investment frameworks, incentive schemes and performance monitoring for consumer services.[18, 19] So far, however, few studies have explored performance metrics for export services in any systematic way. While no international precedents and systematic studies were found, there are recent relevant activities in the Australian national context. In 2020 Cambridge Economic Policy Associates (CEPA) was engaged during the AEMC's rule change process to consider the feasibility of options for export capacity obligations and incentives, including a list of initial thoughts on metrics to monitor export services performance.[20] Additionally, the AEMC's final determination rule led the AER to start investigating and developing export service incentives as well as annual performance reporting and benchmarking frameworks. The AER's report is expected to be published by 31 December 2022. The outcomes and principles within this work were incorporated into the long list export service performance metrics.

Building on the initial findings from the CEPA and AER reports and relevant literature on performance metrics[21,22,23,] a long list of metrics was established. This long list includes 26 metrics and is fully presented in

18 Raoufi, H., Vahidinasab, V., & Mehran, K. (2020). Power Systems Resilience Metrics: A Comprehensive Review of Challenges and Outlook. *Sustainability*, 12(22), 9698.

19 Australian Energy Market Commission (AEMC). (2021). Access, pricing and incentive arrangements for distributed energy resources. Rule Determination, 12 August 2021.

20 Cambridge Economic Policy Associates (CEPA). (2020). Feasibility of export capacity obligations and incentives. 20 July 2020, pp. 28–30. https://www.aemc.gov.au/sites/default/files/documents/cepa_report_-_feasibility_of_export_capacity_obligations_and_incentives_1.pdf

21 Great Plains Institute. (2019). Performance Metrics for Xcel Energy's Electric Utility Operations, Stakeholder Engagement Process, Meeting 1, Summary Report.

22 Raoufi, H., Vahidinasab, V., & Mehran, K. (2020). Power Systems Resilience Metrics: A Comprehensive Review of Challenges and Outlook, *Sustainability*, 12(22), 9698.

23 National Renewable Energy Laboratory (NREL). (2017). *Next-generation performance-based regulation: Emphasizing utility performance to unleash power sector innovation.* Technical Report NREL/TP-6A50-68512.

Appendix B. Assessment criteria were then needed to score the long list and develop a shortlist of metrics of up to ten options that could be tested during the project.

3.2 Metric assessment criteria

To assess what makes a good export service quality metric, three meta-criteria and a series of sub-criteria were developed. These were refined with feedback from the industry reference group to arrive at the list outlined below.

1. ***Does it measure services that customers value?***
    a. **Increases volume of energy utilised from DER:** Increases contribution of DER to meeting overall energy demand, which implies increasing DER uptake and reducing solar spillage/curtailment; DER utilisation also includes market system services such as FCAS and inertia.
    b. **Does not discourage self-consumption:** Supports customer desire for self-sufficiency.
    c. **Encourages emissions reduction:** Positively rewards reduce CO_2 emissions for energy supply and use.
    d. **Respects power quality, reliability and system security standards.**
    e. **Improves financial benefit for customers:** Customers have the opportunity for financial benefit from the provision of energy, capacity or other system services.
    f. **Facilitates diversity of new DER connections:** Supports future DER uptake, including EVs and battery storage technologies.

2. ***Is it practical and cost-effective?***
    a. **Ease of data accessibility:** Data that are not readily available may be costly to collect.
    b. **Time-series data granularity:** Data have good time granularity, so metrics can be calculated based on different time intervals, including years, months, weeks, days and hours.
    c. **Data quality:** Data are sufficiently reliable, accurate and have good coverage across the relevant levels of the system, assets or customer types.
    d. **Ease of calculation:** Metric formula and calculation approach are transparent (can be independently validated) and replicable.
    e. **Ease of interpretation:** Metric formula, calculation approach and implications are relatively simple to understand and explain.
    f. **Consistent over time:** The definition and reporting of the metrics do not change over time, thereby reducing potential ambiguity. For example, a metric that measures export services that occur at peak or off-peak periods would change with shifting timing of system peaks. Similarly, metrics should be future resilient to support future greater EV and battery storage penetration.

3. ***Does it consistently drive the right outcomes/behaviour?***
    a. **Applicable across different network types:** Metric is replicable and can be applied to different network types such as urban versus rural.
    b. **Applicable across different customer types and classes:** Metric is replicable and can be applied to different customer types and classes.
    c. **DNSP can positively affect metric:** Metric is substantially within the control of the DNSP in order to limit the evaluation of DNSP performance against factors they cannot control or improve.

d. **Low potential for unintended perverse incentives/outcomes:** Providing financial incentives for particular behaviours may encourage certain operating, planning and investment decisions. Examples of perverse outcomes include that they require lower fixed export limits or smaller system sizes to reduce curtailment, incentivise over-investment, discourage self-consumption, and that benchmarks get worse if customers increase self-consumption and exports fall as a result.

e. **Compatible with market-based pricing developments:** Metric is compatible with future possible pricing arrangements such as dynamic tariffs, time-based export pricing or localised tariffs.

f. **Fair and consistent under different monitoring capabilities:** If not all networks have the same means of monitoring available to them, this should not disadvantage those networks, and should facilitate reliable comparisons across utilities.

g. **Captures network investment:** Metrics reflect the actions and approaches taken by network businesses to more efficiently invest in, operate and improve customer export services.

h. **Optimise export services to the system: Metric encourages exports when they are most valuable to the system**.

3.3 Shortlist of proposed metrics

The long list of 26 metrics was assessed and rated against the multi-criteria framework shown in Section 4.2. Metrics were then sorted according to their total score to focus attention on the assessment of the highest priority measures for inclusion in our road test. Feedback on the shortlisted metrics was received over a series of project industry reference group meetings and other one-on-one consultations, which informed the addition, removal or modification of the shortlist. The proposed list was ultimately prioritised into four 'headline' metrics (Table 3) and three supplementary metrics (Table 4).[24]

[24] Note that descriptive formulae enclosed by square brackets are included for each metric. While these formulae aim to facilitate the interpretation of the metrics, the format and method to calculate and communicate each metric depends on the use case application.

Table 3. Proposed headline metrics for export services

ID	Name	[Simple Formula/e] Summary and examples
5	Total Utilised DER Generation	[Volume or % change: Total DER energy generated in kWh] Ideally, this metric is measured directly from customer telemetry, which is currently available for dynamic export customers in South Australia. For other customers, however, it would need to be calculated from estimated potential DER generation, minus the estimated volume of curtailment. This metric is considered the best overarching indicator of desirable service performance because it aligns well with what customers value from DER, is not affected by changes in customer consumption (e.g., metric does not decline if people charge their EVs during the day) and reflects all strategies to accommodate more DER (tariffs and incentives, flexible export limits, network improvements etc). As the DNSP does not have full control over how much DER is connected, this places some limits on its application. The metric can be normalised *per kW installed capacity* or *per customer* to compare network performance or to contextualise curtailment in the context of greater access to export services. Contextual examples: *"Customers on flexible exports product receive* Total Utilised DER Generation per kW installed DER capacity *of X kWh/kW, placing it in line with the average performance benchmark for networks with the highest penetration of DER customers."* [Use case 2b] *"During the period, total estimated DER generation for small DER customers has increased by X% while the estimated volume of curtailment grew by only Y%, giving an average improvement in* Total Utilised DER Generation *of Z%. This exceedance of the performance benchmark is rewarded through an incentive of $X and reflected in the revised incentive rate and target for total utilised DER generation for the next Regulatory Control Period (RCP) of Y and Z."* [Use case 2a]

ID	Name	[Simple Formula/e] Summary and examples
10	Duration of Full Export Access	[Total minutes per year minus minutes of voltage-related curtailment events and minutes customer sits at their dynamic export limit / Total minutes per year] Measures the annual percentage of time (or can be expressed in minutes) that customers experience unconstrained access up to the maximum export limit set in their connection agreement. This metric is used to *define* and communicate the network export availability dimension of export service product offers. As DNSPs have full control over this measure, Metric 28 is developed to set penalties to ensure DNSP compliance with the customer export service agreements defined by this metric (#10). This metric subtracts periods of voltage-related curtailment (which generally includes V-W and V-VAr curtailment, or in occasional extreme circumstances, voltage tripping) and dynamically signalled export limitation measured as the periods the customer maintains their dynamic export limit. Static export limitations (in cases where the customer has chosen to install a system larger than the static export limit) are not counted in this metric as the maximum agreed connection limit is being met. Contextual examples: *Defining Export Service Products* (*combines #5 and #10*)*: "On the static exports, product customers can export up to 1.5 kW for 99.5% of the time. Export availability may be reduced below this limit for up to 44 hours per year. On the flexible exports product, customers can export up to 10 kW for 97% of the time. Export availability may be reduced to 1.5 kW for up to 260 hours per year. This translates to XX% higher <u>Total Utilised DER Generation per customer</u> on the flexible export product."* [Use cases 1b, 2b] *"Customers in Substation X have experienced 20 hours of interruption to full export access this week. An inspection has been scheduled to review and resolve the current situation."* [Use case 3a, 1a] *"Network A's worst-served 5% of small DER static export customers experienced only 94% full network access relative to the agreed 99.5%. To improve equity of access to export services, a target of 97% is set for the 5% of worst-served small DER customers."* [Use case 2c]
28	Export Service Levels Achieved	[% of customers for whom export service level agreement is met] This metric measures a network's delivery on contractually agreed export service level offers defined through Metric #10 (e.g., Did flexible exports customers receive full export capacity up to 10 kW 97% of the time?). Contextual example: *"During the period, Network A met its customer export service level agreements for 90% of customers. As the stipulated performance benchmark is 95%, a penalty is applied for this period."* [Use case 2a]

ID	Name	[Simple Formula/e] Summary and examples
27	Volume of Curtailment	[Volume of energy curtailed (total and by each type of curtailment)] This metric estimates the total volume of energy curtailed by i) voltage-related curtailment, as well as curtailment during periods when customers reach their (ii) static export limits or (iii) dynamic export limits. The estimate is calculated using *expected* DER generation based on DER register and climate data. This metric feeds into Metrics #5 and #17. It can be expressed in energy (kWh/year) or as a percentage of total production. Customers and industry parties can use these figures to calculate the Financial Impact of Curtailment (in $/year) based on prevailing consumption rates and feed-in-tariffs, or DNSPs can calculate the economic impact of curtailment based on the Customer Export Curtailment Value (CECV). As each type of curtailment is calculated separately, this, for example, enables industry parties to place a higher value on the loss of behind-the-meter generation from voltage-related curtailment. Contextual examples: *"Customers on flexible export limits on average experienced estimated curtailment of XXX kWh/year, or 1% of total production. Customers on static export limits on average experienced estimated curtailment of YYY kWh/year or 4% of total production."* [Use case 1b] [Flow-on application when converted to $] *"We propose to invest $X million in Y program to deliver $Z million of value to customers in reduced volume of curtailment valued at the CEVC."* [Use case 1c] [Or the granular time-based format can be aggregated for simpler customer communication of curtailment timing][25] *"For small solar customers on flexible exports, 90% of the energy curtailed occurred between 11 am and 1 pm in spring."* [*Use cases 1b, 2b*]

Table 4. Proposed supplementary metrics for export services

ID	Name	[Simple Formula/e] Summary and examples
22	Volume of DER System Services	[Volume: Annual volume provided by service type by DER] AEMO supplied measures of DER market services, such as frequency control ancillary services (FCAS), fast frequency response (FFR), synthetic inertia, wholesale demand response (WDR) and reliability and emergency reserve trader (RERT) services. Figures are normalised per MW-installed DER capacity or per customer. Currently, only WDR and FCAS are available via AEMO. Contextual example: *"Network A's improvement in export service provision from DER unlocked the following system-level benefits:* *XX MW of wholesale demand response/customer;* *XX MW of RERT;* *etc...* *These figures are in line with industry benchmarks."* [Use case 2b]
17	CO_2 Emissions Reduction	[Volume: Gross renewable DER generation x Emission factor] This metric translates Volume of Energy Enabled (#5) into environmental impact. Ultimately, this metric should be calculated from time-based emission factors, thus the underlying data supply needs to be at high temporal resolution. Contextual example: *"New DER has increased the total annual CO_2 emission reduction from rooftop solar to 1 Mt across South Australia. This is the equivalent of taking XXX cars off the road."* [Use case 1c]

[25] Curtailment Timing was initially a separate metric, #30.

ID	Name	[Simple Formula/e] Summary and examples
12	Customer Complaints	[Number of customer complaints received and resolved related to export services] This is a direct measure of notable export service problems experienced by customers. Contextual example: *“Customer complaints regarding export services in Zone X have increased by 20%, warranting planned programmatic investment in X management measures to ensure equitable access to exports.”* [*Use case 1c*] *“X complaints were reported in Zone Y, prompting the replacement of component Z.”* [*Use cases 3a and 3b*]

3.4 Matching metrics with use case applications

Table 5 summarises which of the proposed metrics are best applied to each of the use cases. Specific contextual examples of how each use case could be met with the suite of metrics is then presented in Section 3.4.

For **new and existing customers** (Use cases 1a and 1b), communications primarily regard the level of export service received and expected. For these cases, *Duration of Full Export Access* was chosen alongside the export limit size to define export service products offered by the network. These are within the full control of the network and not affected by factors such as the size of the PV system that a customer chooses to install. To help customers interpret the implications of this metric in energy (and potentially cost) terms, it is supported by *Volume of Curtailment* and to better distinguish how dynamic limits allow customers to productively use greater volumes of DER compared to static limits *Total Utilised DER Generation* was also selected. Both metrics are presented on a *per customer basis* to compare current or prospective network offerings most tangibly. For companies seeking to help their DER customers access additional financial benefits by supporting the grid or market operation, *Volume of DER system services* is also used.

Table 5. Metric application to different use cases

		Use cases							
		1) Customer communication			**2) Regulatory compliance**			**3) Grid operation and planning**	
ID	**Shortlisted metrics**	a) Current DER customers	b) Connection applicants	c) Stakeholders engaging	a) STPIS	b) Performance benchmarking	c) Jurisdictional service	a) Operation	b) Planning
27	**Volume of Energy Curtailed**	✓	✓	✓		✓		✓	✓
5	**Total Utilised DER Generation**		✓	✓	✓	✓	✓	✓	✓
10	**Duration of Full Export Access**	✓	✓	✓		✓	✓	✓	✓
28	**Export Service Levels Achieved**				✓	✓		✓	✓
22	Volume of System Services Provided by DER		✓	✓		✓			✓
17	CO_2 Emissions Reduction			✓					
12	Customer Complaints			✓		✓	✓	✓	✓

For **stakeholder engagement** and **grid planning** applications (Use cases 1c and 3b), a wide range of metrics was selected to help understand how successfully the network is maintaining transparent limits on *Volume of Curtailment* and to support the development of business cases to improve export service. This metric is emerging as a key focus of the AER. These use cases also need to be supported by metrics articulating non-energy benefits of DER such as *Volume of DER System Services* and *CO_2 Emission Reduction* as other forms of value.

For **regulatory performance penalty applications** (Use case 2a), *Export Service Levels Achieved* was selected to ensure networks meet the export service commitments agreed with customers based on a metric over which they have full control. For **regulatory performance incentive applications** (also Use case 2a), *Total Utilised DER Generation* was used to help balance the tension between the need to increase the scale of DER connections and to limit resulting curtailment from associated network congestion. This recognises that an increasing *Volume of Curtailment* is not necessarily a negative outcome if it has also facilitated a large increase in DER grid access.

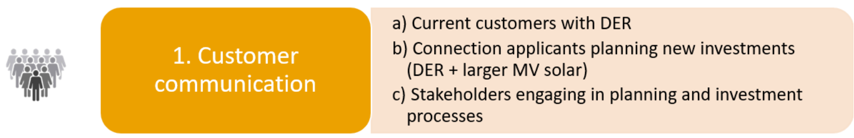
For **performance benchmarking applications** (Use case 2b), a wide range of metrics normalised for different purposes are proposed to understand how networks compare in facilitating DER export services. For **jurisdictional regulation** (Use case 2c), performance outcomes such as *Total Utilised DER Generation* per customer are compared according to critical groupings such as urban/rural and worst-served/best-served in order to identify and limit customer inequity.

For **grid operations** (Use case 3a), metrics selected tend to be more temporally or spatially granular versions of the regulatory metrics to ensure ongoing day-to-day compliance and identify specific parts of the network where export service improvement is required.

3.5 Metric contextual examples by use case

This section describes the range of use cases and, through contextual examples, the suite of metrics service each need.[26]

3.5.1 Customer communication



Use case 1a: Current customers with DER

This use case describes a customer wanting to know what export service they are receiving in practice and whether a more beneficial arrangement is potentially possible.

#10 Duration of Full Export Access (localised)/#5 Total Utilised DER Generation *per customer*:

[26] The contextual examples follow the technical language used throughout the document. However, it is worth noting that the customer communication use case may need to adapt the metric formats to a language that customers may find more tangible. Also, headline metrics may need to be directly associated with their complementary metrics to provide a more customer-friendly description. Examples include estimation of financial impacts (i.e., related savings or costs) and CO_2 Emissions Reductions (Metric #17).

"On average during the past year, small solar customers on static exports in X Zone have been able to export to the grid at full capacity 99.7% of the time, which is slightly higher than the 99.5% stipulated in the connection agreement."

"Customers on dynamic export arrangements in your area have access to a higher 10 kW export limit 97% of the time, which generally allows customers to utilise XX% more energy from a rooftop PV system. Discuss with your energy provider which export arrangements will work best for you or contact us directly on XXXXXX to switch your export arrangements."

#10 Duration of Full Export Access (hours):

"Customers in Substation X, which covers suburbs A and B, have experienced 20 hours of interruption to full export access this week. An inspection has been scheduled to review and resolve the current situation."

Use case 1b: DER connection applicants

While similar to Use case 1a above, this use case primarily represents communication with third party industry representatives such as solar suppliers, retailers and aggregators and explains the performance of standard export service arrangements to aid DER product design and sales choices based on tailored business cases.[27]

#10 Duration of Full Export Access (hours)/#5 Total Utilised DER Generation *per customer*/Volume of Curtailment (product type):

"On the *static exports* product, customers can export up to 1.5 kW for 99.5% of the time. Export availability may be reduced below this limit for up to 44 hours per year. On the *flexible exports* product, customers can export up to 10 kW for 97% of the time. Export availability may be reduced to 1.5 kW for up to 260 hours per year. This translates to X% higher Total Utilisable DER Generation per customer on the *flexible exports* product. Indicative half-hourly curtailment profiles for each product type are provided on our website."

