



Baringa
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► **Development of Renewable Energy Zones in the NEM**

Key Findings

CLIENT: Australian Renewable Energy Agency

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Key Findings Report

Background

A significant volume of new generation and storage capacity will be needed in the NEM over the coming decades to maintain reliability and affordability as ageing generators retire. Australia has some of the best renewable energy resources in the world, but with limited existing network capacity extending to locations with the highest potential. As identified in the Australian Energy Market Operator's (AEMO) Integrated System Plan¹, developing Renewable Energy Zones (REZs) to leverage these strong resources will be critical to facilitating new generation and storage capacity in the NEM, at least cost to consumers.

The current regulatory framework and approach to network development were not designed to support REZs, nor to mitigate the technical challenges of integrating a high penetration of variable renewable energy (VRE).

The Australian Renewable Energy Agency (ARENA) engaged Baringa Partners, in partnership with DigSILENT Pacific, to undertake a study into the technical, commercial and regulatory challenges of developing REZs in the National Electricity Market (NEM), and to identify potential commercial and regulatory solutions that could facilitate the development of REZs in an efficient and sustainable manner.

Baringa, DigSILENT and ARENA undertook targeted consultation with a range of stakeholders including government agencies, network businesses, developers and investors, to understand the technical and commercial challenges of developing REZs within the current regulatory framework.

Modelling was undertaken in collaboration with AEMO to understand the potential of network and technology solutions to unlock more connection capacity to support renewable build-out in new REZs. The modelling focused on two REZs as defined in AEMO's Integrated System Plan (ISP), namely North-West VIC and Central-West NSW. These two REZs were chosen as they have both attracted significant interest from developers, but each have different network topologies and technical challenges. This case study analysis informed commercial and regulatory options that could support REZ development in the near and longer-term.

REZ technical challenges

There is growing awareness of the technical challenges of integrating a high penetration of renewable energy capacity into the NEM. Stakeholder consultation and market analysis identified a broad range of challenges, with two of the most immediate for REZ development being thermal constraints and low system strength. These are defined below.©

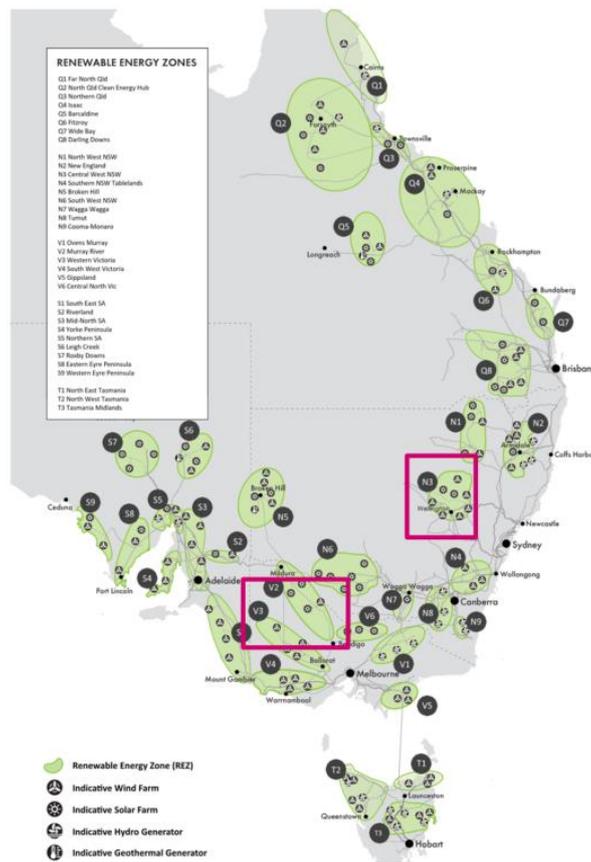
¹ AEMO (2018), Integrated System Plan, <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan>. The draft ISP (2019) is expected to be released in December 2019.

Thermal constraints refer to the upper limits on the amount of electrical current a transmission line can carry. Exceeding these limits can damage equipment and cause transmission lines to heat and physically sag, creating safety and operational issues.

System strength refers to the resilience of the system to a drop in voltage. System strength is usually approximated based on the available fault current or short circuit ratio at a given location in the network. A high fault level reflects a stronger power system that is better able to restore the power system after a drop in voltage.

