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Roadmap to Queensland Renewable Energy Target 2020

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Executive summary

The solar and wind project pipeline for Queensland provides evidence of significant appetite for private investment in solar and wind power developed in response to the announcement of a Queensland 50% renewable energy target (QRET) by 2030. Achieving QRET will be challenging without a complementary National Electricity Market framework, but due to the Queensland Government's ownership of coal generators and the network infrastructure, it has levers to pull to facilitate this transition. The achievement of QRET however, requires a robust project plan to ensure a managed transition. This report can serve as the first step in such a roadmap.

Any plan for high levels of renewable energy across a large state with dispersed regional centres, requires an understanding of the implications of the best locations for renewable energy not only to harvest renewable resources but also to utilise existing network infrastructure to reach the large demand centres. Queensland's existing coal generators have been located at the confluence of the network structure, or vice versa, such that they are able to direct large energy flows to demand centres. The modelling conducted to inform this report, is a nodal National Electricity Market model (ANEM), which derives the dispatch of energy based on available generation at each node or available transmission capacity to transmit energy to demand centres. The output provides insight into how power will flow around Queensland's network with decentralised, more remote, renewable energy generation.

A managed transition plan for Queensland needs to establish a framework for manipulating what may appear at times to be incompatible parameters. Although solar energy is predictable, it is not available outside of sunlight hours and whilst wind energy is available outside of sunlight hours, it is less predictable. The variable availability of wind and solar energy needs to be considered in conjunction with electricity demand, which is not cognisant of energy supply, and may occur when neither wind nor solar energy is available. While Queensland's coal generators are young enough to play a role in the transition plan they are not technologically designed to plug the gaps between the availability of wind and solar energy, and demand, which complicates the optimum dispatch of energy. Thus, energy storage is an essential ingredient in a managed transition framework to store surplus energy for dispatch at periods of high demand. The problem identified in the modelling is that the inclusion of storage in the supply mix complicates nodal supply-demand balance and by extension, energy supply security.

The modelling for this report derived outcomes for a variety of scenarios to achieve QRET or higher. Outcomes indicate that high levels of coal generation closure create systemic energy deficits (referred to here as Energy-Gaps) whilst insufficient coal generation removal creates systemic renewable energy curtailment (referred to here as VRE spillage). Energy storage in the form of pump hydro energy storage (PHES) reduces the Energy-Gaps and renewable energy spillage, but it introduces new challenges in the form of significantly increased demand, potentially at nodes with insufficient generation or transmission capacity, to resolve materially either Energy-Gaps or VRE spillage.

In consideration of the modelling outcomes, a roadmap to achieve QRET by 2030 using decentralised renewable energy needs to address the following:

1. Withdrawal of coal generator units should be based on nodal location of renewable energy, and transmission infrastructure to reach the large demand centres of Brisbane and Gladstone, not on age or other considerations. The modelling outcomes indicate that partial closures at Gladstone, Stanwell and Tarong provide the lowest level of Energy-Gaps utilising the existing network capacity, rather than full closures at Gladstone and Tarong;

2. Planning permission for renewable energy generation should be based on available or planned transmission infrastructure to reach the large demand centres; not necessarily on the best solar or wind resources. The modelling outcomes show that renewable energy generation located in the Wide Bay, Tarong and Gladstone nodes plays a significant role in facilitating higher levels of supply security;