This could be represented in a simple comparison table such as the one below.

	Static	**Dynamic**
Maximum export limit	1.5 kW	10 kW
Temporary lower export limit	–	1.5 kW
Duration of full export access	99.5%	97%
Export interruption	44 h/year	262 h/year
Utilisable solar generation per customer	X kWh/year	Y kWh/year

Note that solar industry representatives stressed the importance of being able to understand the current state of network congestion relative to the expected conditions over the period of the business case. We recommend that export service level offers are made with a 10-year time horizon in mind (i.e., that the committed level should be designed with the intent to be valid for 10 years) and that data on the DER hosting capacity of the network ultimately be made available alongside these metrics. This is covered in data recommendations in Section 5.

[27] We assume that the third-party representatives would translate and communicate the metrics to their existing and potential new customers.

Use case 1c: Stakeholders engaging in planning and investment processes

To examine Use case 1c, this section explores engagement regarding network investment to address constraints limiting exports from customer solar for the next regulatory period. SAPN is working on forecasting the level of curtailment under three scenarios: 1) No investment (i.e., current network conditions), 2) Investment justifiable according to the AER's published draft CECV, and 3) A higher level of investment that may better align with some customer expectations of higher export service quality. Supported by the suite of proposed metrics, we now examine how this communication of Scenario 2 relative to Scenario 1 would be undertaken.

Scenario 2 involves $30 million of investment in network upgrades to improve the quality of export services that customers receive. This is defined by the AER as prudent investment as customer benefits outweigh the cost of upgrades.

#27 Volume of Curtailment/#10 Duration of Full Export Access/#17 CO_2 Emission Reductions:

The proposed investment will reduce the average Volume of Curtailment of small solar customers by 20%. By primarily investing in poorer performing areas of the network, this will ensure that the worst-served 5% of customers will receive an improvement in Duration of Full Export Access to meet the committed service levels of 97% for dynamic export customers and 99.5% for static customers.

Across the system, this performance improvement will enable an X % increase in in Total Utilised DER Generation, which will further reduce carbon emissions by X tonnes per year, equivalent to taking Y cars off the road. The investment will specifically reduce customer interruptions from voltage-based curtailment, which may reduce a customer's ability to supply their own behind-the-meter load from solar by hours/year per customer.

[Flow on application] **#29 Financial Impact of Curtailment:**

Valued at the AER's Customer Export Curtailment Value, this average improvement is worth $2/year per solar customer or $5/year for worst-served solar customers. Across the network, Scenario 2's proposed investment of $30 million will deliver $32 million of customer value. Figure 2 below shows how comparative scenario figures may be presented.

Figure 2. Improvement in customer export service metrics by scenario relative to Scenario 1 (no investment)

Metric	Scenario 1 No investment	Scenario 2 $30 m investment (CECV)	Scenario 3 $50 m investment
#10 Duration of Full Export Access	–	X% availability X h/year	Y% availability Y h/year
#27 Volume of Curtailment	–	X kWh/year (average) X kWh/year (worst)	Y kWh/year (average) Y kWh/year (worst)
#5 Total Utilised DER Generation	–	X MWh/year X% of total generation	Y MWh/year Y% of total generation
#17 CO_2 Emissions	–	X kg CO_2-e X cars off the road	Y kg CO_2-e Y cars off the road
[Extension application] #29 Financial Impact	–	$X million in customer benefits	$Y million in customer benefits

3.5.2 Regulatory compliance

2. Regulatory compliance

a) Service Target Performance Incentive Scheme (STPIS)
b) Performance benchmarking
c) Jurisdictional service standards

Use case 2a: Service Target Performance Incentive Scheme

> The first metric informs the question *Is network management of export services driving improvement in efficient integration of DER*?

#5 Total Utilised DER Generation:

"During the period, gross DER generation for small DER customers has increased by X% while the estimated volume of energy curtailed grew by only Y%, giving an average improvement in Total Utilised DER Generation of Z%.

This exceedance of the performance benchmark is rewarded through an incentive of $X and reflected in the revised incentive rate and target for Total Utilised DER Generation for the next regulatory control period (RCP) of Y and Z."

> The next two metrics inform the question *Are networks delivering on customer export service agreements?*

#10 Duration of Full Export Access: Used to *define* export service levels that are enforced or incentivised via #28.

"On the static exports product, customers can export up to 1.5 kW for 99.5% of the time. Export availability may be reduced below this limit for up to 44 hours per year. On the flexible exports product, customers can export up to 10 kW for 97% of the time. Export availability may be reduced to 1.5 kW for up to 260 hours per year. This translates to XX% higher Total Utilised DER Generation per customer on the flexible export product." **[1b, 2b]**

#28 Export Service Levels Achieved (% of customers for whom service level agreement is met): *"During the period, Network A met its customer export service level agreements for 90% of customers. As the stipulated performance benchmark is 95%, a penalty is applied."*

Note that Metric #28 ensures that DNSPs are only *penalised* for not providing the level of service *agreed* with the customer, but it does not incentivise system improvements in DER access to export service—this occurs via #5. Without a target/incentive for #5, #28 would create an undesirable incentive for DNSPs to set lower limits and potentially favour static over dynamic limits. Thus #28 relies on #5 for driving the desired system behaviour.

Use cases 2b and 2c: Performance benchmarking, jurisdictional service standards

> The first metric informs benchmarking for the question *Is network management of export services driving improvement in efficient integration of DER?*

#5 Total Utilised DER Generation *per kW DER installed capacity*:

This version of Metric #5 normalises the *technical yield of connected DER* by the installed DER capacity. This metric should be broken down according to export service product type (static versus dynamic) to give insight into the effectiveness of different management strategies.

"During the period, Network A achieved Total Utilised DER Generation per kW DER installed capacity of X kWh/kW, placing it in line with the average performance benchmark for networks with the highest penetration of DER customers." **[2b]**

While this metric deteriorates with higher DER, it could still be used for benchmarking if this was acknowledged.

Another benchmarking option that could be explored in more depth is the expression of Volume of Curtailment as a percentage of potential DER generation. In other words, what proportion of total energy that could have been produced by DER was lost to curtailment? Similar ideas are explored in the road test.

The next two metric representations inform the question *Are the customer-level export service offers sufficiently fair/generous/consistent between jurisdictions* (*considering network differences*)?

Export services offered: Direct comparison of the export service levels offered by all DNSPs are shown in Figure 3 below according to maximum agreed export limit (kW) and Duration of Full Network Access (%) (i.e., how the service levels are defined and communicated to customers).

Note, however, that this representation does not take into account the size of the *lower* export limit when the dynamic signal is being received (for example, if one network constrained down to 1.5 kW while another constrained down to 3 kW).[28]

[28] If this were of concern, it could potentially be addressed through converting export performance commitments to a 'maximum volume of curtailment' under each product, taking into account upper and lower export limits. Moreover, this representation could be enhanced with sizing indicators (e.g., bubble size chart) to describe the total volume of utilised DER generation for each customer type.

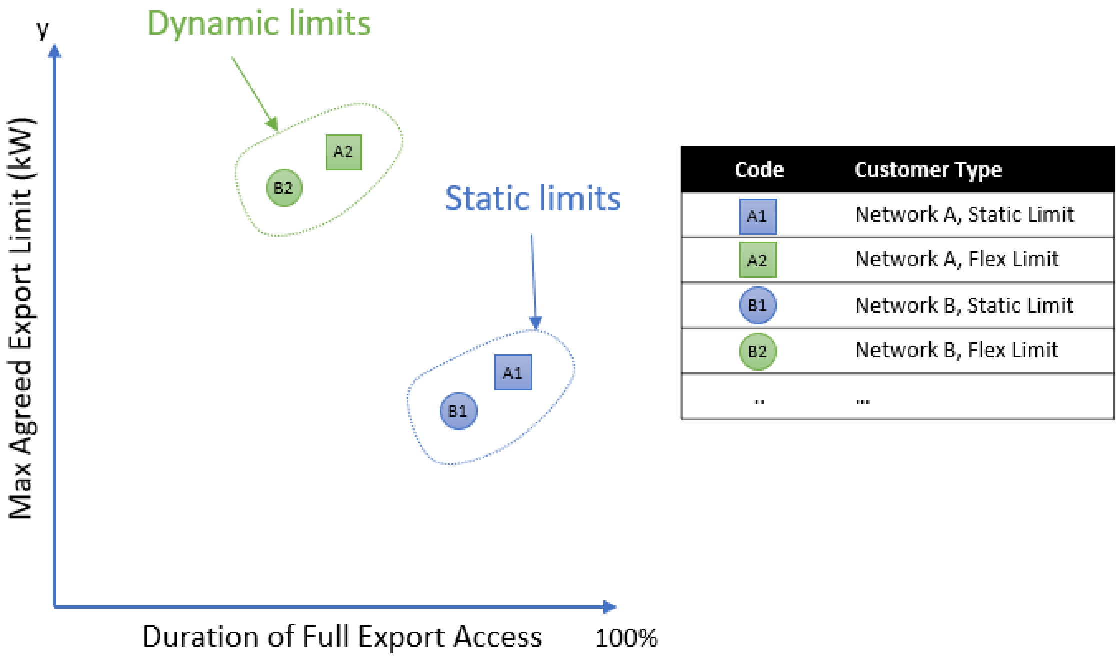


Figure 3: Comparison of export services offered between networks and export product types

#5 Total Utilised DER Generation *per customer*:

This version of Metric #5 normalises, by the number of customers to benchmark, the *scale of the productive volume* of energy being achieved by customer DER. This metric should be broken down according to export service product type (static vs. dynamic) to give insight into the effectiveness of different management strategies.

"During the period, Network A achieved Total Utilised DER Generation *per customer* of X MWh, placing it in line with the average performance benchmark for networks with the highest penetration of DER customers." **[2b]**

The application of this metric would deteriorate with higher DER but could still be used for benchmarking if this was recognised.

The next metrics inform the question *Is export service equitably distributed?*

#10 Duration of Full Export Access/#22 Customer Complaints:

"Network A's worst-served 5% of small DER static export customers experienced only 94% Duration of Full Export Access relative to the agreed 99.5%. This trend was reflected in a X% increase in Customer Complaints relating to export services in this cohort. To improve equity of access to export services, a target of 97% is set for the 5% of worst-served small DER customers." **[2c]**

The final metric informs the question *Is network management of DER eliciting additional value from connected customers?*

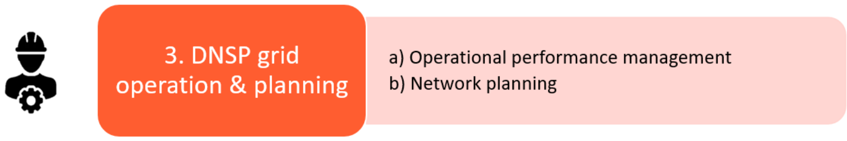
#22 Volume of DER system services:

"Network A's increase in DER export service performance represented by the figure of Z% total utilised DER generation and Y% Duration of Full Export Access unlocked the following additional system benefits:

- XX MW of wholesale demand response/customer
- XX MWh of frequency control services/MW DER-installed capacity.

These figures are in line with industry benchmarks." **[2b]**

3.5.3 DNSP grid operation and planning



Use case 3a: Operational performance management

Operational performance management has a large overlap with the STPIS use case (#2a) and will mainly comprise more temporally and spatially granular applications of these metrics to ensure networks are managing daily performance in line with STPIS requirements. For this reason, the #2a versions are shown boxed in grey at the top and the granular #3a versions are shown flowing on beneath.

#10 Duration of Full Export Access/#28 Export Service Levels Achieved:

"On the static exports product customers can export up to 1.5 kW for 99.5% of the time. Export availability may be reduced below this limit for up to **44** hours per year. On the flexible exports product customers can export up to 10 kW for 97% of the time. Export availability may be reduced to 1.5 kW for up to 260 hours per year."

"During the period, Network A met its customer export service level agreements for 90% of customers. As the stipulated performance benchmark is 95%, a penalty is applied for this period."

#10 Duration of Full Export Access/#12 Customer Complaints:

"10 export service Customer Complaints were reported in Zone X this week. This corresponds to Zone X's small DER customers experiencing an average of XX-minute interruption to Full Export Access, representing 30% of the annual STPIS interruption budget for these customers. An inspection has been scheduled to review and resolve the current situation to stay within agreed Duration of Full Export Access performance criterion."

Volume of Curtailment (timing) as direct customer communication: "A transformer outage in Glengowrie is causing temporary curtailment of customer solar exports to the grid between 12.00 pm and 2 pm. Works to restore full grid export capability are expected to be completed in four days."

#5 Total Utilised DER Generation:
"During the period, gross DER generation for small DER customers has increased by X% while the estimated volume of energy curtailed grew by only Y%, giving an average improvement in Total Utilised DER Generation of Z%.
This exceedance of the performance benchmark is rewarded through an incentive of $X and reflected in the revised incentive rate and target for Total Utilised DER Generation for the next regulatory control period (RCP) of Y and Z."

#5 Total Utilised DER Generation (system wide):

"During the first two quarters, Total Utilised DER Generation across the network is tracking 10% higher than the same period last year, placing expected performance on track to meet the STPIS performance benchmark."

#5 Total Utilised DER Generation (zone): "During the first two quarters, Total Utilised DER Generation in the growth area of Sunny Park has reached the threshold of 20% below the same period last year and has been flagged for maintenance inspection."

Use case 3b: Network planning

The network planning use case has a large overlap with the customer communication use case regarding planned investment (use case 1c) but with more internal or regulator-facing audiences.

#27 Volume of Curtailment:

"To arrest the declining performance in Total Utilised DER Generation in Zone X, we propose to implement Project Y at the cost of $Z. This will reduce the Volume of Curtailment by 30% to yield customer value of at least $Z based on the CECV."

#22 Volume of DER system services:

"The elimination of voltage-based curtailment events in Region X has maintained the connection of all DER to the system, enabling the use of YY MVAr of reactive power from DER within the region."

4 Detailed metric analysis

This section describes the detailed outcomes of testing each metric, incorporating a description, diagram, contextual examples, general calculation approach, limitations and challenges encountered, and example results for our two network test cases (where available):

- Urban residential customers on flexible export trials (SA Power Networks case study)
- Larger and small embedded generators on rural networks such as solar farms connected to the medium-voltage network (Essential Energy case study).

Figure 4 presents the proposed headline and supplementary metrics and shows the calculation links between some metrics as noted in Section 3.3. Several of these metrics were road-tested with real data (included in Appendix C), while others that were not road-tested emerged from iterative feedback at later stages of the project.[29]

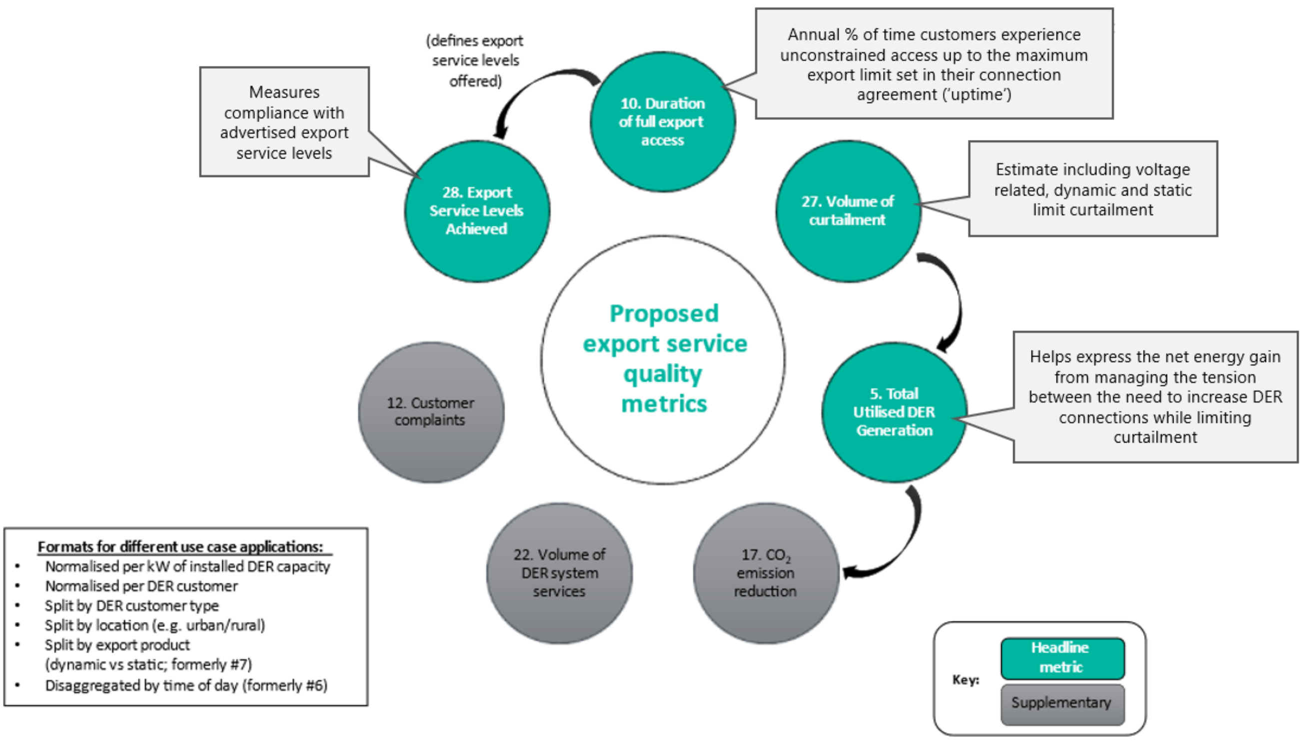


Figure 4. Overview of proposed headline and supplementary metrics

4.1 Total Utilised DER Generation (#5)

Description

This metric provides an estimate of the total energy that the installed DER capacity (in kWh) is producing after subtracting estimates of curtailment volume, incorporating i) voltage-based curtailment as well as curtailment during periods when customers reach their (ii) static export limits or (iii) flexible export limits.

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[29] Note that Metric #7 (Dynamic Limits vs. Static Limits) was initially part of the road test but was later excluded as it was better represented as a piece of meta-data captured to aid additional breakdowns of other metric results. A detailed description and road test results of Metric #7 are presented in Appendix C.

