CHAPTER 2

The transforming energy system

2 The transforming energy system

Key highlights

- This chapter discusses the opportunities and challenges arising as a result of a rapidly evolving energy system.
- In response to energy transformation, Powerlink is strategically planning, guiding and enabling opportunities for the Queensland's future transmission network and continues to deliver a secure, safe, reliable and cost-effective service to customers.
- Powerlink's long-term strategic planning takes into account:
  - the central role the transmission network will play in enabling the transformation to a lower carbon future
  - dynamic changes in the external environment, including load growth, storage and the growth in variable renewable energy (VRE) developments in Queensland
  - the condition and performance of existing assets, planning the network that in such a way that it is best configured to meet current energy needs while maintaining the flexibility to adapt as the future evolves.
- Powerlink is playing an active role in shaping the electricity system of the future enabling the transformation to a new energy system, underpinned by clean, sustainable and reliable energy.
- Powerlink has committed to establishing three Queensland Renewable Energy Zones (QREZ). Working in conjunction with the Queensland Government, these QREZ will exploit the state's high quality renewable resource and encourage economic growth, place downward pressure on electricity prices and support both industry and local communities.
- The rapid uptake of rooftop photovoltaic (PV) systems is significantly changing the physical nature of daily load flows and the way in which transmission and generation systems are planned and operated.

2.1 Introduction

The pace and scale of change of Australia's energy system is one of the fastest in the world. The share of VRE generation is increasingly rapidly with significant growth in grid connected solar and wind farms as well as distributed rooftop PV installed behind the meter. This is presenting new opportunities for communities and local businesses throughout the State, but also driving significant technical challenges for the electricity supply chain.

Customer behaviour is central to the energy transformation. Customers, now more than ever, are demanding choice and the ability to exercise greater control over their energy needs, with expectations of reliability and greater affordability. Given this, the future load is uncertain due to a number of factors including variability of customer uptake, push for net zero emissions, emergence of new technology, composition of distributed energy sources (DER)[1] and the commitment and/or retirement of large industrial and mining loads.

The new energy system, driven by the need to decarbonise and underpinned by VRE, will use technology that is very different to that of most existing traditional large and centralised generation plant. It will not have the same physical and supply characteristics as the existing system. Powerlink is addressing these differences to enable the transformation to a new energy system, underpinned by clean, sustainable, reliable and cost effective energy.

2.2 Integrating energy pathways through collaboration

The transmission system is central to the efficient transformation to a low carbon future, integrating significant customer DER responses with the connection of a balance of grid-scale renewables, storage and dispatchable generation.

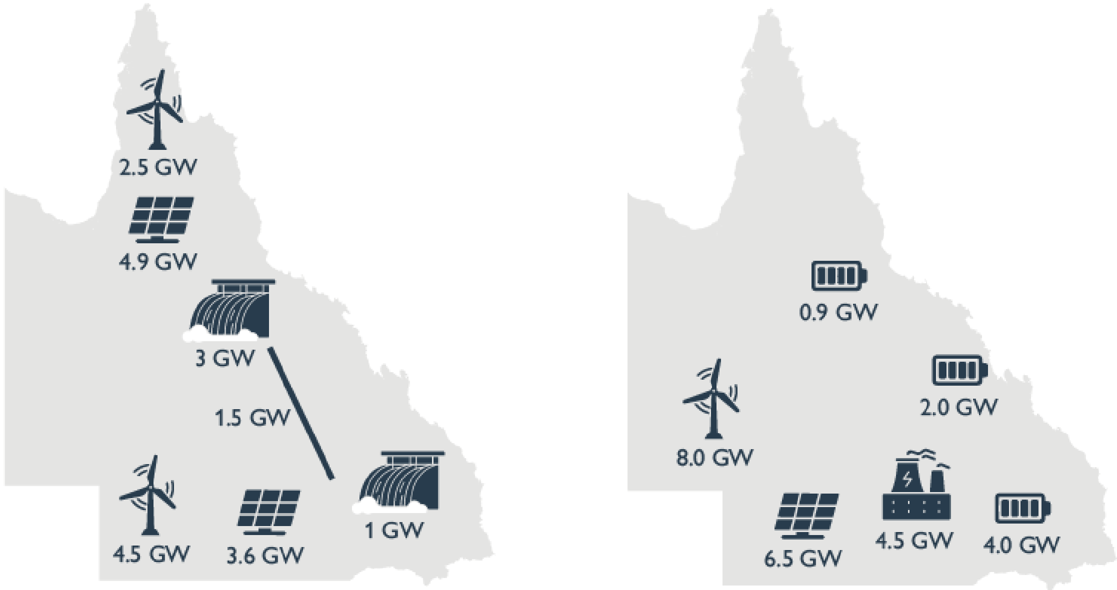
Significant cross collaboration is underway across the industry to inform and respond to the emerging challenges. These include the development of AEMO's 2022 Integrated System Plan (ISP) and its Engineering Frameworks Review, the Energy Security Board's Post 2025 Market Review work and various Australian Energy Market Commission (AEMC) reviews and rule changes including the System Strength Frameworks review.