3. Without robust information on the quality of wind and solar resources around the state, it is time consuming for investors to gather adequate data to support proposals. If investors do gather data at their cost, this information will not be publicly available to other investors nor policy makers for determining requirements for a managed transition to high levels of VRE. Inasmuch as Queensland conducted geological surveys into coal and other mineral resources in the 1960s and 1970s to attract investors from Japan and elsewhere, it would be similarly good practice to conduct surveys and gather public data on the wind and solar resource across the state, to attract local and international investors.
4. Transmission network augmentation may be required in the following transmission corridors if high levels of renewable energy is to reach demand centres consistently:
    a. Central West Queensland – Gladstone
    b. Wide Bay – North Moreton (Brisbane North)
    c. South West Queensland – South Moreton (Brisbane South)
5. Location of energy storage is fundamental to the success of a transition to high levels of variable renewable energy. Modelling conducted for this report assumed that 1 GigaWatt (GW) of pump hydro storage (PHES) was located at Mt Byron within the North Moreton node and 1 GW at Urannah within the North Queensland node. As both of these nodes have little generation capacity, energy deficits and transmission congestion were identified as probable outcomes of locating PHES at these locations. Plans for PHES need to consider the proximity to load centres, availability of generation within the node, transmission infrastructure to transmit to load centres and geophysical resources for adequate sizing.
6. Capacity of energy storage is equally important for securing a managed transition. The modelling conducted indicates that more than 2.8GW is required to secure supply after sundown and before dawn when wind drops off. Higher levels of storage however increase demand which in turn increases the need for additional generation capacity. The impact of PHES loads on nodal and state supply-demand balance needs to be fully analysed, so that optimum levels of PHES capacity can be determined.
7. Higher levels of energy storage than required for daily energy time-shifting, will provide longer-term seasonal storage capacity which will be fundamental to energy security during extended periods of low variable renewable energy supply (VRE). Generating adequate returns for investors from infrequent dispatch of energy from storage may be challenging, so consideration should be given to incentive or ownership models to encourage investment in storage and enable energy security during infrequent periods of low resource for VRE.
8. The Australian Energy Market Operator's (AEMO) Integrated System Plans (ISP) for Queensland do not discuss the nodal supply-demand energy balancing problems that were encountered in the modelling conducted for this report. Greater reliance should be placed on models that can reflect network and nodal challenges of electricity supply to ensure security of supply, than on higher level zonal (state) models.
9. Achieving QRET will require coordinated effort from the Queensland Government, the Queensland generators, Powerlink, AEMO, AEMC and investors. The Queensland Government can direct its state owned electricity supply entities to follow a prescribed plan in an attempt to achieve QRET or higher targets, but if NEM governing bodies are not equally committed to those plans, they will not succeed. AEMO's actions affect investment through unpredictable changes to MLFs, and Integrated System Plans that do not reflect the complexities and uncertainties of commissioning, connecting and dispatching to the grid. The AEMC's rule changes are too slow to accommodate a fast transition to QRET. There is a need for a joint collaborative body tasked with developing a roadmap to achieve QRET comprised of investor groups, AEMO, AEMC, Powerlink, Queensland generators and the

Queensland Government. Roadmaps developed through this collaborative body would give greater security to investors, and the Queensland public, of the achievement of high levels of VRE in Queensland electricity supply.

In conclusion, the success of a roadmap to high levels of renewable energy will depend on its effective communication to investors and electricity market participants alike. Without a clearly articulated roadmap to reach QRET, it will be difficult to succeed in transitioning to an electricity system dependent on high levels of variable renewable energy

Transition to decentralised, renewable energy supply

1. Introduction

Queensland's electricity supply is predominantly from coal generation. Consequently, the carbon emission intensity of public electricity consumed by industry in Queensland was 0.762kgCO2/kWh during the first quarter of 2020 (AEMO, 2020a). As a result of large private investment in utility solar and wind power 2018-19, the carbon emission content of public electricity has decreased from 0.902kq/CO2/kWh in quarter 3 of 2017, so private investment in wind and solar power has played a significant role in reducing the carbon content of electricity consumed by industry. While this is a notable achievement Queensland lags behind South Australia which has reduced its carbon emission content of electricity from 0.515kgCO2/kWh in 2015 to 0.276kgCO2/kWh in quarter 1 2020 as a result of investment in renewable energy. Tasmania, as Australia's hydro powerhouse had a carbon content of electricity of 0.002kgCO2/kWh in quarter 1 2020.

Carbon intensity of electricity is important because the European Union has recently committed to a raft of measures to reduce their carbon emissions, one of which is a carbon border adjustment mechanism (CBAM) (European Commission, 2019). The CBAM seeks to place an adjustment price calculated from the cost of carbon embedded in imported goods, to protect the mitigation efforts that European companies are pursuing, from carbon leakage. Thus, the carbon content of goods produced in Queensland, including the carbon content of electricity consumed in the production of those goods, will dictate the competitiveness of Queensland exports to Europe. In this context, South Australia, Tasmania and New Zealand will be more competitive when seeking to export to Europe, than will Queensland. Therefore, if a global transition to low-carbon electricity supply, primary metal manufacturing and industrial production proceeds faster than is currently predicted, Queensland will need to move quickly to facilitate the transition of its electricity supply industry to variable renewable energy (VRE).

VRE is the preferred fuel source for electricity supply for investment because it is fast declining in price, such that it is already cheaper than electricity sourced from new coal generation and gas generation. Pump hydro energy storage (PHES) can store excess energy generated when variable resources are plentiful for dispatch when resources are not available to secure supply. Li-ion battery costs are also declining fast, so there are multiple technologies available to facilitate reliable supply.