Ideally this metric is measured directly from customer telemetry, which is currently available for dynamic export customers in South Australia. For other customers, however, it would need to be calculated from estimated potential DER generation minus the estimated volume of curtailment. The estimated potential DER generation can be calculated based on DER register and climate data. In the short term, system-level figures could draw on existing AEMO metrics of solar generation calculated for each NEM region broken down by distribution network and include AEMO data for other forms of DER. In the long term, however, it is critical to incorporate DER curtailment estimates to ensure the metric represents total *utilised* DER, but this requires bottom-up DNSP calculation. The focus on the *productive use* of DER seeks to avoid metrics that drive higher DER connections with increasing curtailment and thus declining export performance.

This metric is considered valuable because it aligns well with what customers value from DER, is not affected by changes in customer consumption (e.g., metric does not decline if people charge their EVs during the day) and still shows an upward trajectory for all strategies to accommodate more DER (tariffs and incentives, flexible export limits, network improvements etc).

As this metric relies on *estimates* of curtailment that are due to voltage-based curtailment and static and flexible export limits, it is complemented by Metric #10 (Duration of Full Export Access) and the associated performance benchmark of #28 (Export Service Levels Achieved).

While some regulatory applications will be appropriate at the system level, more granular application by DER customer type or zone substation is anticipated for customer communication and grid operation and planning purposes.

Contextual examples

"During the period, gross DER generation for small DER customers has increased by X% while the estimated volume of curtailment grew by only Y%, giving an average improvement in Total Utilised DER Generation of Z%. This exceedance of the performance benchmark is rewarded through an incentive of $X and reflected in the revised incentive rate and target for Total Utilised DER Generation for the next regulatory control period (RCP) of Y and Z." **[Use case 2a]**

"Customers on the dynamic export product received Total Utilised DER Generation per kW installed DER capacity of X kWh/kW, placing it in line with the average performance benchmark for networks with the highest penetration of DER customers." **[Use case 2b]**

General calculation approach

General formula: [*Volume of Estimated Potential DER generation - Total Estimated Curtailment*]

The long-term method incorporates a bottom-up estimate of curtailment and it is unlikely that many DNSPs will be able to calculate this across their territory in the near term. For this reason, a second short-term top-down approach could be used that subtracts rough curtailment extrapolations from AEMO system-wide data.

A simplified diagrammatic representation of the long-term calculation is shown in Figure 5 below.

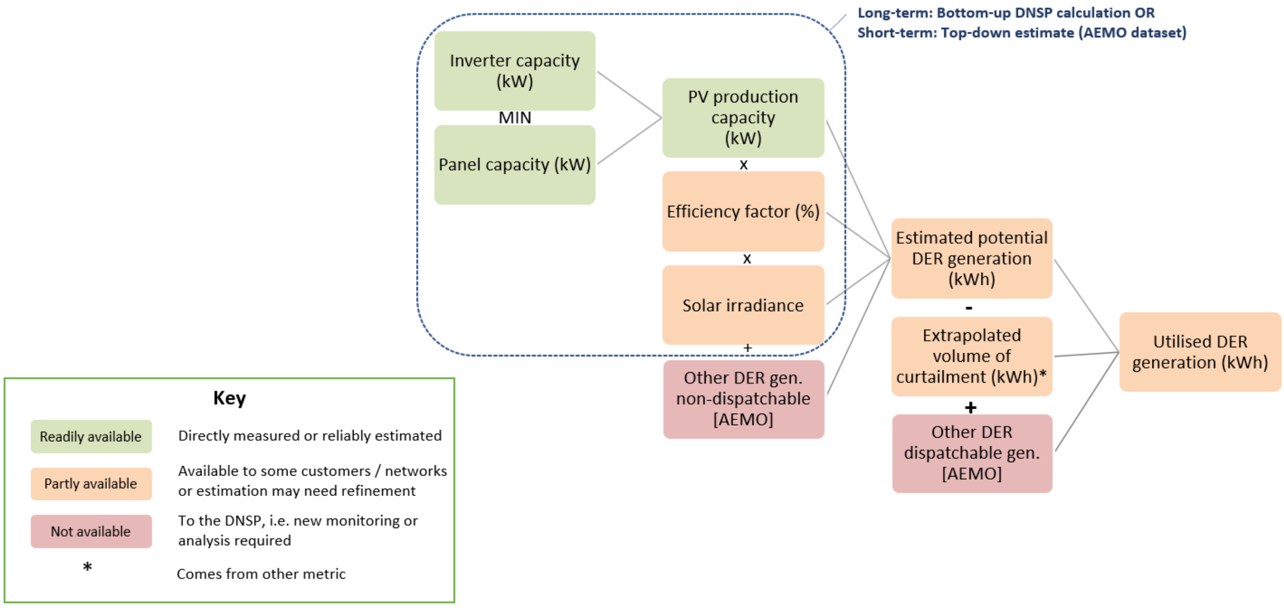

Figure 5. Simplified calculation diagram: Total Utilised DER Generation (Metric #5)

Note the diagram colour coding: Green elements are considered a reliable and readily available data source that is either directly measured or reliably estimated. Orange inputs indicate available source data that either needs refinement such as better estimation techniques or broader coverage across networks. Red inputs are those that are not currently available to the network. In this case, for example, efficiency factors and solar irradiance are not directly known and system-wide estimates are used. These are therefore marked orange. AEMO data for DER other than rooftop solar requires additional breakdowns to be applicable to distribution connected systems and are hence currently marked red.

Limitations and Challenges

- As the metric relies on estimation methods rather than direct measurement and is not fully within the control of the DNSP, this may compromise some STPIS applications.
- The generation to be included needs to be defined: we propose that anything distribution system connected should be included rather than an arbitrary MW size threshold.
- In the long term it requires a new data workflow for DNSPs to undertake bottom-up curtailment calculations. Ideally, this should be combined into a collaborative workflow between DNSPs and AEMO to provide consistent system-level data access.

Three issues exist with current AEMO data to calculate the short-term version of this metric that would need to be resolved or agreed:

1. AEMO solar generation data are only provided by NEM region and would need to be broken down by DNSP service region.
2. Additional generation data currently available through AEMO include wind power (1.3 MW–400 MW), hydropower (1 MW–1.5 GW) and utility-scale solar (1 MW–320 MW), but whether a facility is connected to the distribution system or transmission system is not evident. This may be the appropriate criterion to define whether the data are included in these DER metrics.
3. There is currently a gap between AEMO solar data (for systems less than 100 kW) and the utility-scale solar at 1 MW and above that needs to be clarified.

- It is not clear from available data whether including larger scales of DER within the same metric would create perverse incentives for DNSPs to favour connection of different scales/classes of generation. Therefore, we tentatively suggest that for regulatory purposes it may be appropriate to apply this metric to different DER customer classes rather than at the system level.

4.2 Duration of Full Export Access (#10)

Description

This metric measures the annual percentage of time (or it can be expressed in minutes) that customers experience unconstrained access up to the maximum export limit set in their connection agreement. It is used as the basis on which to define elements that DNSPs have full control over: Their export service product offers and setting penalties for non-compliance with customer agreements (via Metric 28 below).

This metric subtracts periods of voltage-based curtailment and dynamically signalled export limitation measured as the periods the customer sits at their dynamic export limit. Static export limitations (in cases where the customer has chosen to install a system larger than the static export limit) are not counted in this metric as the maximum agreed connection limit is being met. This distinguishes this metric from other curtailment-focussed metrics (#27, #5) which include static limitations within the definition of curtailment.

This metric provides a relatively accurate *direct measurement* of the period of time when the network is not meeting the maximum agreed export levels.

There may be differences in this metric between DER customer types or locations, so more granular computation (e.g., zone substation or region) is recommended to maintain customer equity or monitor operational issues with export access or plan targeted investment to address specific issues in certain zones.

Contextual examples

Defining Export Service Products (NB: Combines #5 and #10): "On the static exports, product customers can export up to 1.5 kW for 99.5% of the time. Export availability may be reduced below this limit for up to 44 hours per year. On the flexible exports, product customers can export up to 10 kW for 97% of the time. Export availability may be reduced to 1.5 kW for up to 260 hours per year. This translates to X% higher Total Utilised DER Generation per customer on the flexible exports product." **[Use cases 1b, 2b]**

"Customers in Substation X have experienced 20 hours of interruption to full export access this week. An inspection has been scheduled to review and resolve the current situation." **[Use cases 3a, 1a]**

"Network A's worst-served 5% of small DER static export customers experienced only 94% full network access compared to the agreed 99.5%. To improve equity of access to export services, a target of 97% is set for the 5% of worst-served small DER customers." **[Use case 2c]**

General calculation approach

Simplified formula: [*Total minutes across the period*[30] - (*minutes of voltage-based curtailment events*) - (*minutes customer sits at their dynamic export limit*)/*total minutes across the period*[26]]

[30] Generally one year

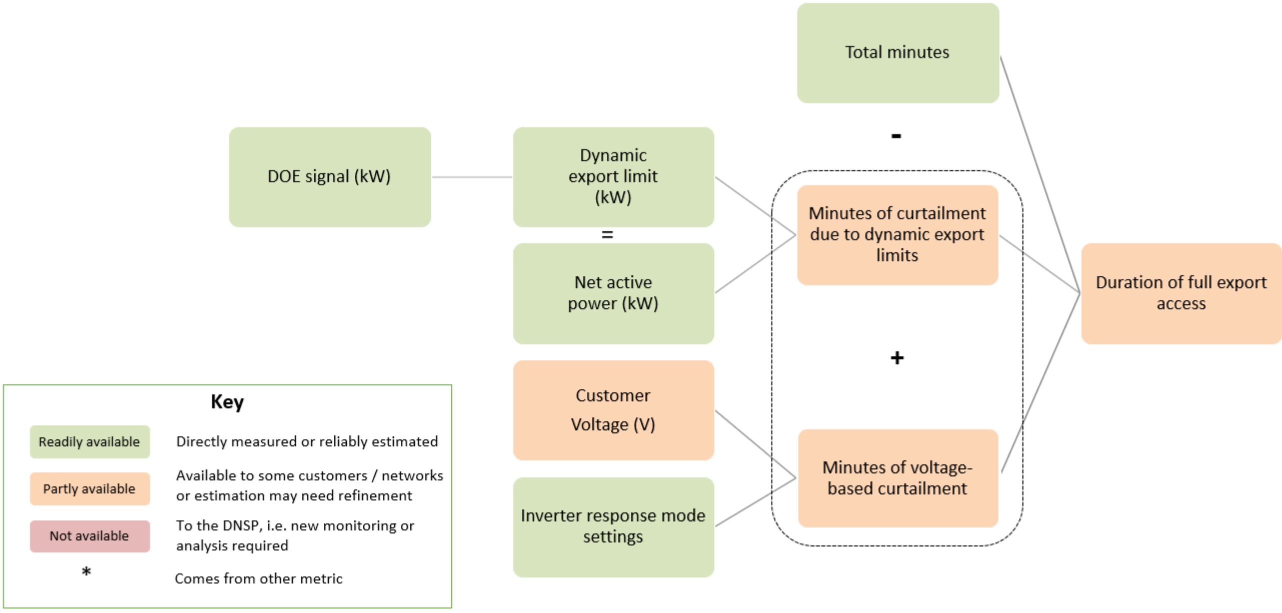

Figure 6. Simplified calculation diagram: Duration of Curtailment (Metric #10)

Limitations and challenges

- Metric deteriorates with higher DER penetration and thus it will be important to establish product offer thresholds that are both acceptable to customers and can be maintained for the life of the customer investment.
- 97% availability of export service translates to ~15,750 mins/year or ~260 hrs/year of interruption to full export access. Expression of the metric in this format may have some limitations:
  - Percentage figures of constrained time relative to *total hours* may not be intuitive to customers as it includes night hours
  - Performance variations in the *percentage* format may only be fractions of one percent
  - Conversely, *minutes* of curtailment per year sound very large, even when they are relatively inconsequential to a customer's business case
  - Therefore, the two metric formats are best reported alongside one another.
- If retailer-based export curtailment occurred at the level of the dynamic limit, it may be confused as network-driven in the data, however, this is considered an unlikely occurrence.
- This metric assumes that inverters are operating at the agreed operating settings. Unusual behaviour, such as exports over the agreed export limit, needs to be identified before carrying out the calculations to avoid misleading results.[31]
- While estimating curtailment due to static and dynamic export limits may be easily measurable, identifying voltage-based curtailment events is challenging, especially if voltage data are unavailable. The rationale and method used in CANVAS and firstly proposed in Stringer et al. (2021)[32] can be used to identify curtailment events using the normalised generation data. Nevertheless, this method has some limitations in its capacity to prove that the curtailment identified is due to inverter voltage response modes. Also, the technique relies on clear sky conditions for PV estimation and local load

[31] This issue may apply to Metrics #10 and #27.

[32] Stringer, et al. (2021), "Fair consumer outcomes in the balance: Data driven analysis of distributed PV curtailment," *Renew. Energy*, 173, 972–986. https://doi.org/10.1016/j.renene.2021.04.020.

behaviours, which may lead to estimation errors. Hence, voltage-based curtailment could be initially ignored subject to future review and this is an important area for future research.

4.3 Export Service Levels Achieved (#28)

Description

This metric measures a network's delivery on export service level offers agreed with customers in their connection agreements. For example, did dynamic export customers receive the agreed full export capacity up to 10 kW 97% of the time? Did static export customers receive the agreed 1.5 kW full export capacity 99.5% of the time? (Service levels are proposed to be defined using Metrics #10 supported by #5)

This metric is used for penalties or incentives under a potential STPIS scheme. It is intended to ensure that networks meet their contractual obligations to customers and that export service offers are reflective of actual performance.

For regulatory purposes this would be applied at the system level and for operational purposes (to ensure ongoing STPIS compliance) this may be calculated by the zone or feeder.

General formula: [*# of DER customers for whom export service level agreement is met/# of DER customers*]

Contextual examples

"During the period, Network A met its customer export service level agreements for 90% of customers. As the stipulated performance benchmark is 95% a penalty is applied for this period." **[Use case 2a]**

Limitations and Challenges

- This metric ensures that DNSPs are only *penalised* for not providing the level of service *agreed* with the customer, but it does not incentivise system improvements in DER access to export service—this occurs via #5 (Total Utilised DER Generation). Without a target/incentive for Metric #5, #28 would create an undesirable incentive for DNSPs to set lower limits and potentially favour static over dynamic limits as they only need to be concerned with voltage-based curtailment. Thus #28 relies on #5 for driving the desired system behaviour.
- Penalising NSPs based on the *percentage of customers* achieving agreed service levels may create a perverse incentive towards customer inequity as fewer customers suffering more curtailment would reflect better on this metric. A potential solution to this issue would be to allocate a total annual budget (in minutes per year) where full export service is not available based on the performance enshrined in customer connection agreements. This may also present a simpler means of operationally managing STPIS compliance throughout the year.

4.4 Volume of Curtailment (#27)

Description

This metric estimates the total volume of energy curtailed by i) voltage-based curtailment[33] as well as curtailment during periods when customers reach their (ii) static export limits or (iii) flexible export limits. The estimate is calculated using *expected* DER generation based on the DER register and climate data. This metric informs Metrics #5, #17 and #30. It can be expressed in energy (kWh/year) or as a percentage of total production.

Customers and industry parties can use these figures to calculate the Financial Impact of Curtailment (in $/year) based on prevailing consumption rates and feed-in-tariffs, or DNSPs can calculate the economic impact of curtailment based on the Customer Export Curtailment Value (CECV). As each type of curtailment is calculated separately, this enables industry parties to place a higher value on the loss of behind-the-meter generation from voltage-based curtailment, for example. For those DNSPs that adopt dynamic export limits to actively manage export capacity, we expect that the incidence of overvoltage curtailment—and hence loss of BTM generation—will remain very low, and it is expected to become negligible as management strategies through export limits improve. Nonetheless, this distinction is important to DER owners because the loss of any BTM generation forgoes the offset of full retail prices rather than just a lower export feed-in-tariff. There may also be a greater emotional customer connection to the loss of BTM generation.

This metric is most useful for customer communication and business case preparation. Its broader use is within the calculation of Total Utilised DER Generation (#5) to ensure that higher curtailment is considered in the context of greater levels of DER connection and access. Also, BTM energy curtailment has greatest relevance for customer communication Use case 1b as it informs the customer's business case, which is a primary driver for DER investment.[34] More granular (below-system-level) calculation of this metric is generally recommended to clarify the variation in customer outcomes between DER customer types, regions or zone substations.

Contextual examples

"Customers on flexible export limits on average experienced estimated curtailment of XXX kWh/year or 1% of total production. Customers on static export limits on average experienced estimated curtailment of YYY kWh/year or 4% of total production." **[Use case 1a, 1b]**

[Flow on application when converted to $]: "We propose to invest $X million in Y program to deliver $Z million of value to customers in reduced volume of curtailment valued at the CEVC." **[Use cases 1c, 3b]**

Note that this metric can be reaggregated according to time-of-day and season block formats, which would enable the underlying data to be used for simpler communication with industry/customers regarding new DER connections[35] as per the following example:

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33 While V-W curtailment is estimated in the test data, V-VAr curtailment is currently excluded as estimation methods are still being developed within the industry.