[1] Common types of DER include 'behind the meter' sources, such as household and business rooftop PV units, battery storage and smart meters.

Powerlink developed the Integrated Electricity Pathways (IEP) and has actively engaged with key stakeholders to explore key investment options for transmission, energy storage and renewable generation against a range of changing sensitivities such as rooftop PV installations, generation portfolios, load developments, and future fuel prices.

Powerlink's IEP identified two broad development pathways that represent the bookends of how the Queensland transmission network could evolve to enable the cost effective transformation to a low carbon future (refer to Figure 2.1). It is anticipated that a mix of the characteristics of both pathways will eventuate over time to meet the changing requirements of the energy system. The pathways presented will frame further policy analysis and future discussions.

Figure 2.1 IEP Development Pathways

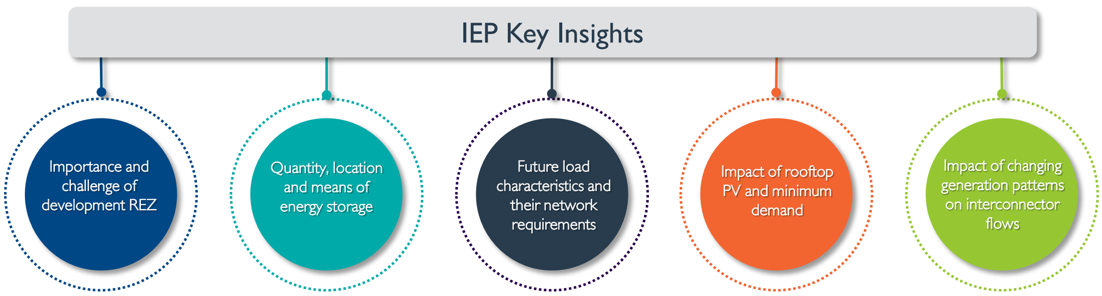


Pathway 1 - Development of significant pumped hydro in southern and northern Queensland, complemented by large-scale solar PV. This pathway, across a number of sensitivities is the optimal least cost option.

Pathway 2 - Development of batteries concentrated around loads in southern Queensland, complemented with additional gas generation.

Powerlink has identified five key insights (refer to Figure 2.2) which are discussed in sections 2.3 to 2.6.

Figure 2.2 IEP Key Insights



2.3 Importance and challenge of developing REZ

A REZ is a geographic area proposed for the efficient development of renewable energy sources and associated electricity infrastructure[2].

Queensland is an attractive location for grid-scale VRE generation development projects as it is rich in a diverse range of renewable resources – solar, wind, geothermal, biomass and hydro.

2.3.1 Economic drivers and future VRE generation development opportunities

While largely driven by changes in customer behaviour, the uptake of VRE generation is also being driven, in part, by the falling cost of solar and wind farm technology. Commonwealth Scientific and Industrial Research Organisation (CSIRO) GenCost report has indicated that the cost of grid connected solar is expected to continue to fall, with the cost of onshore wind also declining[3].

Queensland's first transmission connected solar farm was commissioned in 2018[4] and the number of solar farms has grown rapidly since that time, with 1,024MW operating and a further 1,484MW committed (refer to Table 8.1). Development of grid connected solar farms has slowed in recent years, likely due to the falling spot price of electricity for Queensland during the day time and the expectation of further growth in rooftop PV capacity.

Queensland has practically unlimited potential for the development of additional solar generation. The challenge in utilising this resource is the mismatch between when solar energy is abundant (i.e. during the day time) and the all day demand for electricity. Shifting load demand to times when solar energy is abundant coupled with energy storage will increase the potential for increased solar generation capacity. In Queensland's context, one of the economic merits of deep storage such as pumped hydro is the ability to source a greater share of the State's energy needs from low cost solar.