The alternatives to a VRE-led electricity supply are to embark on a program of nuclear power development or to capture and store emissions from existing coal plant. Absent the expense of both carbon capture and storage (CCS) and nuclear power as identified by CSIRO recently (Graham et al., 2019) which should disqualify both technologies from a market-led decarbonisation of electricity supply, there are other factors that render both nuclear power and coal coupled with CCS less attractive for decarbonisation in Queensland. The first is that both nuclear and the majority of coal generation in Queensland (excluding Kogan Creek) are reliant on water for cooling. The Tarong and Swanbank power stations were shut down during the Millennium Drought in 2007 because of a lack of water. The consequences of drought remain a high risk for Tarong power station (Stanwell, 2020). The French experience with nuclear power is that during hot summer days generation has to be scaled down because adequate cooling is not possible (Felix and Eckert, 2019). Nuclear research is now focussed on small modular reactors which may or may not have water cooling mechanisms, depending on the technology (World Nuclear Association, 2020). Second, International Energy Agency (IEA) member countries' public budgets 1978-2019 for nuclear power research exceeds US$2019 255 billion, 43% of all energy research funding, including US$2019 53 billion on nuclear fusion (International Energy Agency, 2019). Despite four decades of public money allocated to nuclear power research, the problem of waste (particularly in the United States of America (USA) remains unresolved, and the technology commercially uninsurable. The third factor to consider is speed of deployment. This is important because if

Queensland has to act to respond to global trends, then it is expedient to pursue options that offer the quickest route to the desired outcome. Deploying nuclear power in Queensland will not be a quick option. Australia has regulated against nuclear power and the population remains ambivalent about its application here (Murphy, 2019). Over-turning public ambivalence and regulation take time, Australia has little nuclear expertise, and nuclear power stations are slow to construct. Retrofitting post-capture CCS to existing coal plant remains an option, but the efficiency overhead is high, capture does not remove all emissions and there is little evidence of affordable, successful implementation anywhere in the world. By comparison, renewable energy is popular with the public and investors, has technology that is affordable and decreasing in price and can be deployed in large quantities in a short period of time.

Queensland has committed to a 50% renewable energy target (QRET) by 2030, which will help Queensland electricity supply become more carbon competitive. However, the transition from electricity supply designed for centralised generation with bespoke transmission infrastructure to the primary load centres, is not necessarily fit for the requirements of a system dominated by regionally located, decentralised VRE. The Queensland Department of Natural Resources, Mines and Energy (DNRME) has already commissioned research/modelling to inform how QRET should be accomplished and AEMO has produced forecasts of Queensland's electricity system through to 2040 (AEMO, 2019). The modelling commissioned by these bodies focuses on the projected deployment of technologies over the next 2 decades but less on the regional location of renewable energy generation, transmission congestion, energy spillage/loss due to regional supply-demand constraints, and long-term management of regional energy supply.

The discussion here considers the regional implications of VRE investment, primarily from a technical perspective, of transmission network and generation adequacy. The report provides a framework for identifying how to facilitate a transition to low-carbon electricity supply.

2. Method

As there has been a lack of analysis of the regional/nodal technical consequences of a large investment in VRE, detailed modelling was conducted to consider the role that renewable energy can play in meeting demand at regional transmission nodes. Unlike other National Electricity Market (NEM) models, the model chosen is a University of Queensland model called ANEM, developed by Dr Phillip Wild. ANEM is a novel agent-based model where the agents include demand and supply side participants as well as an Independent System Operator (ISO). Network structure closely resembles the actual nodal structure of Australian states' transmission network. The ISO operates optimal dispatch based on Locational Marginal Pricing (LMP) which in turn is calculated from short run marginal cost, power flows, branch congestion, intra-regional and inter-state trade. Calculation of transmission branch power flows also permits transmission losses to be calculated and allocated to nodes. Further detail on the ANEM model can be found in the National Electricity Market Nodal Modelling Final Report 2020.

Assumptions about existing generation and transmission are taken from AEMO's Integrated System Plan 2020 (AEMO, 2019). After the announcement of Queensland's 50% Renewable Energy Target by 2030, private investors indicated their interest in developing projects to meet this target. Projects that have been awarded planning approval are detailed on the AEMO website (AEMO, 2020c). Projects with planning permission as at the end of 2019 were assumed to be successfully rolled-out by 2030 and included as new entrant generation in modelling. These VRE projects are jointly referenced as the 'Pipeline'.

The outcomes of the modelling are used to discuss the effectiveness of deployment of renewable energy in Queensland electricity supply.

3. The consequences of increased variable renewable energy in Queensland electricity supply

The Pipeline of VRE projects reflects 8,736MW of solar PV and 4,820 MW of wind power, as can be seen in Figure 1.