To understand the practical implications of these technical challenges, this study focused on two case study regions in the NEM – Central West NSW (CW-NSW) and North West Victoria (NW-VIC).

Figure 1: Two case study regions, NW-VIC and CW-NSW, marked with boxes on the ISP 2019 map².



Both NSW and VIC are facing coal plant retirements in the coming decade, and leveraging new generation and storage potential will be important to maintaining reliability in these regions.

² AEMO (2019) 2019 Inputs and Assumptions Workbook, <https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan/2019-Integrated-System-Plan>

The two case study regions demonstrate different technical challenges, and are useful in highlighting the spectrum of REZ topologies in the NEM. Currently, NW-VIC is severely impacted by both thermal limits and system strength issues, and there are limited opportunities to unlock new VRE hosting capacity or reduce curtailment risk until significant steps are taken to address system strength challenges. CW-NSW, by comparison, faces less technical challenges at present, which provides more opportunities to deploy a range of technical solutions to unlock additional network hosting capacity. The difference in technical challenges between the two REZs is largely related to the different network topologies, as well as the current state of the network and generation build-out. These differences are summarised in Table 1, below.

Table 1: Key differences between the two case study REZs modelled in this study

Attribute	Central-West NSW	North-West VIC
Classification	Mostly 'Greenfield'	Mostly 'Brownfield'
Topology	Meshed 132 kV network next to 330 kV strong grid	Single circuit 220 kV radial network
Performance	Slightly limited by thermal and system strength issues	Heavily limited by thermal and system strength issues
Existing and committed generation capacity	940 MW (with some of this capacity at risk of curtailment)	1875 MW (with some of this capacity at a high risk of curtailment)
Available capacity for new network connections, without new network or technology build	216 MW	0 MW

Both case study regions offer significant VRE resource potential that cannot be facilitated by the current network. According to the ISP, they have a total of almost 15 GW of VRE potential, with around 2.8 GW that has been developed or committed at present. Due to critical constraints in the network, we estimate that it will only be possible to unlock a further 0.2 GW of capacity without intervention, with this capacity all located in CW-VIC (our 'Base Case' or 'Do Nothing Case').

Solutions to technical challenges

Baringa and DigSILENT, in collaboration with AEMO, undertook network and market modelling to explore the relative potential of network and technology solutions to address the challenges of system strength and thermal capacity in the two case study regions.

Overview of the solutions modelled

The findings of this study are based on modelling of the following network solutions ('poles and wires') and technology solutions in each of the case study REZs, over the near and longer-term:

Table 2: Network solutions modelled in the case study REZs

Network solution	Description
NW-VIC network build	'Poles and wires' transmission network solution. Based on ISP 2018 and Western VIC RIT-T – assumes both the Western Victorian RIT-T projects and longer-term augmentation identified by ISP are built.
CW-NSW network build	'Poles and wires' transmission network solution. Based on ISP 2018 and discussion with Transgrid - assumes new 500kV circuits are built to Liverpool Ranges in 5-10 years.

Table 3: Technology solutions modelled and their impact on system strength and thermal capacity

Technology solution	Description	System strength	Thermal capacity
Synchronous condenser	A grid-powered synchronous electric motor that spins freely, and is not connected to generation or load. It either absorbs or generates reactive power to regulate the voltage in the grid.	Improve	Neutral
Battery with grid-following inverter	Utility-scale battery connected to the grid with an inverter that ensures the output voltage follows that in the local grid – therefore behaves like current source.	Reduce	Improve
Battery with grid-forming inverter	Utility-scale battery connected to the grid with an inverter that can set the voltage in the local grid without needing external reference – therefore behaves like voltage source.	Neutral (core scenario) Improve (sensitivity scenario) (Capability dependent on technology suppliers)	Improve
VRE with grid-forming inverter	VRE connected to the grid with an inverter that can set the voltage in the local grid without needing external reference – therefore behaves like voltage source.	Improve (technology under development)	Neutral
Synchronous Static Series Compensator (SSSC)	Often considered a 'smart wire' technology. An SSSC is a technology (transformer and inverter) that can manage voltage or alter the power flow on a transmission line to manage technical outcomes like constraints.	Improve (Existing SSSC may have a limitation during fault; technology under development)	Improve (Depending on network topology)

Modelling of the range of different technology solutions considered each technology in isolation, deployed to address technical challenges and unlock additional network capacity. Modelling did not

consider the deployment of multiple technology solutions in an optimal combination, which in practice is likely to be driven by technical, market and regulatory conditions.