34 Energy Consumers Australia (ECA). (2021). *Behaviour Survey results—Households*. https://ecss.energyconsumersaustralia.com.au/behaviour-survey-oct-2021/purchase-intentions/

35 This was originally a separate metric called Curtailment Timing (#30) which has been rolled into #27.

"For small DER customers on flexible exports, 90% of the energy curtailed occurred between 1 am and 1 pm in spring to maintain a safe and stable supply when local energy demand was almost entirely met by rooftop solar." **[Use cases 1b, 2b]**

General calculation approach

Simplified formula: [*Volume of energy curtailed* (*total and by each type of curtailment*)]

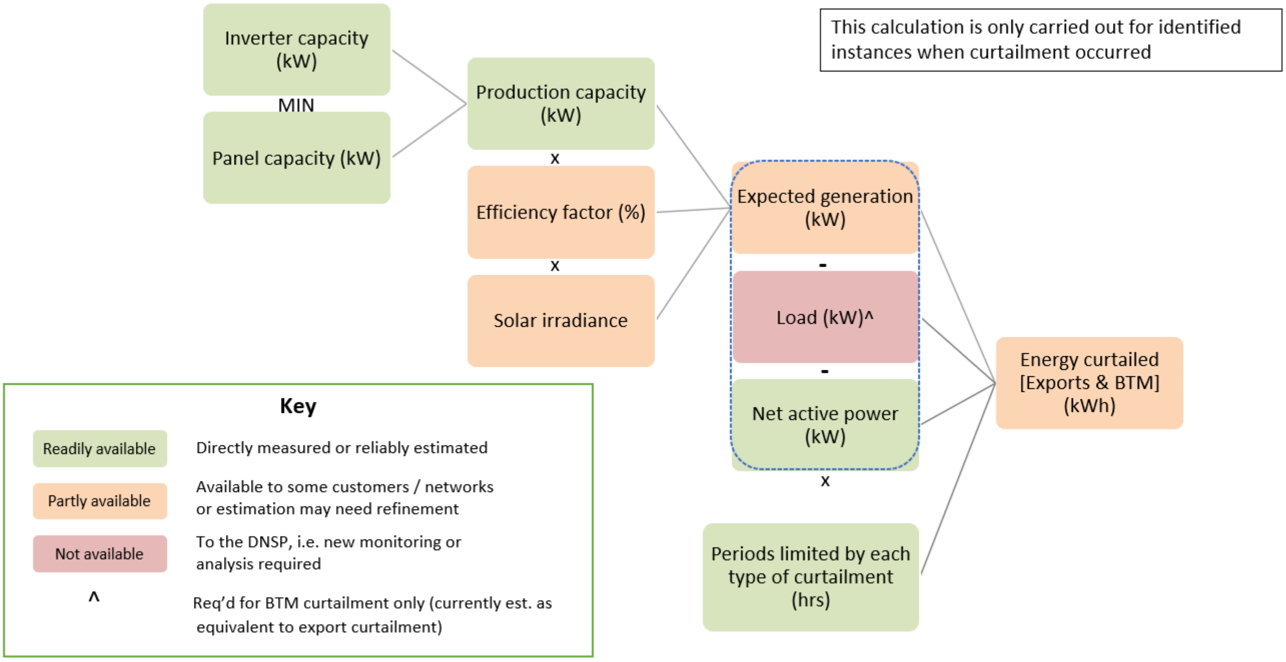

Figure 7. Simplified calculation diagram: Volume of Energy Curtailed (Metric #27)

Limitations and challenges

As the base data and method for this metric are similar to Duration of Full Export Access (#10), this metric faces similar limitations and challenges related to accuracy, data availability and deterioration with higher DER penetration. Additional challenges include:

- More work is required to accurately estimate the volume of behind-the-meter (BTM) curtailment caused by voltage-based curtailment. Until this is available a 'rule of thumb' of doubling the export curtailment is used. Note that
  - This metric requires the estimation of DER generation so the actual energy export data can be compared with the *expected* generation.
  - Local load data is required to accurately identify the energy curtailed BTM and the energy related to exports.
- This metric assumes that inverters are operating at the agreed operating settings. Unusual behaviour, such as exports over the agreed export limit, needs to be identified before carrying out the calculations to avoid misleading results.[36]

[36] This issue may apply to Metrics #10 and #27.

- In calculating the volume of curtailment (based on periods in which customer metering data shows active power sitting at the agreed export limit), it is important to avoid utilised DER being mistaken for curtailment. However, given the expiry of premium feed-in tariffs, self-consumption is almost always more desirable than exporting so these theoretical scenarios are considered very unlikely to actually occur and are thus ignored. The three example scenarios are:

1. Battery storage systems (BSS): If the management system directs solar to the battery only when the export limit is reached, this would be counted as curtailment, even though the excess solar is in fact being utilised. However, as self-consumption is more desirable than export, it is more likely that BSS recharge would be prioritised before any export and the customer data would *not* show them as sitting at their export limit.[37]
2. EV charging: A customer could theoretically charge their EV only when their export limit is reached, which could be mistaken as curtailment (as per the BSS case). In practice, as EV batteries are much larger and have an additional primary use for transport, it is considered much more likely that *any* excess solar would be directed to the EV before exporting and the customer data would *not* show them as sitting at their export limit. We therefore propose to ignore EV-charging in calculating the volume of curtailment. This could be reviewed with future inclusion of EV-charging in the DER Register.
3. Smart energy management: A customer with smart energy management could direct excess solar generation beyond their export limit to power an electric storage hot water system or pre-heat or pre-cool the premises using an HVAC unit. This is a slightly more plausible scenario given that these uses of excess generation are perhaps more discretionary than transport (at least in the case of pre-cooling, for example). However, we propose to ignore smart energy management as its penetration in the system is currently negligibly low. This should be reviewed in the future.

Given the levels of uncertainty in the above scenario assumptions, they are areas recommended for future research to ensure the most accurate accounting is undertaken when the situations are more commonplace.

4.5 Volume of DER System Services (#22)

Description

This supplementary metric measures the volume of system-level (market) services provided by DER such as (i) Frequency Control Ancillary Services (FCAS), (ii) Fast Frequency Response (FFR), (iii) Synthetic Inertia, iv) Wholesale Demand Response (WDR) and (v) Reliability and Emergency Reserve Trader (RERT) services. The estimation of this metric relies on AEMO's data and records for system services provided by DER. Figures are normalised per MW installed DER capacity or per customer. Currently only WDR and FCAS are available via AEMO.

System-level metrics are considered sufficient for customer communication, regulatory and planning purposes.

[37] If it was considered material in future, an option would be to ignore periods of static limit driven or dynamic limit driven curtailment for customers flagged on the DER register as having a BSS. This may *underestimate* curtailment in cases where the BSS is fully charged.

Contextual example

Contextual example: "Network A's improvement in export service provision from DER unlocked the following system-level benefits:

- XX MW of wholesale demand response/customer
- XX MW of RERT
- etc...

These figures are in line with industry benchmarks." **[Use case 2b]**

General calculation approach

Overall, DER system services data are currently not easily accessible or readable because (i) system services provided by DER exist in many forms, (ii) diverse communication channels, including reports or databases and (iii) lack of public data that captures all DER market services. Since this metric depends on AEMO data, formal definitions and categories based on AEMO's reports are required. Two major categories for market services are delivered by DERs:

1. **Demand response** (also referred to as *demand side participation* in AEMO's reports[38]), which captures direct response by industrial users and consumer response through programs run by retailers, DSP aggregators or network service providers
2. **Ancillary services** are used by market operators to manage the power system securely, safely and reliably. Ancillary services are evolving to integrate DER participation.

Table 6 below summarises relevant information about DER market services programs based on AEMO definitions and classifications.

Table 6. DER system services data stream summary

	Market service	Relevant data	Frequency	How to access	Notes
Demand response programs	Wholesale Demand Response (WDR)	WDR AEMO reports would include: - Amount of dispatched WDR - Number and capacity of WDR units - Analysis of the spot market price levels at which WDR was dispatched - Analysis of trends, including year-on-year changes.		TBD	Alternatively, relevant data are available in the NEM Electricity Statement of Opportunities report. NEMWEB data are grouped by region ID (state).
		Estimated power amount of WDR through the NEMWEB portal	Daily and half-hourly	See Demand and Forecast data on NEMWEB portal	
	Reliability and Emergency Reserve Trader (RERT)	In case of reserve activation events, AEMO publishes estimated payments and volumes activated per state.	Based on service provision	RERT reporting	

38 https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/nem-electricity-demand-forecasts/2018-electricity-forecasting-insights-march-2018-update/demand-side-participation

	Market service	Relevant data	Frequency	How to access	Notes
	Contractual arrangements via retailer or NSP	Maximum potential size of demand response, load and technology type		DSP Information Portal	
Ancillary services	Frequency Control Ancillary Services (FCAS)	Amount of dispatched FCAS services	5-minute resolution	See Dispatch data on NEMWEB portal	Needs data processing task to aggregate data by DNSPs using units ID
	Fast Frequency Response (FFR)	Amount of dispatched FFR services			Not available yet[39]
	Synthetic Inertia	Amount of dispatched synthetic inertia services			Not available yet

AEMO has recently deployed solutions to capture DER market services that would facilitate the calculation of this metric. For example, wholesale demand response values are now available on the NEMWEB portal and annually reported in the NEM Electricity Statement of Opportunities Report. Additionally, marketplaces such as the FCAS market could facilitate the estimation of DER market services. Currently there is no market for FFR and synthetic inertia services, and therefore the estimation of DER participation in these market services may need to develop other approaches.

Limitations and challenges

- Current AEMO databases and reports aggregate data by NEM regions. These data need to be broken down so metrics can be estimated by network businesses.
- Currently this metric relies on pulling data from multiple sources, including reports and data portals. This condition adds extra complexity to collecting data and estimating the underlying DER market services. There is therefore a need to develop a single platform that integrates and summarises DER market services.
- DER market services have a strong dependency on factors exogenous to the network business such as customer behaviours, market price signals and third-party product providers. Thus, the metrics are more useful for quantifying customer and market benefits from DER export access (customer and network business cases) but less so for shaping network behaviour towards increasing use of these resources.

4.6 CO_2 Emissions Reduction (#17)

Description

This metric translates the environmental impact of renewable DER generation into carbon emission reductions, which may be of particular interest to environmentally oriented customers.[40] This metric currently

[39] Currently there are no Fast Frequency Response spot markets. However, In July 2021 AEMC published a final determination on the introduction of two new market ancillary services that would include FFR services, which may facilitate the access to relevant data for this metric. See https://www.aemc.gov.au/rule-changes/fast-frequency-response-market-ancillary-service.

[40] The ECA Behaviour Survey results show that around 40% of households invest in PV solar panels and battery storage systems to protect the environment. For further details see https://ecss.energyconsumersaustralia.com.au/behaviour-survey-oct-2021/purchase-intentions/.

relies on the final Total Utilised DER Generation metric (#5) and the regional emission factor. Essentially it answers the question *How much CO_2 would be emitted if there were no rooftop solar and all energy had to be supplied by the current mix of grid-connected generators?*

For stakeholder communication use cases (such as demonstrating societal benefits from export service investments), this metric could use AEMO data for approximate average region calculations. However, in future it is anticipated to be required to account for time-varying emissions intensity and would thus require a bottom-up calculation approach in the long term. Given that Metric #5 ultimately also requires bottom-up calculation, this is considered manageable. In future time-based emissions calculations are likely to be a key value differentiator for emerging blockchain business models that seek to verify organisational 'true net zero' or 24/7 renewables claims (i.e., where renewable energy sourcing directly matches organisational half-hourly load profiles).

Contextual examples

[Average emissions intensity application]: "Investment facilitating new rooftop solar access has reduced total annual CO_2 emissions to 1 Mt across South Australia. This is the equivalent of taking XXX cars off the road." **[Use case 1c]**

General calculation approach

General formula:

- ***Near-term:* [*Total Utilised (renewable) DER Generation x annual average emissions factor*]**
- ***Long-term:* [*Total Utilised (renewable) DER Generation x hourly emissions factor*]**

Note that electricity consumption is classified as indirect emissions ('Scope 2'). The proposed approach only considers reduction in Scope 2 emissions and not Scope 3 emissions from the upstream extraction of fossil fuels underlying that electricity consumption.

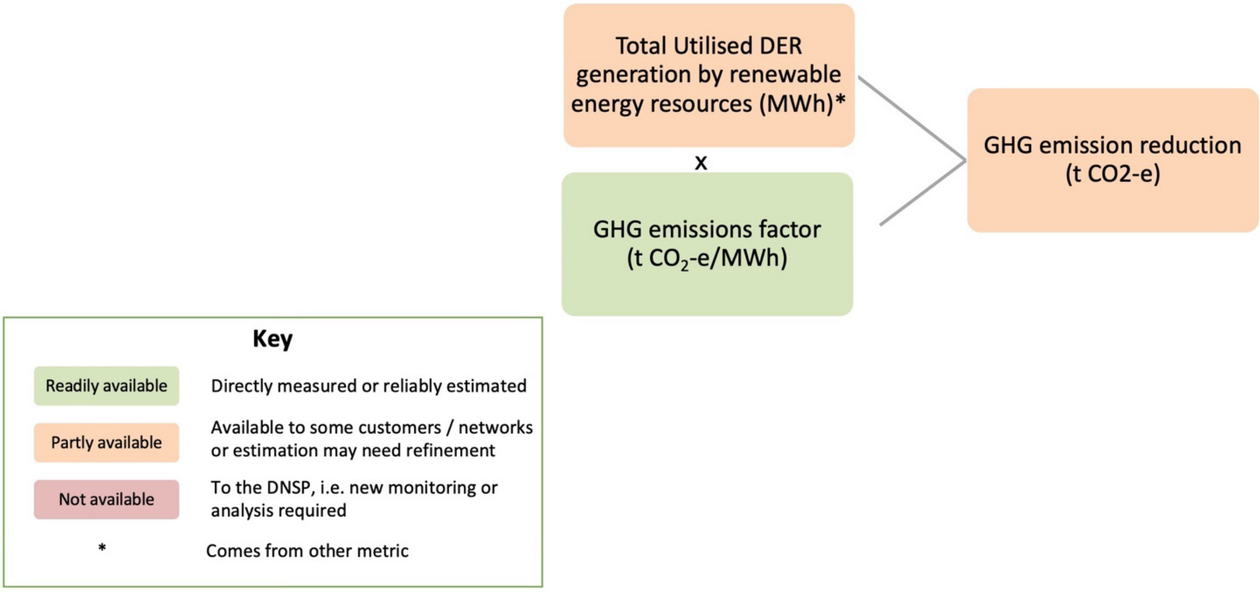

Figure 8. Simplified calculation diagram: CO_2 Emissions Reduction (Metric #17)

Limitations and challenges

- Capturing the impact of flexible DER such as battery storage systems and EVs would need another calculation approach as it may need to determine the source of energy for these systems.
- National greenhouse account factors are only reported by state or territory. This is likely to be adequate as time-based variation in emissions intensity will likely be more important than variation within greenhouse reporting regions.

4.7 Customer Complaints (#12)

Description

This metric provides a direct measure of the service that customers are receiving and the impact of the export service strategy on the network but may require some changes to the format in which customer complaints are recorded. Most DNSPs appear to have a relatively consistent complaint reporting format with regard to overvoltage issues but this format does not *explicitly* account for export service quality. Nonetheless, the existing complaint category of overvoltage could be a sufficiently useful proxy at least in the short term.

Uses for this metric are to support cases for investment in improving export service quality, which might be at the system level or more commonly within a particular zone or feeder requiring dedicated attention.

Contextual examples

"Customer complaints regarding export services in Zone X have increased by 20%, warranting planned programmatic investment in X management measures to ensure equitable access to exports." **[Use case 1c]**

"X complaints were reported in Zone Y, prompting the replacement of component Z." **[*Use cases 3a and 3b*]**

General calculation approach

General formula: [*Number of customer complaints received and resolved related to export services*]

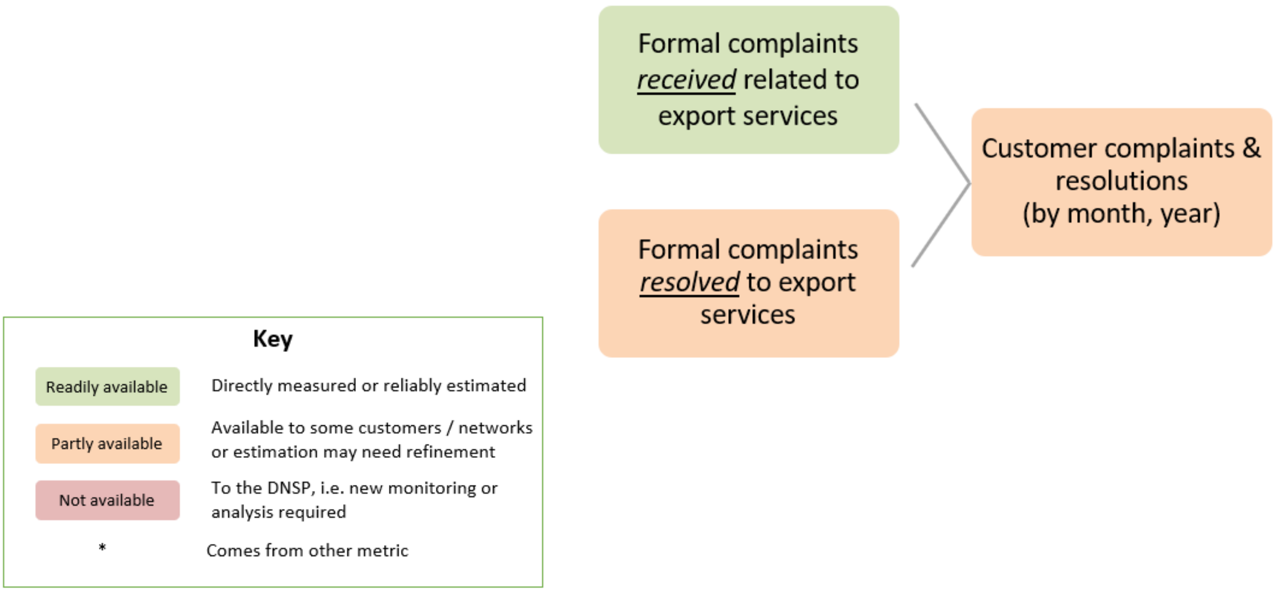

Figure 9. Simplified calculation diagram: Customer Complaints (Metric #12)

Limitations and challenges

- Overvoltage complaints may overestimate export service issues (as not all overvoltage issues relate to DER). Therefore, this metric may require a general review of how complaints are recorded and whether the current format is sufficient for capturing export service.
- How customer complaints are recorded in the DNSP database system is very important as typographical errors or incorrectly selected complaint categories may lead to misleading outputs.
- It is worth noting that when a customer complaint is received it usually enters a 'verification' phase to identify the need to assign a job to resolve the received complain. If no problems are identified then the complaint is not assigned a job. If there are problems, the complaint is categorised into remediation groups depending on the severity of the issue. This process may create some difficulties to track complaints from the complaint received phase to the resolution phase as not all complaints need an assigned job. This may also create complexities to estimate resolution rates based on complaints received and complaints resolved.

5 Data visibility and access capabilities across network businesses

Good data supply is essential for estimating export quality performance metrics. This section summarises the findings regarding data needs that were revealed through the road-test process and the survey of DNSP data access to estimate the proposed metrics. Before exploring these findings Table 7 presents an overview of the data needs. In summary, estimating metrics requires data from multiple sources including market data, DNSP data, customer data and other sources such as weather and emissions data. Note that various metrics that are shown with similar inputs commonly depend on the prior calculation of those other metrics. For example, calculating #28 requires #10 to be calculated first.