The development of wind generation has been eclipsed by solar to date (refer to Table 8.1). This is expected to change in the coming years as there is significant interest and activity in developing large-scale on-shore wind generation projects. As wind generation is dispersed throughout the day (i.e. outside of day time), it complements the existing base of solar generation and is less impacted by depressed market prices for energy during the day time.

Queensland's quality wind resource is finite, and concentrated in specific areas. The Queensland Government's Renewable Energy Zone initiative is focussed on developing these areas of wind resource using scale-efficient transmission in a coordinated manner that maximises the capacity and cost efficiency of wind development and delivers genuine benefits to surrounding regional communities. The development of wind resources in Far North Queensland is particularly attractive as the region exhibits less correlation of output to other wind generating stations across the National Electricity Market (NEM). However, wind developments in these locations may be more susceptible to transmission losses (refer to Section 10.8).

REZ development can involve expanding the transmission network or augmenting the capacity of an existing transmission line to increase hosting capacity allowing multiple generators to be connected to the transmission network in a more cost-efficient way. As Queensland has plentiful solar resources coupled with limited quality wind resources, it is important to efficiently coordinate the development of these key resources to transform to a low carbon energy future in an optimal and cost effective manner.

Renewable Firming

The output of wind and PV solar energy sources are intermittent, and vary depending on a range of factors including weather conditions, cloud cover and extent of daylight hours. There is a need to firm renewable energy supply to ensure the supply and demand balance is maintained in a reliable and cost effective manner to customers. There are a number of measures that can be undertaken such as:

2 Version 169 of the NER, page 543.
3 Refer to CSIRO media release June 2021 release June 2021.
4 Clare Solar Farm in North Queensland (100MW).

- both deep and shallow energy storage (e.g. batteries and pumped hydro storage)
- geographic and renewable energy technology diversity
- transmission as an enabler to facilitate access to diverse renewable sources, locations and technologies and
- demand responses (e.g. time of day demand shifting and load controllability).

Each of these has different costs, advantages and capabilities. The optimal solution is likely to involve using all of the responses to varying degrees. The optimal combination of responses will vary over time as the proportion of variable renewable energy (VRE) generation increases and different forms and degrees of firming are required. The value of energy storage is likely to appreciate over time especially deep forms of energy storage such as the potential 24,000MWh Borumba pumped hydro energy storage (PHES) (refer to Section 2.4.2).

2.3.2 Queensland Renewable Energy Zones

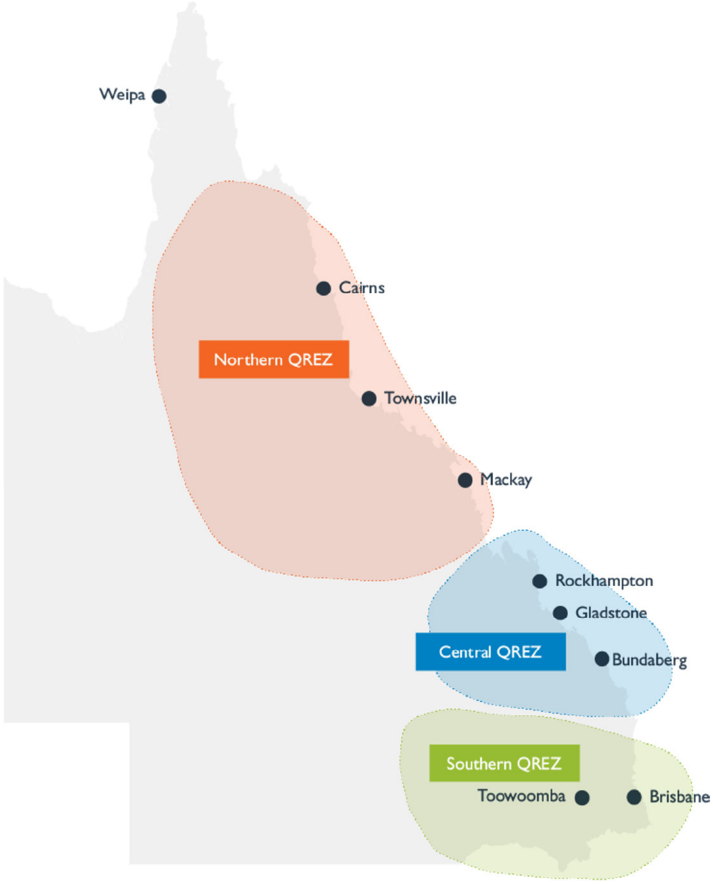
In August 2020, the Queensland Government committed $145 million to establish three Queensland renewable energy zones (QREZ) located in northern, central, and southern Queensland (refer to Figure 2.3)[5]. Powerlink has been working with the Queensland Government to ensure that these developments are coordinated to unlock renewable energy and deliver cost effective network expansion and benefits to host communities by supporting existing and emerging industries within Queensland's regional economies. Powerlink's guiding principles to develop these QREZ are:

- optimising the existing capacity of the transmission network to provide cost effective renewable energy development
- developing QREZ in areas where shared network transmission capacity will enable good access to the market for renewable generators
- efficiently developing QREZ to match regional loads to minimise losses and
- seeking diversity in VRE generation sources to optimise firming services, and ensure continued reliability and security of supply of the energy system at the lowest cost to customers.

The characteristics of the Northern, Central and Southern QREZ is outlined in Figure 2.3.

[5] As published on the Queensland Government website.

Figure 2.3 Queensland Renewable Energy Zones



Northern QREZ

- Good quality wind and capacity factors
- Diverse generation to Southern Queensland and the rest of the NEM
- Queensland Government investing in transmission infrastructure to establish Northern QREZ of up to 500MW capacity
- Neoen's 151MW Kaban Wind Farm as foundational proponent

Central QREZ

- Energy hub of the State with substantial coal fired generation, large loads and export terminals
- Potential renewable energy opportunities and loads converting to renewable energy
- Strong interest in large-scale renewable generation

Southern QREZ

- Large load centres with high capacity interconnector
- Good mixture of energy sources
- Strong transmission network
- Powerlink is working with proponents to develop first stages of Southern QREZ

2.4 Quantity, location and means of energy storage

Energy storage is one of the means of addressing the complexities of demand and supply balance associated with the intermittency of VRE. The types of energy storage available include:

- Large-scale batteries which are most suited to address network needs in shorter timeframes (i.e. hours)
- PHES which may be more suited to larger and longer energy storage requirements and
- Distributed energy resource storage (e.g. residential batteries).

Powerlink's IEP market modelling indicated that there is benefit in building between 4GW and 7GW of energy storage, in stages, as part of the conversion to renewable energy over the next 20 to 30 years. It is expected that approximately 100GWh to 150GWh of energy storage will be required by 2050 to complement VRE sources. Significant long-term storage of at least 24 hours duration will be a critical part of managing the intermittent nature of the rapidly increasing VRE generation. PHES will form a foundation component of energy storage, and other forms of technologies (e.g. hydrogen storage systems) are likely to be candidates in the future.

2.4.1 Residential batteries

Residential battery storage systems, if utilised collectively through 'smart' technology, have the potential to smooth the peaks and troughs of the network across the day, stabilising supply and demand. This could avoid or defer investments in network infrastructure within both the transmission and distribution system[6].

2.4.2 Borumba Dam pumped hydro project

Powerlink is leading a $20 million dollar feasibility study and detailed business case development for the Borumba Pumped Hydro Dam project for the Queensland Government. The project is located near Imbil, south-west of Gympie. Powerlink is working closely with key stakeholders and other Government Owned Corporations to ensure all relevant information is included in the study. The feasibility study and business case is due in late 2023.

2.4.3 Grid-scale batteries and expression of interest (EOI)

Powerlink has recently completed the first customer connected grid-scale battery (100MW and 150MWh) to the transmission network in south-east Queensland. Based on CSIRO GenCost modelling, Powerlink expects additional batteries to connect to the Queensland network over the next decade due to technological advances and the rapid cost reduction of this form of technology[7].

Batteries will play a greater role in the future transmission network providing system security services such as frequency regulation, voltage control, inertia and system strength. Powerlink undertook an investigation with ARENA to improve the awareness of system strength issues and measures that can be addressed through the use of large-scale batteries, including new technology such as grid forming inverters. Grid forming batteries can play a constructive role in increasing the hosting capability of VRE generation within REZs and supporting the operation of the power system (refer to Section 10.3).