It is important to note that the capabilities of grid-forming inverters are currently not well defined in the market. For the purposes of this study, it was assumed that the grid-forming inverter technology is capable of setting local grid voltage. In terms of system strength impacts, two scenarios were modelled for grid-forming inverters with batteries – one with neutral impact on system strength, and one with a positive contribution.

The modelling assumed a rollout of these network and technology solutions, according to each scenario, and then provided an estimate of the increase in the MW export limit for VRE in each REZ compared to the ‘Do Nothing Case’. The relative costs of each solution were then compared, based on the investment required for each kW of VRE potential unlocked.

The study also considered the level of coordination in the deployment of the technology solutions in the two REZs, via two scenarios:

- ▶ ‘Uncoordinated’ deployment: the technology solutions are deployed alongside new generation, at the same connection point in the transmission system
- ▶ ‘Coordinated’ deployment: the technology solutions are deployed at an optimal size and location from a whole of REZ perspective

This analysis allows a comparison of the benefits of REZ-level planning and coordination, which could be facilitated via either commercial or regulatory mechanisms.

The study assessed the cost of each solution deployed in each REZ, and then compared each solution on the basis of \$/kW of the additional VRE connection capacity unlocked. Table 4 below details the key cost input assumptions adopted in the study.

Table 4: Summary table of the key modelling findings for the CW-NSW REZ

Technology	Item	Unit	2020	2025	2030	2040
Synchronous condenser	Total Capex	\$/kVA	500	496	492	484
Grid-following BESS (2 hour)	Total Capex	\$/kW	1,424	1,058	811	734
	Residual cost*	\$/kW	467	59	0	0
Grid-forming BESS (2 hour)^	Total Capex	\$/kW	1,624	1,214	937	847
	Residual cost*	\$/kW	699	244	0	0
Grid-forming inverter for VRE	Total Capex	\$/kVA	255	213	184	149

* Residual cost is derived with the NPV of revenues from arbitrage, cap contracts and FCAS services over the BESS economic life are deducted from Total Capex
 ^ We have assumed an uplift on BESS Balance of Plant (BOP) capex for grid-forming inverters, however we understand that these costs are reducing rapidly, and it is likely that the assumptions used in this study are already conservative relative to costs that can be expected in the near-term.

SSSC technology costs are assumed to reduce modestly, given the technology is reasonably mature, and network build costs were based on ISP 2018 assumptions.

The 'residual cost' was used to calculate technology costs for battery-based technology solutions to reflect that these technologies are likely to access a range of revenue streams in addition to providing network benefits. The residual cost was calculated as the total capex of the system, minus the NPV of revenues the battery could be expected to earn from energy arbitrage, FCAS services and cap contracts over its economic life.

Current capex estimates for the various technologies are taken from AEMO's ISP 2019 workbook, supplemented by DigSILENT inputs. Cost trajectories are based on Baringa learning rate assumptions.

Key findings from the analysis

Modelling highlighted that a mix of both network solutions (traditional 'poles and wires' build) and technology solutions is likely to most efficiently unlock additional connection capacity in REZs. While the two case study REZs (Central West NSW and North West VIC) have very different network topologies and technical limitations, we can make some overarching observations:³:

- ▶ As the starting point can be so different, a **'one size fits all' approach is not appropriate** when considering technology solutions for REZs. The significant differences between efficacy and cost of technology solutions in the two case study REZs results from their different network topologies and technical challenges.
- ▶ **Network augmentations are the most effective stand-alone solution to developing the REZs** and avoiding high electricity prices after major coal plant retirements, capable of unlocking more new connection capacity than any technology solution deployed on a stand-alone basis
- ▶ **Technology solutions are complementary to network solutions** and can facilitate additional connection capacity beyond that unlocked by network build. They also offer a nearer-term opportunity (although at a limited scale) than network solutions.
- ▶ A coordinated approach to implementing technology solutions (scaled and strategically positioned) can reduce the cost of making new REZ capacity available, relative to implementation through an uncoordinated ('do no harm'-style) approach
- ▶ **In the CW-NSW REZ, a number of technology solutions have the potential to efficiently unlock new connection headroom** in the near-term. Coordinated synchronous condensers, synchronous static series compensators (SSSCs) and coordinated batteries with grid-following inverters were found to be cost competitive in terms of dollars per additional kW of capacity unlocked
- ▶ **In the NW-VIC REZ, the network topology and significant existing technical challenges limit the potential of technology solutions** to unlock new connection capacity. Coordinated synchronous condensers were found to be the most cost effective single technology solution for making additional connection capacity available. Once system

³ This is a steady state study that provides insights on the relative strengths and weaknesses of different technologies. The study considers only the direct cost of technology deployment to the developer, and constraints have been calculated based on a system snapshot reflecting the worst-case scenario (e.g. maximum coincident generation, high generation and low load). The study results should be interpreted with these limitations in mind.

strength challenges have been addressed, batteries with advanced inverters could be deployed to offer complementary benefits including reducing curtailment risk

- ▶ While this study modelled technology solutions on a standalone basis, it is likely that a suite of technology solutions could be deployed in each REZ, ahead of network solutions, to open up new connection capacity over the near and longer-term

Key findings for CW-NSW REZ

New renewable generation and storage build is anticipated to replace retiring coal capacity in NSW, deployed into REZs as part of the cost-efficient solutions identified by AEMO’s ISP 2018. However, there is limited opportunity to connect new VRE generation in the CW-NSW REZ without intervention measures.

The modelled network solution (new lines to Liverpool Ranges, based on the ISP 2018 and discussion with Transgrid) is found to enable about 3 GW of new network hosting capacity. This is a significantly larger volume of new network hosting capacity than can be unlocked with any single technology solution.

The modelled technology solutions can unlock an additional ~1 GW of hosting capacity in the near-term, and offer the potential to deliver benefits ahead of network build. Coordinated synchronous condensers, SSSC and batteries with grid-following inverters are found to be cost-competitive technology solutions for unlocking additional hosting capacity in this REZ (based on cost estimates for FY 2020).

The modelling results are summarised in Table 5 below.

Table 5: Summary table of the key modelling findings for the CW-NSW REZ

Technology	Potential increase in VRE export limit (MW)	Technology cost ¹ (\$ million, FY20)	Cost for additional export limit (\$/kW)
Coordinated Synchronous condenser	1404	50	36
Coordinated grid following BESS	1087	42	39
Coordinated grid forming BESS	1117	72	65
Coordinated grid forming BESS with fault contribution of 200% nameplate MVA	1254	72	58
Coordinated grid forming VRE	1407	423	301
Synchronous Static Series Compensator (SSSC)	1148	45	39
ISP network build	2873	200	70
ISP + SSSC	3912	245	63

It is important to note that technology costs are reducing rapidly, particularly for battery technologies and grid-forming inverter technologies. Further, technology capabilities are improving and it is possible that additional revenue streams may become available through market reform in the near to medium-term. It is therefore likely that the costs used in this modelling are conservative relative to what can be expected in the market even in the near-term.

The final 'hybrid' solution modelled for each REZ, combining the longer-term network solution with the nearer-term implementation of a single technology solution, illustrates the potential for a technology solution to unlock additional network hosting capacity, beyond that unlocked by the modelled network solution. The technology solution modelled in the 'hybrid' scenario was chosen for its potential to unlock significant network hosting capacity when paired with the network solution. This scenario does not reflect the optimised solution as it does not consider the combined implementation of multiple technologies, nor the costs of the solutions. The hosting capacity unlocked in the 'hybrid' solution is not the sum of the capacity unlocked by the two solutions in isolation due to the interaction between the two.

Key findings for NW-VIC REZ

In NW-VIC, curtailment risk already affects a lot of existing and committed generation capacity, and no additional VRE capacity can be connected without implementing network or technology solutions.

The modelled network solution (augmentation based on the ISP 2018 and Western VIC RIT-T) is found to be the fundamental solution for unlocking new capacity in this REZ, and is also found to alleviate some of the curtailment risk for existing and committed plant.