Table 7. Data inputs for shortlisted metrics

		DNSP data									Other sources		
ID	**Proposed metric**	**Voltage**	**Active power**	**Reactive power**	**DER installed capacity**	**Inverter capacity**	**Inverter settings**	**Export limit value**	**# of DER customers**	**Customer complaints**	**Solar irradiance data**	**AEMO database**	**Emission factor**
5	Total utilised DER generation		●		●	●			●		●	●	
10	Duration of full export access	○	●	○	●	●	○	●					
28	Export service levels achieved	○	●	○	●	●	○	●		●			
27	Volume of curtailment	○	●	○	●	●	○	●			●		
22	Volume of DER system services				●				●			○	
17	CO_2 emissions reduction		●		●	●					●	●	●
12	Customer complaints									●			

Key:

- (blue) Operations and planning data
- (grey) DER and inverter data
- (yellow) Customer # data and complaint records
- (pink) External source data
- ● Required data (med-high accessibility)
- ○ Required data (limited data available or difficult to process/access)

5.1 Data needs findings

Finding 1: Improved LV network visibility is important

While DNSPs usually have visibility over high voltage levels, DNSPs broadly have low visibility and access to medium and low voltage data, which is where most DER are connected.[41] DNSPs consider that data availability is a key barrier that might interfere with the calculation of some shortlisted metrics, in particular metrics related to curtailment. For example, actual load and inverter data would improve estimation techniques so that curtailment events could be estimated more accurately and the impact on BTM and exports could be analysed separately. However, DNSPs reported low visibility of BTM power flows (which may also raise customer privacy concerns).

There is currently poor access to voltage data across the breadth of distribution networks, especially at customer connection points. Improving voltage visibility would facilitate and improve the accuracy of curtailment estimations. Network businesses with low visibility and lacking monitoring capabilities may need to develop proxies and alternative approaches to calculate the proposed metrics.

In general, adding more visibility to LV networks remains an immediate need. AEMC is currently working with stakeholders on developing a package of measures to support a faster and more efficient deployment of smart meters.[42] Nonetheless, accelerating the rolling out of smart-meters across the NEM still faces key challenges. In particular, a regulatory framework is needed to provide metering services at fair and reasonable price. Under the existing framework, for example, metering coordinators offer services on a monopoly basis without regulation (i.e., DNSPs are price-takers), precluding workable commercial arrangements for establishing the long-term arrangements required by DNSPs.

Finding 2: DNSPs need to develop a data management strategy that improves data quality, data consistency and data access

Data quality and data access pose specific challenges for calculating the proposed metrics. Some input data rely on manual processes and are subject to human errors which may affect metric accuracy. For instance, customer complaint data require additional data processing and cleaning tasks to identify reported complaint anomalies. Also, some network data rely on third-party entities, which may affect the data quality and access. For example, inverter settings, including static limits settings, depend on accurate data captured by the installer.

There is a need to develop a consistent format for collecting and reporting data for the final suite of metrics. DNSPs have different monitoring capabilities, which may raise data consistency issues and make it challenging to use metrics and implement use cases such as regulatory compliance use cases that require consistency across DNSPs.

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[41] Australian Energy Market Commission (AEMC). (2019). *Economic Regulatory Framework Review—Integrating distributed energy resources for the grid of the future*. https://www.aemc.gov.au/sites/default/files/2019-09/Final%20report%20-%20ENERFR%202019%20-%20EPR0068.PDF

[42] Australian Energy Market Commission (AEMC). (2022). *Review of the regulatory framework for metering services*. https://www.aemc.gov.au/market-reviews-advice/review-regulatory-framework-metering-services

Data access issues can add complexity to the metric calculation process. If network data are not stored in digital databases and depend on paper-based documents (this could be the case for data related to legacy equipment), calculation processes would be delayed due to data collection and processing issues.

Finding 3: Further work is needed to make available data suitable for calculating and reporting metrics.

Some relevant data are currently available but require changes to spatial or temporal granularity to enable their use. For example, AEMO data is a valuable source of DER and market data. However, using these data would require developing a new and consistent format to facilitate access and collaboration with network businesses. For example, AEMO reports DER market services by NEM regions so these data would need to be broken down by network jurisdictions. Another example is network data related to dynamic and static limits which tend to be stored in different formats and data capture systems.

Additionally, the input data collection process needs to be able to capture the *most recent* data. The algorithms developed during the road-test need network and DER parameters (e.g., operating voltage limits, inverter settings, export limit in connection agreements) to set conditionals and calculate metrics. Outdated data will result in misestimating the export service performance. For example, DNSPs do not have real-time access to inverter settings, including static export limits in connection agreements, and rely on data reported by installers. Changes in inverter settings without updating DNSPs datasets would result in inaccurate estimations.

Finding 4: We need to understand the current state of DER hosting capacity relative to the expected conditions over the period of the business case.

Solar industry representatives stressed the importance of being able to understand the current state of network congestion relative to the expected conditions over the period of the business case. We recommend that export service level offers are made with a 10-year time horizon in mind and that data on DER hosting capacity of the network ultimately be made available alongside the proposed headline export service quality metrics.

Finding 5: Seek industry feedback on reporting formats and granularity

The metrics commonly require different formats depending on the use case. DNSPs acknowledge that reporting the number of DER customers by feeder type (e.g., CBD, urban, short rural, long rural) and size is relatively easy. It is somewhat more difficult to report DER data by technology type (e.g., PV, battery, EV). DNSPs noted a particular challenge in classifying and reporting data by export management strategies due to a lack of a standard classification and definitions across DNSPs. In particular, curtailment and export limits need to be formally defined.

The frequency of metric reporting can also be adapted based on the use-case practicality. While quarterly and annual reports might be the most practical formats for customer communication and regulatory compliance use cases, network operational use cases may require real-time calculations. For example, real-time calculations of Total Utilised DER Generation and curtailment metrics (#5, #10 and #27) may be needed to inform live operational decisions and manage compliance throughout the year. This may be substantially more challenging for streamlined data systems and calculation processes.

Finding 6: Extension of DER Register to include dynamic export limits and EV-related data is recommended

Metrics can take different formats depending on the use case application. For example, DNSPs may need to report metrics based on feeder types, DER sizes, technology types or management strategies. The DER register held by AEMO is a valuable dataset for classifying DER-related data but does not yet include data associated with EVs/chargers[43] and dynamic limits. Hence, DNSPs may be unable to report on EV customers as they currently do not have visibility of EV data.

Finding 7: Data privacy is a key concern to stakeholders generally, but is not highly problematic for the calculation and communication of export service performance metrics

The use of LV data needs to comply with consumer privacy requirements. It is expected that no new data privacy issues will arise from the data sources contemplated in this report. For example, active power data are currently accessible for billing and have well-defined privacy protections and obligations in place. Another example is voltage data, which may need to be measured at the connection point; this can be done by network providers without impacting data customer privacy. Commercial and business data will also be protected as metric calculations will be performed by DNSPs.

Finding 8: Improved accessibility to DER market service data is important

DER market services data are currently reported in many forms in AEMO reports and databases. AEMO DER register and DSP portal are practical portals to access DER data but do not capture all DER market services such as FCAS and FFR. Further work is needed to assess viable options to improve accessibility to DER market service data such as aggregating DER-related data in a one particular platform/database.

Some DER Register and DSP data require additional granularity by network territory (see Finding 3).

Finding 9: Increase capabilities for bottom-up export service and curtailment calculation

Ultimately bottom-up calculations will be required to accurately understand export service quality. However, this may require more robust data capabilities to manage large datasets and develop more sophisticated estimation methods, for example to estimate expected DER generation and curtailment events.

Finding 10: Customer complaint formats may need to be updated to capture export service issues

43 The need and priorities for EV data has been identified by the EV Data Availability Taskforce led by AEMO. EV data recommendations are available at https://aemo.com.au/-/media/files/stakeholder_consultation/working_groups/der-program/deip-ev/2021/deip-ev-data-availability-taskforce-report.pdf?la=en

While existing complaint data carries some value for overvoltage issues, DNSPs noted that additional work might be required to capture customer complaints specifically related to export services. A new categorisation of complaints may help to identify specific complaints related to the quality of customer export services.

6 Summary and recommendations

6.1 Summary of findings

This project establishes a set of proposed metrics for understanding and communicating the quality of export services. Across the required use case applications, four headline metrics were considered to have the greatest value to monitor and manage network export service quality.

1. **Volume of Curtailment (#27):** Expresses the amount of energy that customers could have exported to the market that was curtailed due to network constraints. The AER has developed its Customer Export Curtailment Value (CECV) to assign an economic value to this energy. This metric aids effective communication of export service quality implications in terms that are meaningful to customers. It provides transparency and allows industry parties to calculate financial implications of network export limitations and improvements.

2. **Total Utilised DER Generation (#5):** Expresses the amount of energy able to be produced by DER taking into account energy exported to the grid and energy consumed behind the meter. This metric is considered the best overarching indicator of desirable service performance because it seeks to drive a net improvement in the productive use of DER while limiting export congestion. Ideally, this metric is measured directly from customer telemetry, which is currently available for dynamic export customers in South Australia. For other customers, however, it would need to be calculated from estimated potential DER generation minus the estimated volume of curtailment.

3. **Duration of Full Export Access (#10):** Expresses the annual percentage of time that customers experience unconstrained access up to the maximum export limit set in their connection agreement. This metric is used to *define* and communicate the network export availability dimension of export service product offers.

4. **Export Service Levels Achieved (#28):** Measures a network's compliance with the export service levels stipulated in its customer connection agreements (defined using #10 above). Penalties could be set with this metric to ensure that networks accurately understand, communicate and deliver on their export service quality agreements with customers.

An additional three supplementary metrics (Volume of DER System Services, CO_2 Emissions Reduction and Customer Complaints) support other use cases and allow the suite to capture the full value customers receive from DER export services.

Many of these metrics cannot currently be calculated across the full customer base and more sophisticated data capture and analysis workflows need to be developed over time. Ultimately a bottom-up understanding of curtailment and export service access is required.

6.2 Recommendations

While this project has laid a solid foundation for export service quality measurement and communication, further work is required to address emerging challenges. Future research topics are classified into three focus areas:

1. Metric refinement

- Strengthen industry experience working with real network data applied to STPIS scheme and benchmarking of economic efficiency with regard to network export services

- More widely test the behaviour of proposed metrics with synthetic 'hypothetical' and a wider range of DNSP data, especially Total Utilised DER Generation and Duration of Full Export Access.
- Test customer response to new and existing DER customer use cases to refine communication (see also workshop suggestions below)

2. Estimation techniques

- Develop methods to overcome low LV data visibility and monitoring issues to estimate and improve accuracy of the proposed metrics
- Develop methods to estimate V-W and V-VAr curtailment

3. Supporting information

- Prototype trend data for DER hosting capacity alongside proposed metrics
- Develop widely shared definitions of curtailment and export service concepts
- Improve forecasting of network congestion to understand export service quality and hosting capacity implications over the lifetime of customer DER investments

Additionally, stakeholders at the final workshop suggested

4. Strengthening customer communication and understanding of export service performance metrics. This would include a guide of how metrics can be used and how they should be interpreted. It would also include a review of communication channels and non-technical language to communicate metrics considering a diversity of consumer expectations, priorities and needs within the customer communication use case. This future work belongs to the supporting information category presented above.

5. Studying additional options for providing non-financial incentives such as reputational incentives as suggested by the AER. Reputational incentives could help to alleviate potential concerns around defining financial rewards and penalties that depend on low network visibility and estimation calculation techniques.

6. Assessing the intersection of regulatory incentives related to network visibility and voltage management. The ESB has proposed that LV network visibility could be improved through developing incentives to increase network data access and visibility over time.[44] The Victorian Government has also noted that a voltage-related incentive could be developed to improve voltage management beyond compliance to unlock additional customer and emission reduction benefits. The deployment of these incentive options alongside metrics to capture their associated performance would require further analysis.[45]

[44] Department of Environment, Land, Water and Planning. (2022). *Voltage management in distribution networks*. Consultation paper. https://engage.vic.gov.au/voltage-management-in-distribution-networks-consultation-paper

[45] Energy Security Board. (2021). *Data strategy*. Final recommendations. https://esb-post2025-market-design.aemc.gov.au/32572/1630275857-esb-data-strategy-july-2021.pdf

Appendices

Appendix A: Project details and method summary

A.1. Project partner team

Organisation	Name	Role
UTS	Edward Langham	Project Director
UTS	Jaysson Guerrero	Project Manager and Researcher
UTS	Kriti Nagrath	IRG Coordinator and Researcher
UTS	David Roche	Researcher
SA Power Networks	Cathryn McDonald	SAPN Project Lead, Network Optimisation Engineer
SA Power Networks	Bryn Williams	Network Strategy Manager
SA Power Networks	Sheryl Mourin	Network Optimisation Graduate Engineer
Essential Energy	Gavin Morrison	Network Capability Manager
Essential Energy	Scott Condie	Senior Engineer, Forecasting and Ratings

A.2. IRG composition

The following organisations provided invaluable input to the industry reference group (IRG) process:

- Australian Energy Regulator
- Energy Networks Australia
- ARENA / Distributed Energy Integration Program
- Australian Energy Markets Commission
- Solar Analytics
- Energy Consumers Australia
- Clean Energy Council
- NSW DPIE
- Queensland DNRME
- South Australia DEM
- Horizon Power
- UNSW
- Australian Energy Market Operator

A.3. Methodology

The developed methodology consists of four core tasks including an environmental scan, metric development, a road test and a set of outcomes and emerging lessons. The emerging outputs of each core task were discussed with key stakeholders through a series of engagement activities encompassing four RACE IRG workshops[46] across the duration of the project, one workshop with SAPN solar industry reference group to

[46] A table showing all IRG participants and the timeline of the workshops is presented in Appendix A.

discuss draft metrics and calculation approaches, and an online survey for DNSPs to flag any potential data access limitations or potential implementation issues across different network circumstances.

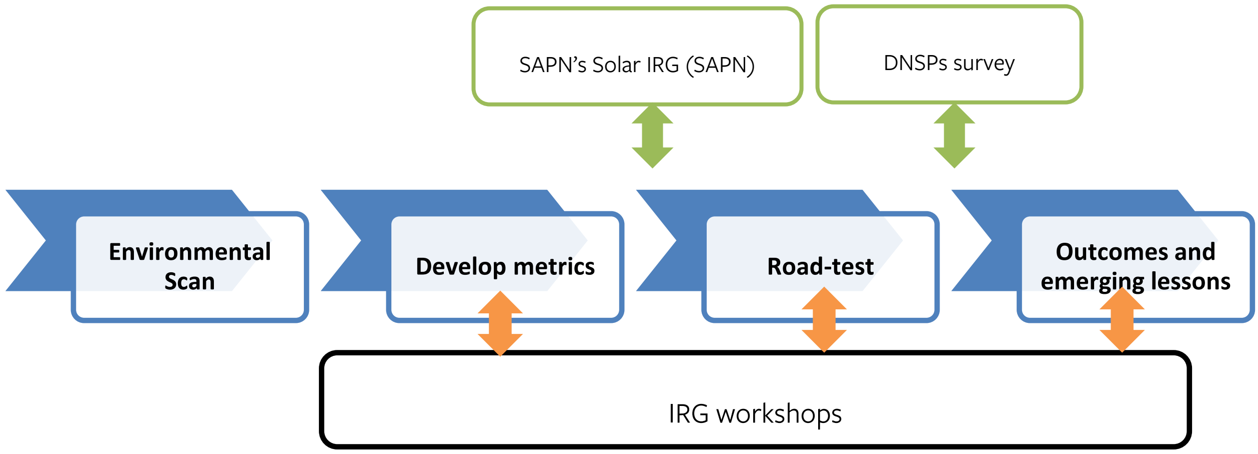


Figure 10. Methodology outline

Environmental scan

To explore relevant academic literature and industry activities an environmental scan review was conducted during the project's first stage. This task sought to clarify the breadth of terminology being applied to related and intersecting work to ensure that the developed work adequately covers the relevant activity and clarifies the interplay with the evolving regulatory environment. The reviewed literature underpinned the background context described in Section 2 above, as well as the basis for the long-list of performance metrics for export services.

Develop metrics and calculation options

As a result of the environmental scan a set of assessment criteria and use cases were developed to define what a successful approach to understanding and communicating DER export service quality looks like. This covered issues such as data accessibility, the accuracy of representation, interpretability, fairness, ability to facilitate higher DER uptake, ability to reduce total curtailment, regulatory outcomes (including unintended consequences) and applicability to different use cases or network types. The assessment criteria were then applied to a long list of metrics to score options and develop a proposed shortlist.

Road test

The chosen shortlisted metrics were tested using SAPN and Essential Energy network data to identify access or reliability issues and review possible formats and use cases. This clarified how the outputs would reach end-users and any technical considerations that this may pose. Throughout this process the research team constantly communicated with network strategy and operations staff from SAPN and Essential Energy, and emerging outputs were discussed internally and presented to key stakeholders during the IRG workshops. Shortlisted metrics were tested using two types of analysis:

1. *A metric-by-metric analysis* in which the shortlisted metrics are estimated using real network data
2. *A use-case analysis* to clarify the use of the proposed calculated metrics and how they will reach end-users and stakeholders.

The metric-by-metric and use case analyses are presented in Sections 4 and 3.5, respectively.

Survey outcomes and emerging lessons

Iterative versions of emerging analysis and feedback were compiled in this document. The outcomes of this project are listed below.