Grid-scale batteries can also play a role as virtual transmission lines (VTLs). This offers the potential to alleviate transmission congestion, increase network and REZ utilisation and defer the need for investment in future network augmentations. Battery services can also be deployed to help manage the impact of outages and minimise the constraints on generation which occur during these periods.

In March 2022, Powerlink published an expression of interest (EOI) to engage with external developers, investors and stakeholders in grid-scale Battery Energy Storage Systems (BESS). The EOI is exploring commercial and technical models that would guide the optimal placement of grid-scale battery systems and adopted technology to meet both Powerlink's network technical requirements and investors' requirements for commercial returns.

Powerlink proposes to offer BESS project proponents the opportunity to construct and install their BESS at optimal points in the transmission network. By guiding the optimal development and placement of battery systems, the value to stakeholders is maximised and positive benefits to customers delivered.

2.5 Future load characteristics and their network requirements

The historical pattern of energy consumption in Queensland is changing.

Presently approximately 20% of final energy consumption in Queensland is from electricity, and this electrical energy is predominantly supplied from the interconnected power system. However, moving forward there are two high level trends:

- Electrification of load historically supplied by the combustion of fossil fuels to various sectors of the economy such as transport, agriculture, mining and manufacturing. The drivers for the electrification of these sectors largely relate to the consideration of environmental factors, community and corporate expectations and the broader global focus on emissions reduction. This has been followed closely by the development and commercialisation of new technologies to address these drivers (refer to Section 9.2.1).

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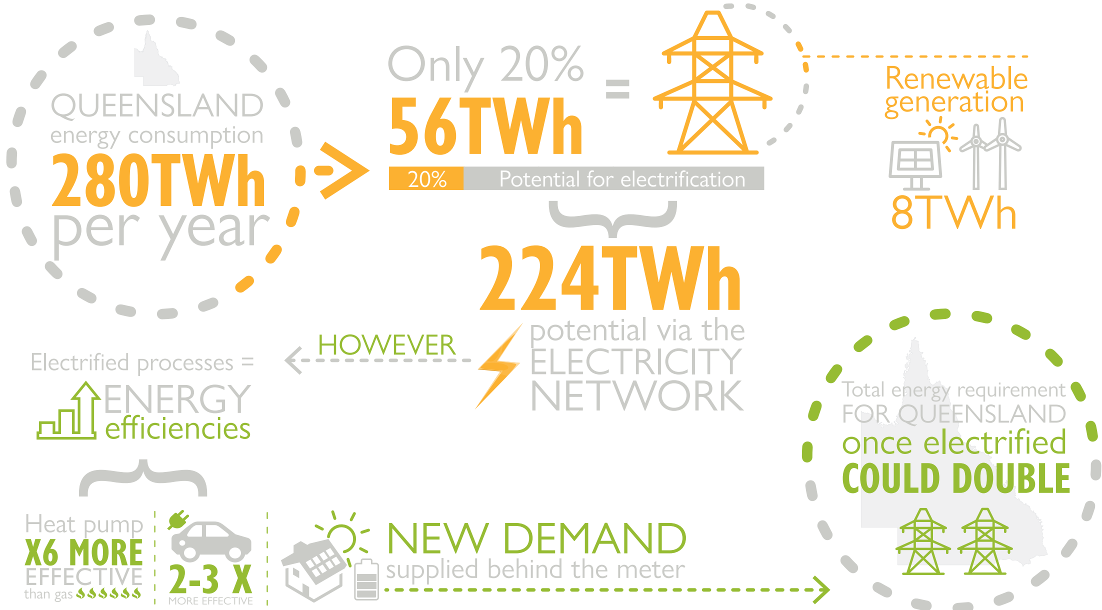
6 Further information on residential batteries is available on the ENA website.
7 Refer to CSIRO GenCost 20-21 Final Report.

- Decentralisation of electricity supply due to the increasing uptake of rooftop PV with some level of firming provided by residential battery systems. The rapid uptake of rooftop PV in Queensland, coupled with emerging technologies such as batteries means that a growing share of households and small businesses are supplying their own energy needs.

The growth in grid-supplied electricity through electrification will to some extent be offset by the increasing decentralisation from the existing customers of the grid. The relative strength of these two effects is uncertain, but on balance overall energy consumption[8] is expected to increase over the long-term (refer to Figure 2.4). Any additional electrical load in Queensland to facilitate energy renewable exports would be additional to this.