The modelled technology solutions are found to have limited potential to cost-effectively unlock significant new network hosting capacity, relative to in the CW-NSW REZ, because the network is more radial with little spare capacity. Shared and strategically located synchronous condensers are found to be the most cost-effective standalone technology option for improving system strength in this REZ, and can unlock new VRE connection capacity at a lower cost than other solutions. However, while synchronous condensers can unlock additional VRE hosting capacity, they will not address the thermal constraints or curtailment risk in the network.

While the modelling for this study did not consider the impacts of deploying multiple technology solutions in combination, it is reasonable to assume that complementary technologies could be deployed to address a broader range of technical issues, deliver more connection capacity and reduce curtailment risk for existing and new generation. For example, in NW-VIC there may be benefit in implementing coordinated synchronous condensers to address the current system strength challenges, and then implement batteries with grid-forming inverters (that are either neutral or improving system strength), to address thermal capacity constraints and reduce curtailment risk.

The modelling results are summarised in Table 6 below.

Table 6: Summary table of the key modelling findings for the NW-VIC REZ

Technology	Potential increase in VRE export limit (MW)	Technology cost ¹ (\$ million, FY20)	Cost for additional export limit (\$/kW)
Coordinated synchronous condenser	641	11	17
Coordinated grid following BESS	As grid following BESS reduces system strength, therefore it is not possible to deploy this technology in the NW VIC area with poor system strength		
Coordinated grid forming BESS	631	419	655
Coordinated grid forming BESS with fault contribution of 200% nameplate MVA	1264	419	332
Coordinated grid forming VRE	639	150	235
SSSC	21	15	714
ISP network build	3125	879	281
ISP + Grid forming BESS	3344	1017	304

As noted in the CW-NSW case study results – battery and inverter costs, in particular, are reducing rapidly. It is likely that the costs assumptions used in this modelling are conservative for some technologies relative to what can be expected in the market even in the near-term.

The final ‘hybrid’ scenario for NW-VIC illustrates the potential for nearer-term implementation of a technology solution to unlock additional VRE hosting capacity, beyond that unlocked by the longer-term network solution. However, this scenario does not reflect an ‘optimised’ solution.

Commercial & Regulatory Considerations

To date, new generation and storage has largely been integrated into the system using minor augmentations to the existing network and incremental amendments to the regulatory framework. Facilitating investment in REZs at the scale required in the future is likely to require more significant network build, revisions of the regulatory framework, and the emergence of innovative commercial propositions and technology offerings.

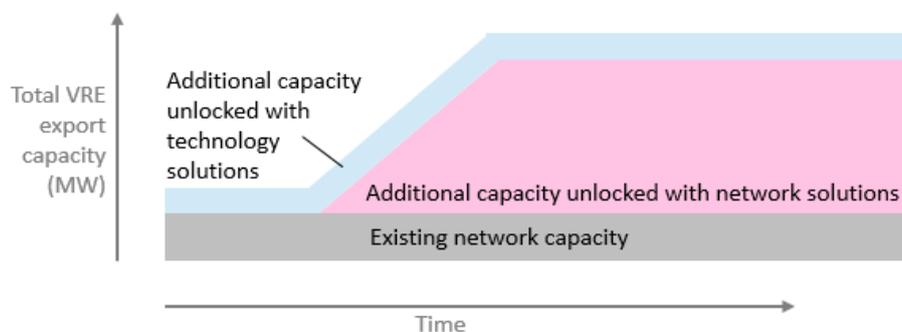
Our consultation with stakeholders as well as precedent in the NEM illustrated significant commercial and regulatory barriers to coordination of generation connections and efficient development of REZs.

In particular:

- ▶ The connection application and approval process, as well as PPA and other commercial arrangements, create a competitive landscape that incentivises speed over potential efficiency gains, and thus creates barriers to information sharing and collaboration
- ▶ The current open access regime appears to be a key barrier to the coordinated implementation of scaled, shared, technology solutions, as it introduces the ‘free rider’ issue
- ▶ In terms of transmission network development, the Regulatory Investment Test for Transmission (RIT-T) was cited by many stakeholders as a key regulatory barrier to REZ development, given the potential for this type of transmission build to be considered speculative by the AER (i.e. network build could come ahead of generators connecting or even fully committing).