1. Assessment criteria for scoring export service quality metrics—Subsection 3.2
2. Long list of potential export service quality metrics—Appendix B
3. Review of potential barriers to implementing the developed metrics across different network circumstances via an online survey—Section 5 shows the reporting of results and Appendix D the survey instrument
4. A detailed review, test and analysis of shortlisted metrics—Appendix C
5. Interim calculation templates of the developed shortlisted metrics—Appendix E
6. Recommendations and conclusions—Section 6

Appendix B: Long list of metrics

No	Potential Metrics	Aim/Reason	Metric Formula Options	Assessment criteria																	
				Does it measure service that customers value?						Is it practical & cost-effective?					Does it consistently drive the right outcomes/behaviour?						
				Increases gross DER utilisation	Not discourage self-consumption	Limits curtailment	Reduces emissions	Maintains/improves power quality	Allows direct financial benefit	Ease of data accessibility	Data quality	Ease of calculation	Ease of interpretation	Consistent over time	Applicability across different network types	Applicability across different customer types	Not influenced by factors outside the DNSP's control	Low potential for unintended perverse incentives/outcomes	Compatible with market-based pricing developments	Fair and consistent under different monitoring capabilities	Lag measure - Captures network investment
1	**Customers with export capabilities**	Reflects DER uptake	*As a percentage: # of DER customers / Total # of customers *Volume: Total DER capacity	Green flag	Grey circle	Red flag	Grey circle	Red flag	Grey circle	Yellow flag	Green flag	Green flag	Green flag	Green flag	Green flag	Green flag	Yellow flag	Red flag	Grey circle	Green flag	Yellow flag
2	**Energy generated for self-consumption**	Accounts for self-consumption	* As a percentage: Energy produced for self-consumption/ gross solar production * Volume: Total energy produced for self-consumption	Green flag	Green flag	Green flag	Grey circle	Green flag	Green flag	Red flag	Green flag	Green flag	Green flag	Green flag	Green flag	Green flag	Red flag	Yellow flag	Green flag	Red flag	Grey circle
3	**Energy stored for self-consumption**	Accounts for self-consumption	* As a percentage: Energy stored for self-consumption/ gross solar production * Volume: Total energy stored for self-consumption	Green flag	Green flag	Green flag	Grey circle	Green flag	Green flag	Red flag	Green flag	Green flag	Green flag	Green flag	Green flag	Green flag	Red flag	Yellow flag	Green flag	Red flag	Grey circle
4	**Energy exported to the grid**	Provides an indication of the overall net exports to the grid	* Percentage = Net electricity export to grid/ gross solar production * Percentage = Net electricity export to grid/ DER capacity * Volume = Total net energy exported to grid from PV system * Volume = Total net energy exported to grid from battery	Green flag	Red flag	Green flag	Grey circle	Red flag	Green flag	Green flag	Green flag	Green flag	Green flag	Green flag	Green flag	Green flag	Amber (!)	Red flag	Yellow flag	Red flag	Amber (!)

5	**Total gross solar generation**	Combines in-house usage, curtailment and exports	*Volume= Gross solar production * Percentage = Gross solar production/ DER capacity *Volume= Solar production - (total and by each type of) curtailment	green flag	check	yellow flag	grey circle	yellow flag	green flag	green flag	green flag	red flag	green flag	green flag	yellow flag	green flag	green flag	green flag	green flag	red flag	green flag
6	**Energy export allowed by export limits**	Provides an indication of the export capacity. Capture the concept of "available dynamic export capacity" emerged from [10]. This could provide a reasonable proxy for measuring the volume of active power curtailed, and gives a sense of the network's	*Ratio: Export limit / DER installed capacity *Volume: Energy export allowed *Volume: Average export limit	green flag	grey circle	yellow flag	grey circle	green flag	yellow flag	green flag	green flag	yellow flag	yellow flag	yellow flag	yellow flag	red flag	yellow flag	yellow flag	green flag	red flag	green flag
7	**Flexible limits vs. static limits**	Compares flexible and static limits. Reflect benefits of flexible limits as allows more exports.	*Volume = Energy exported with flexible limits - static limit (only positive values) * Percentage = |Energy exported with flexible limits - static limit| / static	green flag	grey circle	green flag	grey circle	green flag	green flag	green flag	green flag	green flag	yellow flag	yellow flag	yellow flag	yellow flag	yellow flag	yellow flag	grey circle	red flag	green flag
8	**Total export volume curtailed due to 1) tripping 2) V-Watt, 3) V-Var, and 4) export limits.**	Accounts for amount curtailed.	*Volume: Total energy curtailed due to 1) tripping 2) V-Watt, 3) V-Var, and 4) export limits *Percentage: Energy curtailed due to tripping/Total energy curtailed *Percentage: Energy curtailed due to V-Watt/Total energy curtailed *Percentage: Energy curtailed due to V-VAr/Total energy curtailed *Percentage: Energy curtailed due to	red flag	green flag	red flag	grey circle	green flag	red flag	red flag	yellow flag	red flag	red flag	yellow flag	yellow flag	red flag	yellow flag	red flag	warning (!)	red flag	green flag
9	**Number of times customers are constrained**	Account for service interruptions. Similar to SAIFI	*Ratio: Total # of times export limits were enabled / Total # of DER customers	red flag	green flag	red flag	grey circle	green flag	grey circle	red flag	yellow flag	red flag	yellow flag	green flag	yellow flag	red flag	yellow flag	red flag	grey circle	red flag	green flag
10	**Duration of curtailment: 1) static limits, 2) flexible limits and 3) both**	Account for service interruptions. Similar to SAIDI.	*Ratio: Minutes of sustained active export limits / Total # of times export limits were enabled	red flag	green flag	red flag	grey circle	green flag	red flag	red flag	yellow flag	red flag	yellow flag	green flag	yellow flag	red flag	yellow flag	red flag	grey circle	red flag	green flag

11	**Duration of curtailment via flexible limits per DER customer**	Account for service interruptions. Similar to CAIDI.	*Ratio: Minutes of sustained active export limits / Total # of DER customers	red	green	red	grey	green	red	red	yellow	red	red	green	yellow	red	yellow	red	grey	red	green
12	**Customer complaints**	Accounts for export service quality & it can be used to assess metrics, especially if it's not accounted.	*Volume: Total # of formal complaints related to export services *Volume: Total # of complaints resolved related to export services *Percentage: Total # of formal complaints related to export services/ Total # of formal complaints	grey	grey	grey	grey	green	grey	green	red	yellow	red	green	green	green	yellow	green	grey	green	green
13	**Number of worst-served customers**	Provides an indication of most constrained customers, and it can be used to protect customers under worst-case situation	*Volume: Number of customers that have been constrained off from exporting more than XX times in a month	grey	grey	red	grey	red	grey	yellow	green	red	red	red	red	red	red	green	grey	red	green
14	**Number of best-served customers**	Provides an indication of less constrained customers	*Volume: Number of customers that have been constrained off from exporting less than XX times in a month.	grey	grey	green	grey	green	grey	yellow	green	red	red	red	red	red	red	green	grey	red	green
15	**Customers under static export limits program**	Provides an indication of customers with static export limits	*Volume: Total # of customers with static limits *Percentage: Total # of customers with static limits/ Total # of DER customers	red	green	red	grey	green	grey	green	green	green	green	green	yellow	green	yellow	red	red	green	green
16	**Customers under flexible export limits program**	Provides an indication of customers with flexible export limits	*Volume: Total # of customers with flexible limits	yellow	green	green	grey	green	grey	green	green	green	green	green	yellow	green	yellow	green	green	green	green
17	**CO_2 Emissions reduction**	Measures environmental impact and reflects reduction in carbon emissions	*Volume: Electricity purchased x Emission factor *Volume: (Gross solar generation) x	green	green	grey	green	grey	grey	green	green	green	yellow	yellow	green	green	yellow	yellow	green	green	grey
18	**Profit and savings achieved due to export services**	Reflects profits and savings achieved through export services	*[$]: Energy produced (& stored) for self-consumption x Import tariff *[$]: Energy exported to grid x Export tariff	green	green	grey	grey	grey	green	red	yellow	red	yellow	yellow	green	yellow	red	yellow	green	red	yellow
19	**Avoided or Deferred Investment**	Measure economic impact. Accounts avoided or deferred investments due to DERs	*Volume: Total # of instances where a distribution system upgrade is avoided (or deferred) due to DERs	grey	grey	grey	grey	green	grey	green	green	green	red	red	red	grey	red	green	grey	green	green
20	**Expenditure on DER constraint alleviation (OPEX and CAPEX level)**	Measure economic impact. Accounts cost and investment to accommodate DER	Under consideration. They can be categorised by strategies including, DOEs, voltage management and	green	grey	green	grey	green	grey	green	green	red	red	red	red	grey	red	red	grey	green	green
21	**Power quality**	Reflects power quality service received by customers	*PQ metrics: Transient change, sag, surge, harmonic distortion, flicker and	green	green	green	grey	green	grey	red	yellow	yellow	yellow	green	green	green	green	green	green	red	green

22	**DER value streams**	Accounts for DER stream values	*Volume: Total # of customers enrolled by program (Energy management programs, VPP, P2P trading, etc.) *Percentage: Total # of customers enrolled by program (Energy management programs, VPP, P2P trading, etc.) / Total # of customers *Volume: kWh provided over a period	green flag	green flag	green flag	grey circle	green flag	green flag	red flag	green flag	red flag	yellow flag	green flag	yellow flag	yellow flag	red flag	yellow flag	green flag	red flag	yellow flag
23	**Avoided inverter tripping events due to flexible export limits**	Measures outcome of flexible export limits program	*Volume: Total # of avoided tripping events due to flexible limits	green flag	grey circle	green flag	grey circle	green flag	green flag	red flag	yellow flag	red flag	yellow flag	green flag	red flag	red flag	green flag	yellow flag	green flag	red flag	green flag
24	**Exports off-peak (generation peaks, e.g., midday)**	Measures export services that occurs off-peak	*Volume: Total # of customers exporting to grid that occurs off-peak *Volume: Energy exported to grid that occurs off-peak	green flag	grey circle	green flag	grey circle	green flag	green flag	green flag	green flag	red flag	red flag	red flag	red flag	red flag	red flag	red flag	yellow flag	green flag	green flag
25	**Peak demand reductions**	Indication of peak demand reductions due to export services	*Volume: Peak demands reductions due to export services	green flag	grey circle	grey circle	grey circle	green flag	grey circle	green flag	yellow flag	red flag	red flag	yellow flag	red flag	grey circle	red flag	green flag	green flag	grey circle	yellow flag
26	**Percentage DER penetration**	Measures DER penetration	Histogram for frequency of distribution transformers at different penetration rates	green flag	grey circle	red flag	grey circle	red flag	grey circle	yellow flag	green flag	green flag	green flag	green flag	green flag	green flag	yellow flag	red flag	grey circle	green flag	!

Key:

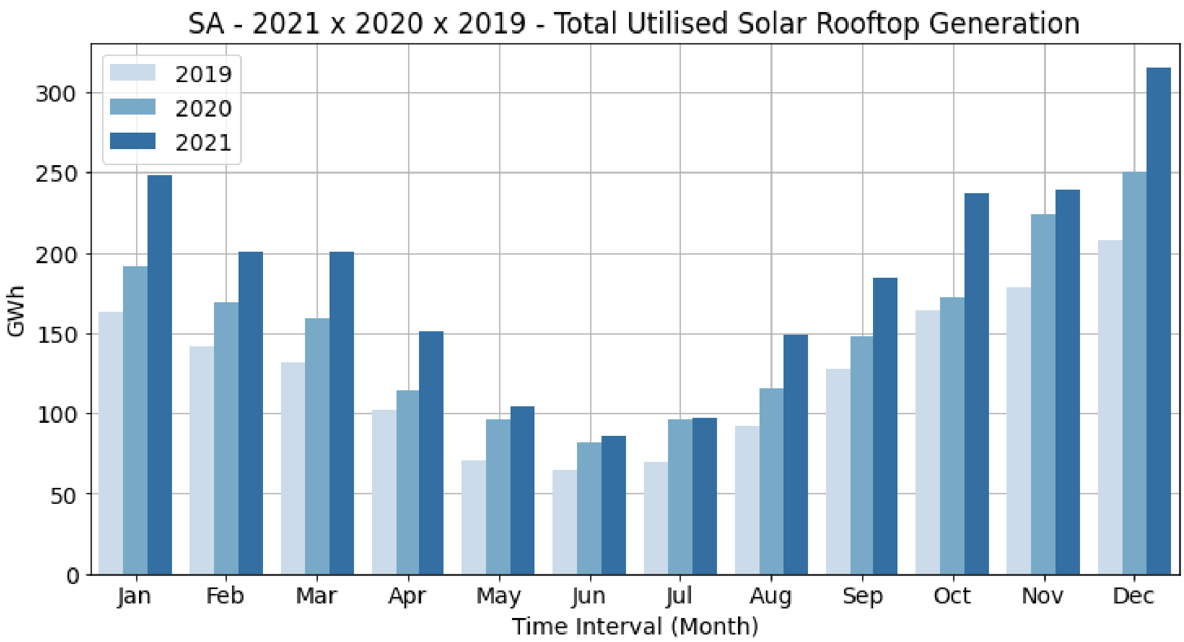
green flag	Has positive effect on criterion
yellow flag	Has weak positive effect on criterion
red flag	Has negative effect on criterion
grey circle	Metric does not inform criterion
!	Not fully clear

Appendix C: Metric 'road test' results

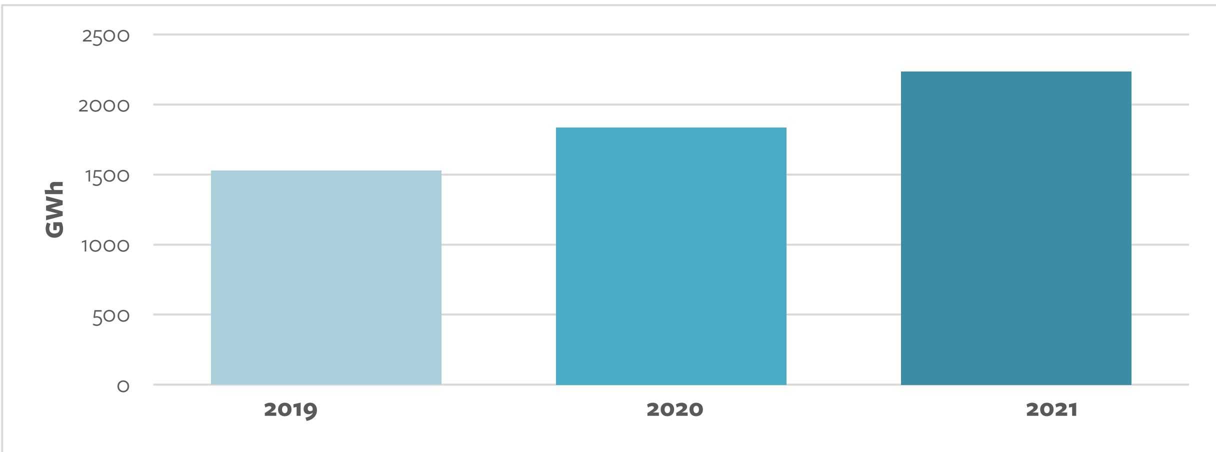
This appendix presents the road test results of the shortlisted metrics.

Total utilised DER generation (#5)

AEMO commissions the production of annual datasets for recent historical and forecast solar production based on trajectories developed by CSIRO. The following examples are based on South Australian AEMO data for solar PV generation only (up to 100 kW) for 2019–21 as it was not possible to separate out the transmission-connected larger-scale renewable energy such as utility-scale solar and wind. These datasets do not take account of curtailment, but because this is relatively negligible currently, accuracy is not strongly compromised in the short-term.



(a)



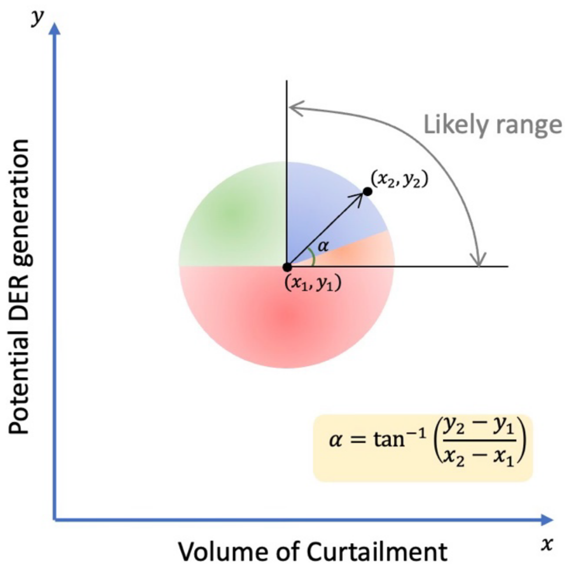
(b)

Figure 11. Growing penetration of rooftop solar. As evidenced by the (a) monthly and (b) annual rooftop solar output across South Australia from 2019 to 2021, penetration of rooftop solar across Australia's electricity networks continued to grow by 20.2% in 2020 and 21.8% in 2021.

Source: AEMO—Market data NEMWEB aemo.com.au/energy-systems/electricity/national-electricity-market-nem/data-nem/market-data-nemweb

The road test also experimented with different ways of expressing and visualising this metric according to its component parts in a 'Total DER utilisation curve'. These two components pull in opposite directions: (i) Potential DER Generation (i.e., *What would connected DER generation produce if unconstrained?*) and (ii) Volume of Curtailment (also Metric #27). The metric representation in Figure 12 could help regulators to better understand the underlying performance trends to inform SPTIS target setting. It may help to understand when higher curtailment volume might be a desirable outcome in the context of facilitating greater DER connections and access. As shown in the contextual example below, if we compare the change in Expected (i.e., unconstrained) DER Generation (vertical axis) with the change in Total Volume of Curtailment (horizontal axis), then the higher the gradient of the line the better the performance outcome. If the gradient of this line is approaching zero (orange zone in the graph below), this is a poor performance outcome as it represents an increased volume of curtailment with a limited corresponding improvement in expected DER generation. If the gradient of this line is high (blue zone in the image below), it is a good performance outcome as it represents a limited increase in the volume of curtailment relative to a strong improvement in potential DER generation.

"The rate of change of Network A's Total DER utilisation curve is +X, which is the strongest improvement relative to other networks and exceeds the performance benchmark of +Y. This performance improvement is reflected in the revised incentive rate and STPIS target for #5 Total Utilised DER Generation for the next Regulatory Control Period (RCP) of Z."



	α	Performance change
	(0,30°]	Poorer performance
	[30°,90°]	Higher performance
	(90°,180°]	Optimal but unlikely
	(180°,360°]	Undesirable and unlikely

Figure 12. Total DER utilisation curve representation using potential DER generation and volume of curtailment estimates.

More work would be needed to refine the application of such ways of viewing metrics with real network data and data scenarios in mind.

Duration of Full Export Access (#10)

Test 1

The goal of this test was to identify when customers are exporting at the received 'export limit'. The test analyses data for three SAPN Flexible Export Trial customers using their 30-minute net active power and flexible export limit signal data for a 7-day period in January 2022. As no dynamic curtailment occurred during the period of available data, this is simulated using synthetic data to represent the plausible bounds of unscheduled maintenance–an ′extreme case scenario′ and a ′mild case scenario′.

‘Extreme’ Case Scenario (n-1 transformer winding)

This case simulates n-1 unplanned major works at a substation where reverse flows typically exceed the thermal limit for a substation transformer winding, resulting in 10 kW solar systems being constrained to 1.5 kW limit from 11.00 am–2:30 pm for one week. Results are shown below.