Figure 2.4 Potential combined impact of identified trends in Queensland



However, these effects are not uniformly distributed throughout Queensland. In particular mining and energy-intensive manufacturing activity is concentrated in particular locations. This may require transmission network augmentations in certain locations to deliver reliability to this load even as contraction may occur in other areas. Powerlink will continue to undertake prudent investment and efficient operation of the transmission network to manage potential growth in some areas, while requirements in other areas may decrease. Even in an area where the possibility of decreased supply needs is anticipated, there continues to be a requirement to supply load as long as it exists and to safely and securely operate the network for customers in a cost efficient manner.

2.5.1 Other future technologies

Currently less than 0.15% of cars on Queensland roads are electric vehicles (EVs). However, recent international policies relating to the sale of internal combustion engines (ICE) vehicles[9] and moves by car manufacturers to phase out ICE vehicles will put downward pressure on costs and increase the models of EVs in the Australian market. Supported by the Queensland Zero Emission Vehicle (ZEV) Strategy which is in development, this is expected to materially increase the number of EVs on Queensland roads over time, which will have the potential to impact the energy and demand requirements of the network.

The Australian Renewable Energy Agency (ARENA) in conjunction with industry is currently exploring emerging new technologies such as renewable hydrogen and renewable energy to understand potential future opportunities at a domestic, commercial and export level.

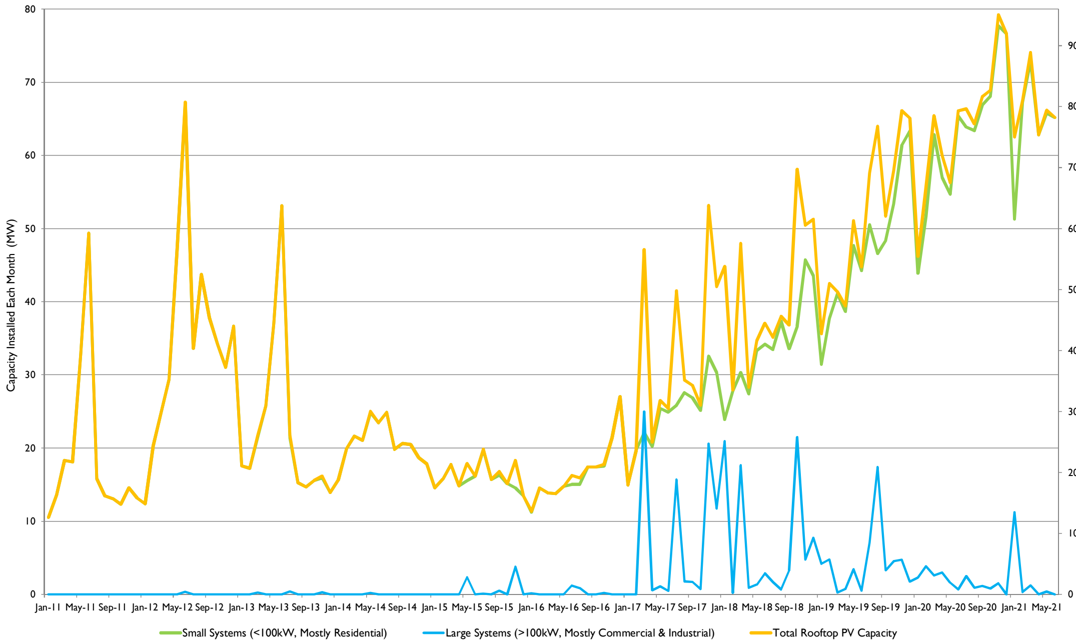
8 Defined in tera watt hours (TWh).
9 UK is banning the sale of ICE vehicles by 2030.

2.6 Impact of rooftop PV and minimum demand

2.6.1 Rooftop PV systems

Queensland has one of the highest penetration of rooftop PV systems in the world with almost 40% of households having installations compared to 25% penetration only five years ago[10]. The installation of rooftop PV in Queensland is increasing at significantly higher rates than recent forecasts. The current installation rate is approximately 800MW per annum (refer to Figure 2.5). Rooftop PV penetration in Queensland is expected to continue with the Queensland Household Energy Survey indicating that 22% of participants intended to purchase new or upgrade existing rooftop PV in the next three years, and 93% indicated they would replace their existing panels with similar sizes or larger.