Based on the findings from the modelling, commercial and regulatory frameworks need to facilitate the uptake of both network and technology solutions to efficiently unlock new capacity across the NEM, and will need to continue to adapt to market changes. As such, this study has considered both the commercial and regulatory opportunities to implement both types of solutions in the medium and longer-term.

Figure 2: Regulatory and commercial solutions should deliver network and technology solutions



Key options that should be considered for the **delivery of technology solutions** are:

- ▶ Implementation as regulated assets: Technology solutions that could deliver a cost-effective network benefit but do not offer additional revenue streams, such as synchronous condensers and SSSC, lend themselves to development by TNSPs in the regulated network. These technology solutions are most cost-effective when implemented on a coordinated (shared and strategically located) basis.
- ▶ Implementation on a commercial basis: Battery-based solutions that provide network services alongside energy arbitrage, FCAS, and cap contract opportunities, could be implemented in REZs on a commercial basis, potentially with some remuneration for the network services provided. Demonstration of these technology solutions to quantify their benefits, as well as design and demonstration of commercial models to value their services, will be important to catalysing their uptake.

Both of these options would benefit from support from ARENA or other grant funding programs to demonstrate their potential ahead of commercial deployment within appropriate regulatory settings.

Although the ISP has indicated that REZs are not required to be fully developed until existing thermal generation retires, accelerated development of REZ may be required to achieve other goals, such as national emissions reduction objectives or minimising electricity prices. There are a number of options for delivery of network solutions in a fast-tracked timeframe.

Key options that should be considered for the **delivery of network solutions in the near-term** (i.e. within five years) are:

- ▶ REZ development on a commercial basis as Dedicated Connection Assets: If generator and storage connection commitments can be secured ahead of network development, REZ network assets can be developed on a commercial basis with bespoke access and charging arrangements. This option avoids the need for regulated revenue approval, which can take a number of years to secure.
- ▶ REZ development on a regulated basis with financial support: TSNPs could commence REZ development without having yet secured regulated revenue approval, potentially with third party financial support to underwrite the financial risks of doing so. This option would reduce the time taken for sequential processes, potentially reducing the overall timeframe by 2-3 years.
- ▶ REZ development on a regulated basis with other government support: State governments can also consider state-based levers, such as licence condition amendments and derogations to the NEL and NER, which may also be options for delivering REZs in the nearer term, without TSNPs having to follow the usual regulated approval process. However, these options tend to carry risks and costs, meaning they may be less suitable for use to develop large-scale REZs.

For all of these options, governments or other parties could play a role in reducing the risk of network development (such as helping to facilitate/coordinate connection commitments). For regulated assets, third parties can also play a role in improving the likelihood of the project getting regulatory approval (such as funding contributions to improve the RIT-T, or facilitating generator connection commitments).

Key options that should be considered for the **delivery of network solutions in the longer-term** are:

- ▶ Regulated REZ development with the RIT-T: In the longer-term, network solutions are likely to be developed as regulated assets, with approval through the RIT-T (assumed to be amended to integrate the ISP). Government bodies or other parties could take measures to improve the likelihood of regulated revenue approval for a REZ, such as measures to secure generator commitments or funding contributions.
- ▶ Regulated REZ development with an amended funding model: If detailed analysis finds the current cost and risk sharing arrangements for transmission investment (i.e. consumers bear full cost) to be inefficient or inappropriate, it may be appropriate to consider amendments to the transmission cost allocation approach in the future.

Concurrent reviews and reforms

This study has been undertaken within the context of the current regulatory framework, and has not considered the impact of proposed or potential future reforms. A number of major reviews and work

programs underway are highly relevant to the development of REZs and the findings of this work. These include:

- ▶ Actionable ISP work program (ESB)
- ▶ The Coordination of Generation and Transmission Investment (CoGaTI) review and work program (AEMC)
- ▶ Review of system strength requirements (AEMC)
- ▶ Amendments to the treatment of batteries in the NEM (AEMC and AEMO)
- ▶ NEM post-2025 Market Design work program (ESB)