Table 8. ‘Extreme’ case scenario

	Percentage of time at export limit	**Percentage of time in which export limit was sent but customer was not curtailed**	**Average volume curtailed per day (actual data)**	
	%	%	(kWh)	(%)
Customer 1	15.18	1.49	7.13	27
Customer 2	16.67	–	14.48	34
Customer 3	16.07	0.59	10.07	10

An extreme case like this is only likely to occur every 10+ years. Averaged across one year, one occurrence of the worst-case Customer 2 situation shown above would represent 0.003% of the time without full export access. Note that as the curtailment was *simulated*, the volume that would have been curtailed is accurately known from the metering data (14 kWh/day for Customer 2).

‘Mild’ Case Scenario (e.g., tap changes)

This case simulates n-1 planned works at a substation where reverse flows typically exceed the thermal limit for a substation transformer tap changer resulting in 10 kW solar systems constrained to 1.5 kW limit for 30 mins at 11 am and 1 pm for one week. Results are shown below.

Table 9. ‘Mild’ case scenario

	Percentage of time at export limit	**Percentage of time in which export limit was sent but customer was not curtailed**	**Average volume curtailed per day (actual data)**	
	%	%	(kWh)	(%)
Customer 1	3.27	0.89	1.57	6
Customer 2	4.16	–	4.50	11
Customer 3	4.16	–	2.63	8

A realistic circumstance is one instance of such an event every two or more years. Averaged across one year, one occurrence of the worst-case Customer 2 situation would represent 0.02% of the time without full export access.

Test 2

The goal of this test was to identify tripping curtailment events due to overvoltage. The test analyses data for up to 50[47] randomly selected SAPN customers using their 10-minute net active power and voltage data for the year 2020. It was assumed that gradual curtailment occurred from 253 V onwards (V-W curtailment), with full curtailment when the voltage is at 258 V or above. The results are shown in below.

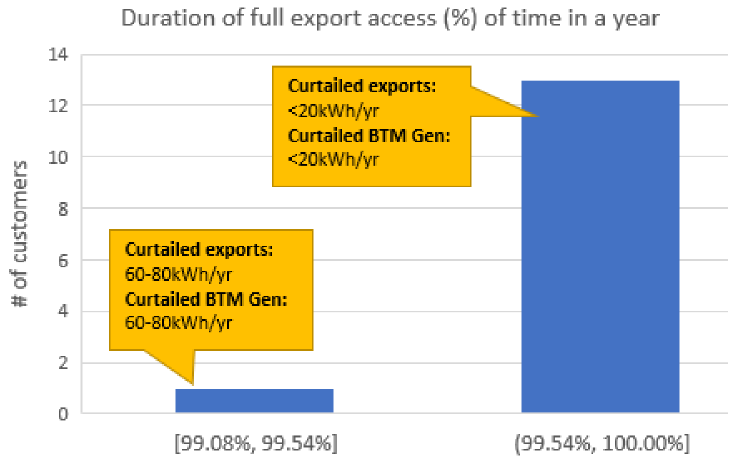


Figure 13. Voltage-driven reduction in full export access in random sample of 50 SAPN customers

Only 14 customers (28%) experienced curtailment across the year due to overvoltage with almost all of these at less than 0.5% duration and less than 20 kWh/year. Thus, while voltage tripping appears currently to be relatively small for SAPN, it is unevenly distributed by customer location on a line and needs to be analysed by customer type of worst-served customer.

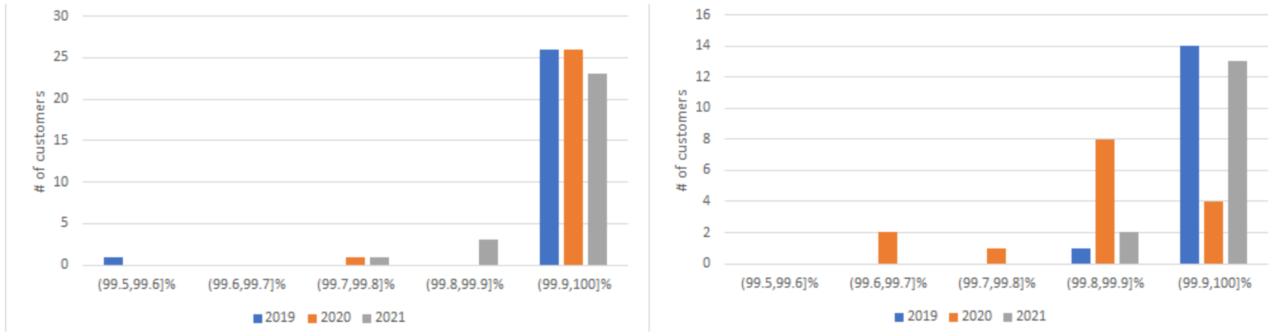
The amount of BTM generation curtailed cannot be calculated without underlying customer load data (i.e., before being offset by solar generation) and rule-of-thumb estimates are required to be used in the absence of these data.

Test 3—Essential Energy data

The goal of this test was to assess the developed metric and calculation approach using Essential Energy data, which allows testing of the proposed method under different operating settings and network arrangements. Essential Energy provided 30-minute resolution data of two groups of customers from 2019 to 2021. Group 1 includes data from 27 generators (in the size range of 0.2–120 MW) and Group 2 includes data from 15 commercial customers with on-site generation (in the size range from 0.2 to 1 MW). Since the provided dataset did not include voltage data, this test applied the methodology proposed in the CANVAS project.[48] The results for this test are shown below.

47 Due to meter churn the initial dataset of 50 customers was lowered to 39 with a full year of data.

48 See CANVAS final report for further details about the methodology



(a) Group 1: 27 generators

(b) Group 2: 15 commercial customers with on-site generation

Figure 14. Duration of full export access for Essential Energy customers

The results show that generators in both groups have similar performance with issues experienced less than 0.5% of the time (i.e., 99.5% full export availability) since 2019. Close scrutiny of the results reveals that the export performance for generators in Group 1 deteriorated from 2019 to 2020 but then increased in 2021. Further analysis may be required to identify the causes of this variation.

Volume of Curtailment (#27)

Building on the test conducted to estimate the Duration of Full Export Access (#10) metric, the volume of energy curtailed was estimated for the timeslots with curtailment events. Revisiting the results for the *simulated extreme case scenario* (i.e., simulated unscheduled transformer maintenance), the average volumes curtailed per day for customers 1, 2 and 3 were 7.1, 14.5 and 10.1 kWh, respectively. For the worst-case customer the total curtailed energy as a percentage of total energy generation if the unscheduled event only occurred once a year is less than 1%. Despite the minimal likelihood of this extreme case scenario occurring more than one or two times in 10+ years, the number of extreme cases was hypothetically extrapolated to assess the potential impact on the volume curtailed per year, as shown in below.

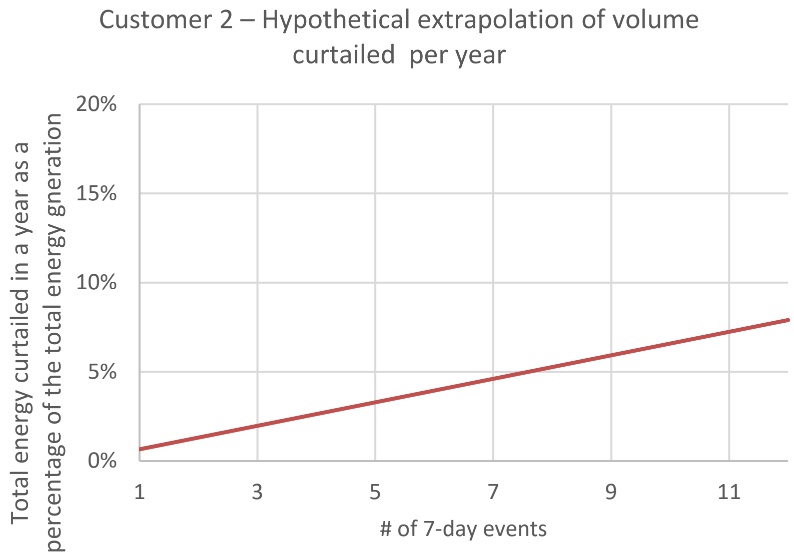


Figure 15. Customer 2—Hypothetical extrapolation of volume curtailed per year

It is evident that this type of extreme event would need to happen 5–10 times in one year to reach 3% and 6.5% of volume curtailment, respectively. As this is very unlikely, the impact of volume curtailed is still relatively low at the customer level.

Volume of DER System Services (#22)

This subsection includes some examples of DER market services reports and emerging insights from trials that assessed DER market services.

Demand response

Demand-side participation information is collected through the DSP portal. AEMO publishes annual reports with demand response statistics. Following the rule change on wholesale demand response[49], AEMO's reports will include an analysis of volumes and types of demand responses in its reporting which might facilitate the estimation of this metric. Examples of current published data are presented below.[50] These statistics are currently reported for the NEM as a whole, so a special request to AEMO to disaggregate the data by jurisdictions and/or networks would be required.

Table 10. AEMO demand-side participation classification. Source: 2021 Electricity Statement of Opportunities, AEMO

DSP type	Explanation
Market-exposed connections	Covers connections exposed to spot price, either directly or via pass-through contracts. This includes loads responding under the wholesale demand response (WDR) rules and any connections that are only spot price exposed during specific events.
Connections on fixed time-of-use tariffs	Includes connections exposed to fixed time-of-use pricing, including day/night tariffs.
Connections on dynamic event tariffs	Connections that are subject to dynamic tariffs which cost price consumption and/or connection differently for specific periods during the year. These periods are dynamically determined by the program operator and could relate to local or regional demand at the time.
Directly controlled connections (fixed schedule)	Connections directly controlled based on a set schedule for the year irrespective of actual demand and/or spot prices at the time. This includes control of hot water load.
Directly controlled connections (dynamic operation)	Connections directly controlled (or manually instructed) based on actual or forecast system conditions and/or price. This includes aggregated response of battery storage systems as a virtual power plant (VPP) and reduction in air conditioner load or controlled electric vehicle charging on extreme demand days.
Not elsewhere classified	This category allows for special cases that do not obviously fit into the above categories. Entries in this category will be reviewed by AEMO and reclassified into the above if possible.

Figure 15 summarises the reports sum of firm response by DSP type and program category. In total there are 1930 MW of firm response. Note that there may be additional responses that are unquantified or simply not reported, as noted in AEMO's 2021 ESOO report.

49 See https://www.aemc.gov.au/rule-changes/wholesale-demand-response-mechanism

50 See AEMO, 2021, Electricity Statement of Opportunities for more details about DSP statistics. https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo

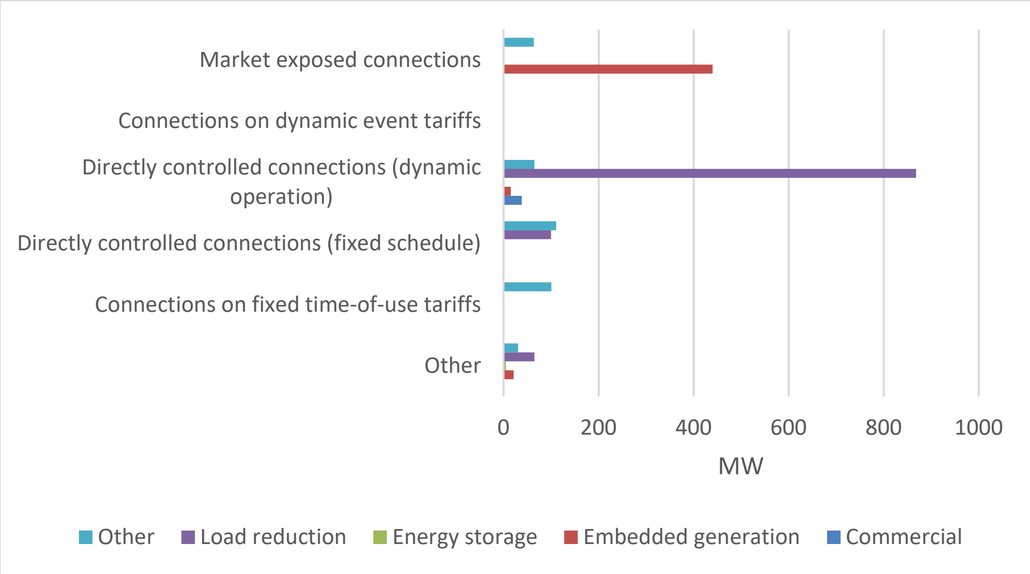


Figure 16. Reported sum of firm response (MW) grouped by program category and DSP type

Additionally, AEMO estimates DSP in response to price or reliability signals. The price-driven response is determined by examining how flexible loads responded to price signals and calculated as the difference between the observed consumption and the calculated baseline consumption. The reliability response represents the estimated DSP response during reliability events. Figure 16 presents the estimation of cumulative response in MW for each state.

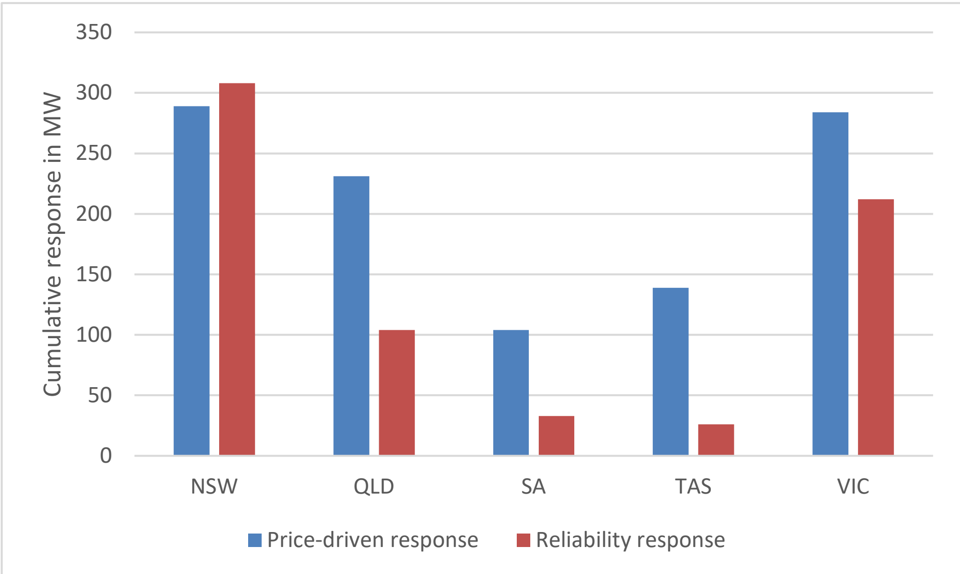


Figure 17. Estimated demand-side participation responding to price or reliability signals

Another source of DER market services data is the RERT reports, which capture demand response services for reserve activation events to maintain power system reliability and system security. For example, on 15 June

2022, AEMO activated RERT reserves in NSW and QLD and the estimated volume for these regions were 1483.5 MWh and 241 MWh, respectively.[51]

FCAS

The AEMO's VPP demonstration project provided early insights on how DERs in VPPs are integrated into market frameworks including FCAS. In total there were eight VPP participants, which represented a registered capacity of 31 MW. This reached 3% of the market share of contingency FCAS in April 2021.[52] It is expected that DER participation in ancillary services will increase as AEMO's ISP has estimated that by 2050 there would be up to 69 GW of distributed PV systems and almost 61 GW of storage capacity in a 'step change' scenario.[53]

CO2 Emissions reduction (#17)

Building on the calculations for Total Utilised DER Generation, CO_2 emissions reductions were estimated by multiplying the greenhouse emission factor and the gross generation of the assessed region. This metric was tested using AEMO data for solar PV generation and the emission factor in South Australia (0.43 kg CO2-e/kWh).[54] Figure 17 shows the estimated CO_2 emission reductions in South Australia due to rooftop solar PV systems (only), which shows a steadily increasing contribution to reducing emissions, reaching almost 1 Mt CO_2 reductions by 2021.

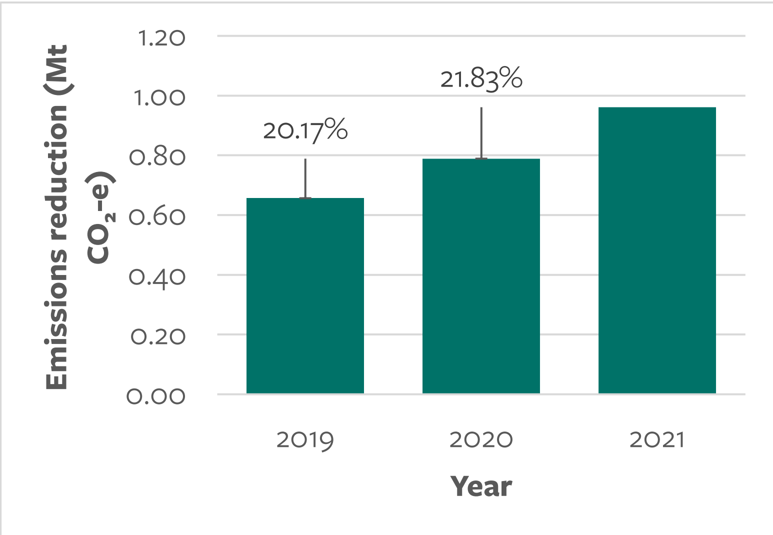


Figure 18. Emissions reductions from rooftop PV in SA, 2019–21

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[51] Note that RERT may include large industrial load or a group of aggregated smaller loads and unscheduled generation assets such as standby diesels. See https://aemo.com.au/energy-systems/electricity/emergency-management/reliability-and-emergency-reserve-trader-rert for more details about RERT.

[52] Australian Energy Market Operator (AEMO). (2021). *NEM Virtual Power Plant Demonstrations*. Knowledge Sharing Report #4, September 2021. https://aemo.com.au/-/media/files/initiatives/der/2021/vpp-demonstrations-knowledge-sharing-report-4.pdf?la=en

[53] Australian Energy Market Operator (AEMO). (2022). Integrated System Plan. https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

[54] Australian Emissions factors per region are available here: https://www.industry.gov.au/sites/default/files/2020-10/national-greenhouse-accounts-factors-2020.pdf

Customer Complaints (#12)

A dataset of SAPN customer complaints was analysed to estimate this metric. Currently customer complaints can be classified into six categories: 1) overvoltage, 2) undervoltage, 3) excessive interruptions, 4) flickering, 5) other and 6) proactive investigation. Among these categories overvoltage complaints are the most suitable to account for export service complaints. Figure 18 shows the number of overvoltage complaints received and resolved from January 2021 to May 2022. This chart shows the received and resolved complaints with assigned jobs. The total number of complaints received may not reflect actual issues if no jobs are assigned to resolve them. As seen in Figure 18, the number of complaints increased during the spring and summer seasons. The number of resolved complaints also accounts for complaints received in previous months that were solved during that period.