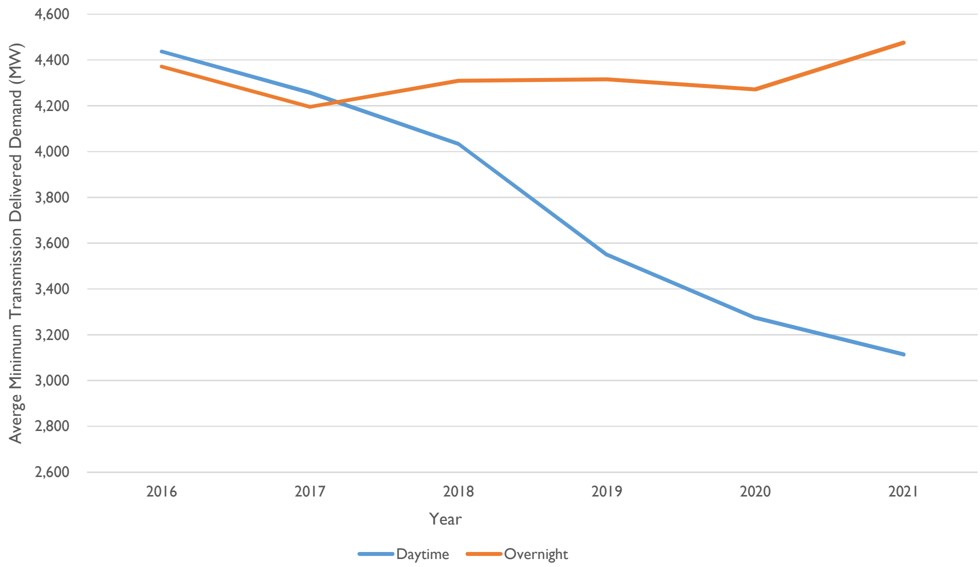
Figure 2.5 New rooftop PV installations



The high uptake of large-scale VRE generation within the distribution networks together with the significant uptake of rooftop PV is changing the transmission delivered daily load (refer Section 3.4.1). These large quantities of solar generation are all highly correlated in output. A noticeable change has been the change in the pattern of minimum demand, shifting from the very early morning to the middle of the day. As embedded and rooftop PV capacity increases, the minimum day time demand set during the winter and spring seasons will continue to decrease. Figure 2.6 shows the shift to day time minimum demands.

[10] Australian PV Institute (APVI) Solar Map, funded by the ARENA.

Figure 2.6 Average of the five lowest demand days per calendar year for day time and overnight



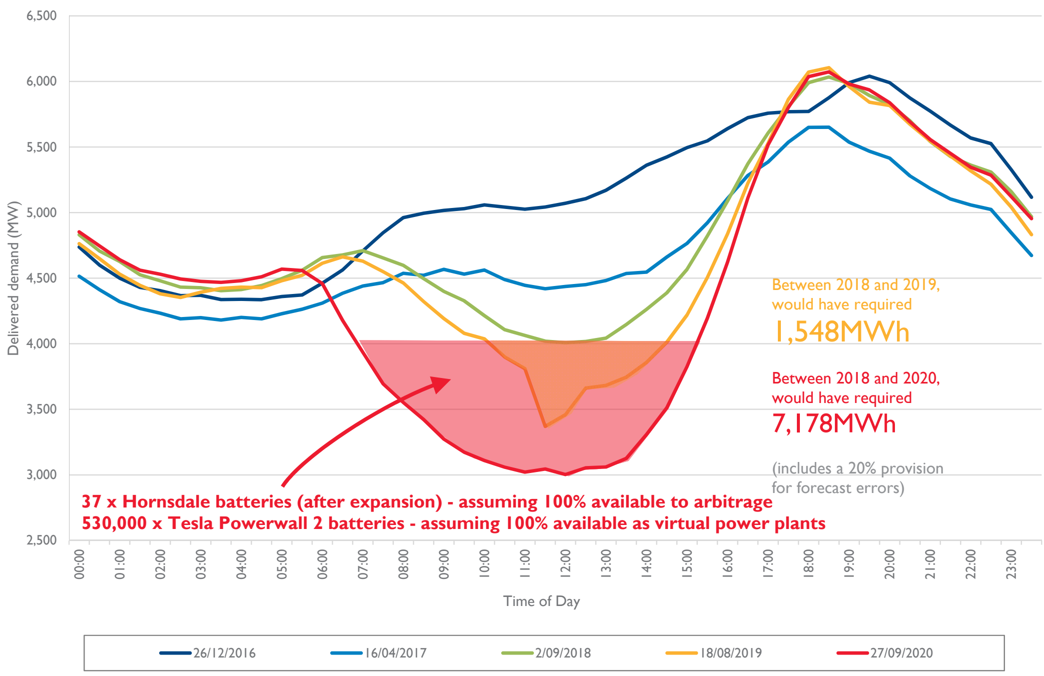
The transmission delivered demand is also partially supplied from transmission connected grid-scale VRE. Therefore, the load available for supply by the traditional synchronous generation or 'residual demand' is reducing. While the minimum demand decline is generally most observable in spring, the overall trend of minimum demand across the year is also decreasing.

This trend is likely to present technical challenges to the power system requiring future investment in network or non-network solutions (such as battery storage). The scale of investment in storage to mitigate medium term adverse impacts of falling minimum demand on the secure operation of the power system is significant. The minimum demand decrease from 2018 to 2020 would be equivalent to over 7,178MWh of storage. This is equivalent to 37 Hornsdale batteries or around 530,000 Tesla Powerwalls. The rate of decrease of minimum demand is the key reason why batteries alone are unlikely to be able to provide the storage capability to manage this issue.

Once adequate deep storage exists, large-scale solar generation can again become a key ingredient in the low-cost electricity supply by providing the capacity to charge the storage facilities through the day where excess generation exists. This then allows the storage to discharge (generate) to meet peak demand at night.

Complementing this is the diversity of wind generation that can also support peak demand and provide renewable energy outside of day time peak PV generation periods. Therefore, in the interim, the wind resources need to be fully exploited to support Queensland's QRET target at least cost (refer to Figure 2.7).

Figure 2.7 Energy required to offset reduction in minimum demand



Powerlink is monitoring and assessing the impacts of changing load profiles and generation mix on the transmission network, and continues to take an integrated planning approach to address emerging issues and challenges with the transforming power system.

The broader technical challenges arising from minimum demand cannot be addressed by a single organisation and will require a cross-industry collaboration to ensure customer centric solutions deliver a safe reliable transition to 50% renewables by 2030 and beyond. The transmission network is increasingly impacted by customer decisions regarding DER adoption occurring in the distribution network. Powerlink, EQL and the Queensland Government recognise the need to ensure that investments to support minimum demand mitigation in either the transmission or distribution network are complementary and ensure that solutions maximise customer benefits whilst not adversely affecting customer cost.

Powerlink, EQL and the Queensland government recognise that likely solutions to manage the impacts of minimum demand include:

- energy storage across the supply chain that operates complementary and coordinated to the system needs (transmission, distribution and behind the meter connected).
- encouragement of the local use of generated energy to limit the need for energy to minimise the flows back and forth between the transmission and distribution system.
- continued refinement for the connection of DER in a manner that ensures the overall reliability and security of the transmission and distribution networks.

2.6.2 Impact of changing generation patterns on interconnector flows

Queensland has historically exported energy to New South Wales and other NEM states over the Queensland to New South Wales Interconnector (QNI). The development of significant VRE resources in other states as well as Queensland has the potential to significantly alter the flows on both inter and intra connectors.

For example, through the NSW Energy Infrastructure Roadmap (EIR), NSW is expecting to deliver around 12GW of additional renewable generation by 2030. If the NSW EIR is implemented to its full extent, southerly flows across QNI would materially reduce or potentially reverse.

2.7 Ongoing transformation

The power system of the future will present many operational, planning, regulatory and market challenges. New frameworks, strategies and infrastructure are required to enable the orderly transformation to a power system which is underpinned by clean, sustainable, resilient and reliable energy at the lowest long run cost to consumers.

Powerlink is keeping abreast of new technological developments and formulating strategies with AEMO, the Queensland Government, Energy Queensland, and other market participants. This will ensure that the high voltage transmission grid is capable of unlocking opportunities and benefits associated with a decarbonised low emissions energy system to power economic growth, enable market efficiencies and reduce cost to customers.

Powerlink will continue to proactively plan for the future and update the IEP to make certain that electricity pathways include new developments and remain relevant for the changing environment. Regular assessments will focus on delivering positive outcomes for customers by addressing shifts in physical, technical and economic environments.