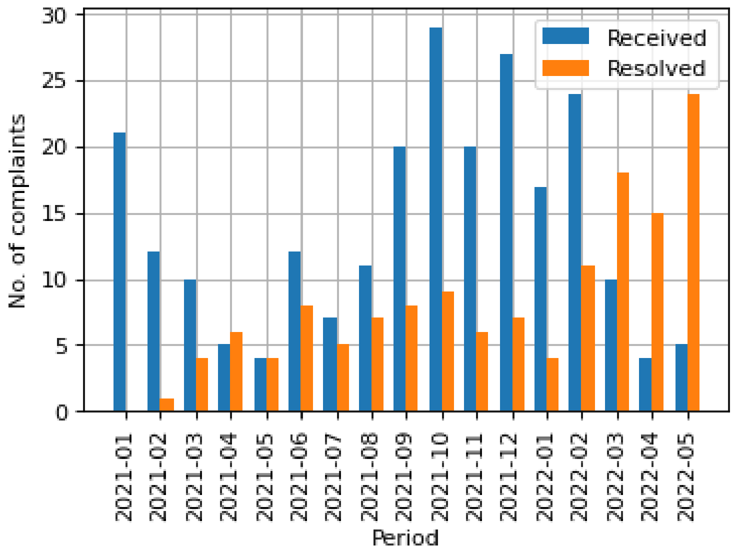


Figure 19. Number of complaints received and resolved

Dynamic Limits versus Static Limits (#7)

Note that this metric was included within the road test but later excluded as it was deemed more appropriate to include as a metadata field to allow breakdowns of other metric results to be undertaken according to export service product type.

Description

This metric provides an estimation of the number of customers and capacity under two types of management strategy: (i) static limits and (ii) dynamic limits. It also accounts for customers with no effective limit, that is, when the fixed static limit is equal to or greater than the panel or inverter capacity. This metric was included to reveal the trends in DSNP export management strategies and the performance achieved in each case. The 'performance' format seeks to inform customers of actual outcomes of export management strategy offers and for regulators to understand the general trend of export limit effectiveness alongside customer uptake.

Contextual examples

"The number of NEM customers with export limits increased by X% in 2021. For Networks A & B this included a X% reduction in customers under static export limits while Networks C & D saw a Y% increase in static limits.

On average, customers with flexible limits received X% higher Total Utilised DER Generation compared to static limits." **[Use case 2b]** (note this example considers a combination of Metrics #7 and #5)

General calculation approach

General formulas:

- [Customers: No. or % of customers with dynamic/static/no effective limit]
- [Capacity: Capacity under flexible/static/ no effective limit ÷ Total DER capacity]
- [Performance: % total production curtailed by export limit type]

Simplified diagrammatic representations of these formulas are shown in Figure 19 and Figure 20 below.

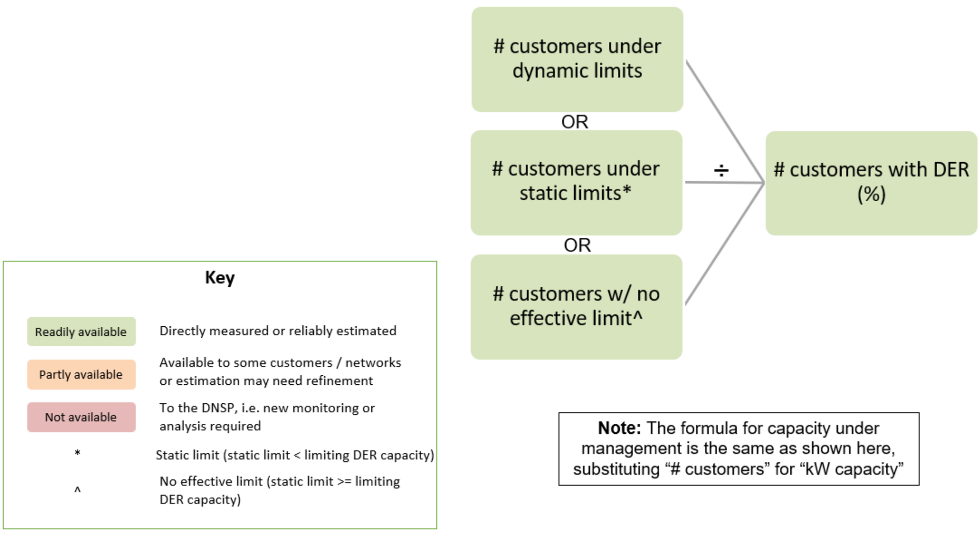


Figure 20. Simplified calculation diagram: Dynamic Limit vs Static Limit (Metric #7)

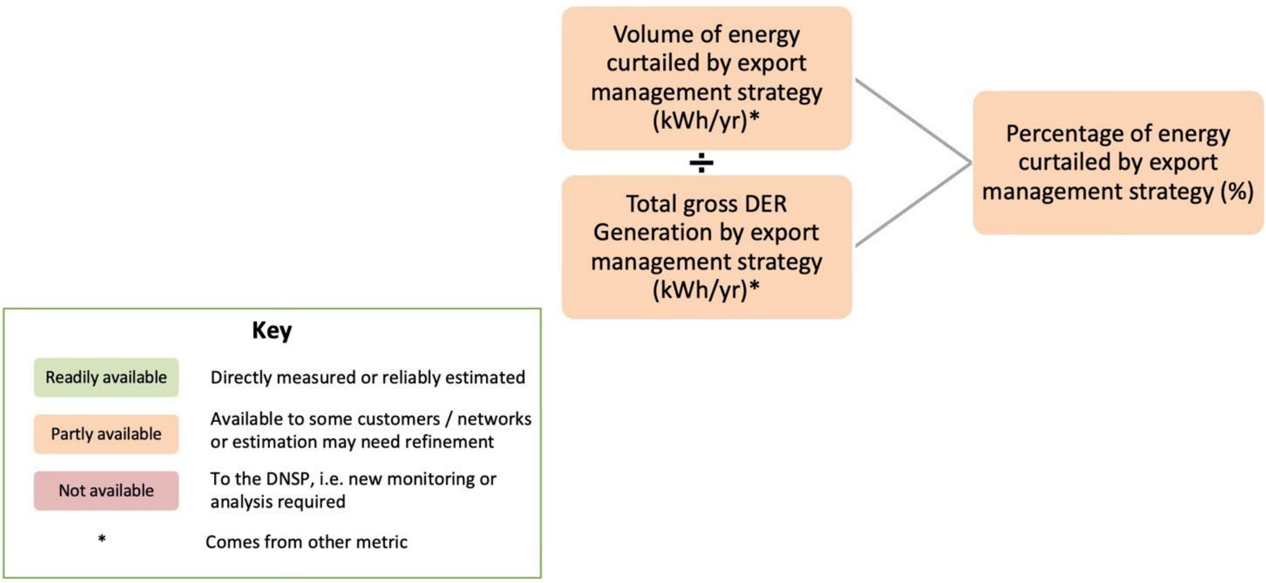


Figure 21. Simplified calculation diagram: Dynamic Limit vs Static Limit (Metric #7) performance form

Limitations and challenges

- Need to define the best way to classify and present metric forms—many constituent parts could be useful (e.g., total numbers, capacity, %, change trends)
- May require working with data over time for trends to emerge to determine best forms
- Needs adjusted data management processes to calculate as static and dynamic customer datasets are stored in different formats
- This metric can capture whether an export limit constrains generation, that is, when the static limit is lower than the limiting capacity (minimum capacity between DER capacity and inverter capacity). However, this metric cannot capture when customers request a higher capacity than the allowed capacity. For example, a customer asks for X capacity but it is only given Y. These data are not recorded.

Road-testing results

This metric was tested using SA Power Networks data. Figure 21 presents the number of PV systems that can be classified per management strategy. Table 11 shows the number of customers (and percentage) and installed capacity for each strategy. There are around 1560 customers with dynamic and static limits, which is equivalent to installed capacities of 0.3 and 11.2 MVA, respectively. This metric can take different formats depending on the use case and type of customers. For example, a percentage format per DER size can be useful for customer communication use cases as shown in Table 12.

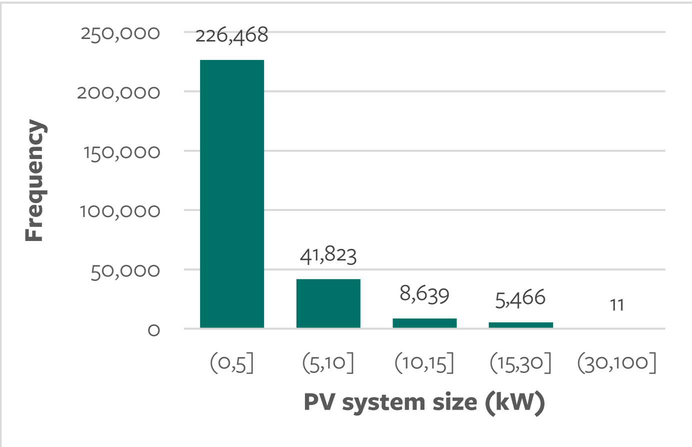


Figure 22. Total number of DER customers with systems up to 100 kW

Table 11. Dynamic Limit vs Static Limit: Road-testing results

	Number of customers		Installed capacity
	#	(%)	(MVA)
Dynamic	40	0.01	0.3
Static	1,526	0.54	11.2
No effective limit	281,909	99.45	1,378.7
Total	**283,475**	**100**	**1390.2**

Table 12. Dynamic limit vs static limit: Road-testing results—Percentage format & PV size

Size	Dynamic	Static	No effective limit
(kVA)	(%)	(%)	(%)
0–5	0.01	0.36	99.63
5–10	0.04	1.33	98.63
10–15	0.02	1.16	98.82
15–30	0.00	0.82	99.18
All	**0.01**	**0.54**	**99.45**

In general, this metric can take many formats depending on the use case, but its calculation process is simple and direct. The performance form of this metric can be calculated using a bottom-up approach by identifying the customers under each management strategy when calculating Metrics #5 and #27.

Appendix D: DNSP survey questions

Section 1: Export Service Quality Metrics

Background

The table below summarises the input data required to calculate the shortlisted metrics. The questions in this section aim to determine the availability and format of these data.

		Data required from DNSPs								
Metric ID	Shortlisted Metrics	Voltage	Active power	Reactive power	DER installed capacity	Inverter capacity	Inverter settings	Export limit value	# of DER customers	Customer complaints
5	Total utilised DER generation		•		•	•				
10	Duration of curtailment	•	•	•	•	•	•	•		
N1	Volume of energy curtailed	•	•	•	•	•	•	•		
7	Flexible limits vs Static limits	•	•	•	•	•	•	•	•	
22	Volume of system services provided by DER									
17	CO_2 Emissions reduction		•		•	•				
12	Customer complaints									•
N2	Financial impact of curtailment	•	•	•	•	•	•	•		
24	Curtailment in peak periods	•	•	•	•	•	•	•		

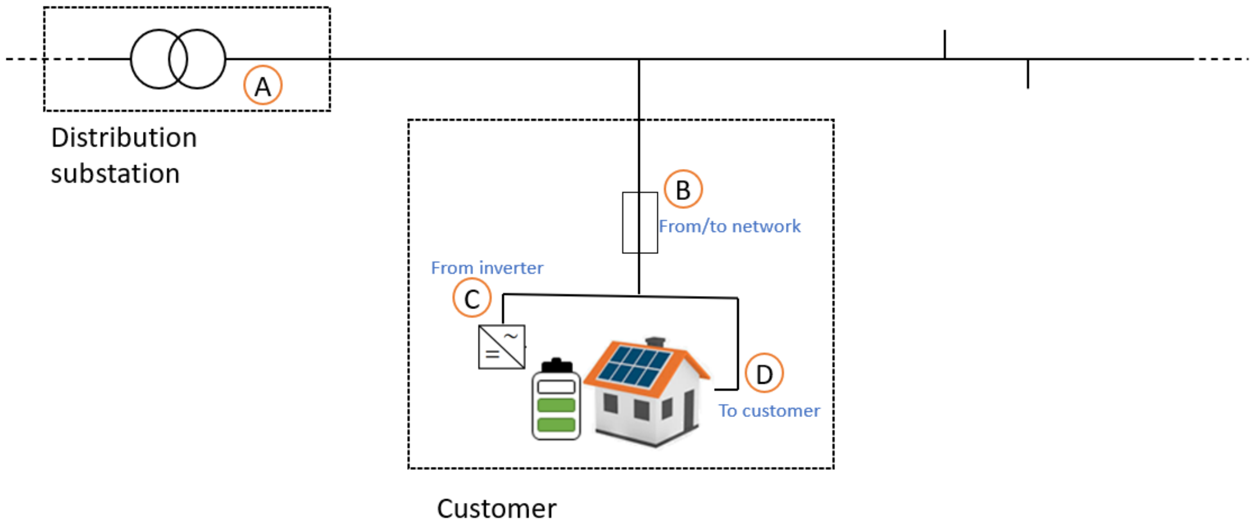
Key:

- (light blue) Operating Network data
- (grey) DER and inverter data
- (light yellow) # of DER customers and complaint records

Do you have any initial comments about the coverage of the proposed list of metrics? Are there aspects relevant to export service quality you think are missing from this list?

(More details and context of each metric can be found HERE, but are not otherwise necessary to complete the survey).

Q1. The proposed metrics may need to be calculated at a system level, feeder level or customer level. Therefore, we'd like to determine the data available at different locations to calculate and communicate these metrics. What percentage (%) of data access do you have across your network at the following levels:



Insert percentage of data coverage

	Distribution substation (A) (5)	Customer connection (B) (1)	Inverter AC-side (C) (2)	Customer consumption, including self-generation (D) (3)
Voltage (1)				
Active power (2)				
Reactive power (3)				

Q2. What is the maximum frequency at which these data are recorded at each metering point?

	Greater than hourly (1)	Hourly (2)	15-30 min (3)	5 min (4)	< 5 min (6)	Not applicable (5)
Distribution substation (A) (1)	○	○	○	○	○	○
Customer connection (B) (2)	○	○	○	○	○	○
Inverter AC-side (C) (3)	○	○	○	○	○	○
Customer consumption (D) (4)	○	○	○	○	○	○

Q3. Looking to the future, does your organisation expect to develop new strategies (e.g., install monitoring equipment, develop estimation methods etc.) to increase the network visibility and access to **customer-level data** (Locations B, C, D) in the next 5 years?

○ Yes (please provide more details below) (1) ____

○ No (2)

○ Not sure (3)

Q4. How easy or difficult is for your organisation to report the following system data?

	Extremely easy (17)	Somewhat easy (18)	Neither easy nor difficult (19)	Somewhat difficult (20)	Extremely difficult (21)
Number of customers with DER (1)	○	○	○	○	○
Number of customers with DER by **feeder type** (CBD, urban, short rural, long rural) (2)	○	○	○	○	○
Number of customers with DER by **size** (e.g., less than 30kVA, between 30kVA and 100kVA, and greater than 100kVA) (3)	○	○	○	○	○
Number of customers with DER by **technology** (PV, Battery, EV, Wind) (4)	○	○	○	○	○
Number of customers with a **static (fixed) export limit*** determined by a connection agreement. *Includes customers whose static limit is higher than their installed capacity (7)	○	○	○	○	○
Number of customers with **flexible export limit** (e.g., DOEs) (8)	○	○	○	○	○

Q5. For any data noted above as 'somewhat difficult' or 'extremely difficult' please provide additional context below.

____

Q6. How easy or difficult is for your organisation to report the following customer-level data?

	Extremely easy (17)	Somewhat easy (18)	Neither easy nor difficult (19)	Somewhat difficult (20)	Extremely difficult (21)
Installed capacity of DER (1)	○	○	○	○	○
Inverter capacity (2)	○	○	○	○	○
Inverter settings (3)	○	○	○	○	○
Value of export limit signal or setting (4)	○	○	○	○	○
Type of export limit (e.g., dynamic, static) (5)	○	○	○	○	○

Q7. For any data noted above as 'somewhat difficult' or 'extremely difficult' please provide additional context below.

____

____

Q8. How does your organisation currently access and download solar irradiance data? (*select all that apply*)

Solcast portal subscription (1)

Bureau of Meteorology (BOM) data (2)

Do not currently use irradiance data (4)

Other (please specify) (5) ____

Not sure (3)

Q9. How easy or difficult is for your organisation to report the following customer complaints data?

	Extremely easy (19)	Somewhat easy (20)	Neither easy nor difficult (21)	Somewhat difficult (22)	Extremely difficult (23)
No. of customer complaints related to **overvoltage** events (1)	○	○	○	○	○
No. of customer complaints related to **curtailment** events (2)	○	○	○	○	○
No. of customer complaints with **assigned jobs** (4)	○	○	○	○	○
No. of customer complaints **resolved** (i.e., assigned jobs have been completed) (5)	○	○	○	○	○

Q10. For any data noted above as 'somewhat difficult' or 'extremely difficult', please provide additional context below.

____

____

Q11 In your opinion, would the format in which your organisation captures customer complaints data need to change in order to isolate issues specifically related to **quality of customer export services**?

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Appendix E: Calculation templates

As part of the road-testing activity, the research team produced interim calculation templates using the Google Collaboratory environment so they can be executed online. The calculation templates include instructions, a summary of each metric, links to download the XLSX files to fill the datasets and the code to calculate the metrics. These calculation templates have been tested by Essential Energy and SA Power Networks.

[**Note:** The code at these links has interim calculation templates, which were developed during the road-test activity. Therefore, metrics that emerged from iterative feedback in the last stage of the project were not part of this activity.]

Table 13. Calculation template links

No	File name	Metrics	Link to edit
1	Utilised DER generation and Emissions Reduction	#5 and #17	Link
2	Duration of Curtailment	#10	Link
3	Curtailment Volume Metrics	#27 and #7 (performance) and #24	Link
4	Flexible versus Static	#7 (customer/capacity)	Link
5	Customer Complaints	#12	Link