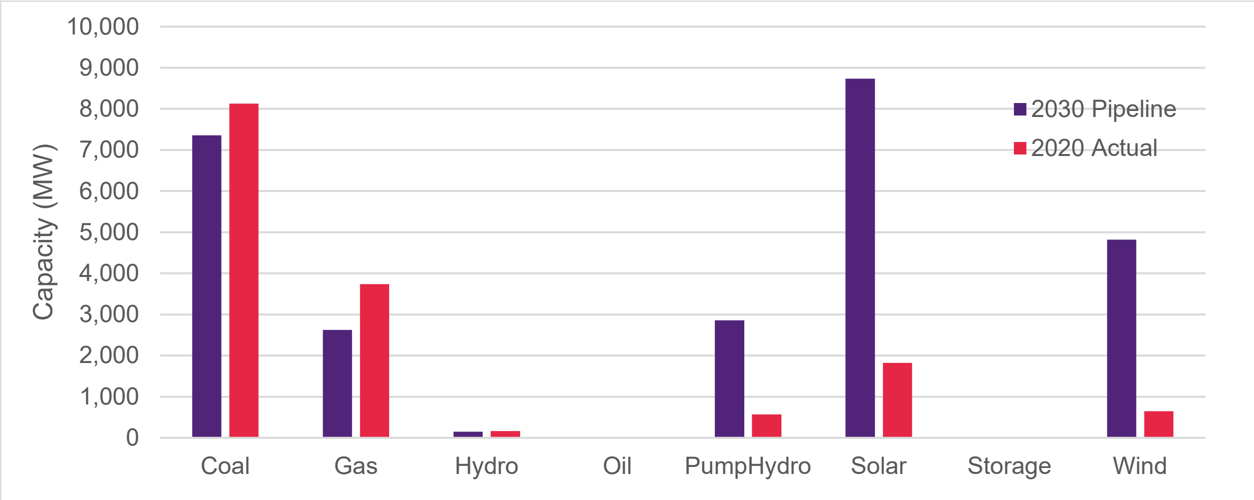


Figure 1: Queensland electricity supply capacity: 2020 and 2030 Pipeline Scenario

AEMO's ISP Central Scenario assumptions are for an increase in demand of 3% between 2022 and 2030, and yet the investment Pipeline forecasts a Queensland electricity supply capacity increase of 11 GW from wind and solar PV by 2030, with the closure of only Callide B power station. Although wind and solar PV do not operate at the same capacity factor as coal, 11 GW of additional supply will result in surplus capacity, especially during daylight hours when solar PV supply will be larger than all Queensland demand. Large supply of electricity from solar PV conflicts with coal and gas must-run requirements which results in curtailed energy (ie energy that is discarded, not dispatched, and referred to here as energy spilled) particularly from solar PV.

AEMO's Optimal Development Path for ISP Central Scenario does not forecast a requirement for additional PHES in Queensland by 2030, and only 300MW additional PHES in the Step Change Scenario. The Counterfactual Case (without optimal transmission infrastructure) for ISP Central Scenario also has no additional PHES by 2030, but does have additional 2.8GW by 2040 and 1.6 GW by 2030 for the Step Change scenario. The ANEM model outcomes point to a requirement for significant storage to mitigate against high levels of VRE spillage. For this reason, PHES is introduced to absorb surplus VRE for dispatch at peak periods at the North Queensland node (assumed to be equivalent to the Urannah proposal) and at the North Moreton node (assumed to be located at Mt Byron), in addition to the PHES included as part of the Kidston project. This 2.3GW of PHES facilitates the dispatch of 3TWh of solar PV (or 14% of the potential PV dispatch based on the available solar resource) and 610 GWh of wind power, which makes it critical for the achievement of QRET.

Notwithstanding the addition of 2.3GW of PHES, the ANEM model predicts that 28% of solar and 6% of wind power will be spilled because it conflicts with must-run capacity of coal plant. Analysis suggests that QRET will only be achieved if the dispatch from PHES is included as renewable energy (without off-setting dispatch against energy consumed in pumping actions) and rooftop solar included in the generation mix. Without the inclusion of rooftop solar or energy dispatched from PHES plant in the generation mix, coal plant is forecast to contribute 56% to the generation of electricity in Queensland in 2030. Thus investment in some 13.5 GW of utility solar and wind generation by 2030 would not result in the desired contribution of renewable energy to centralised generation.

2030 Fuel source for electricity generated, excluding VRE spilled (N transmission)	**2030 Fuel source for electricity generated, with VRE spilled notionally added to VRE and removed from coal generation (N transmission)**

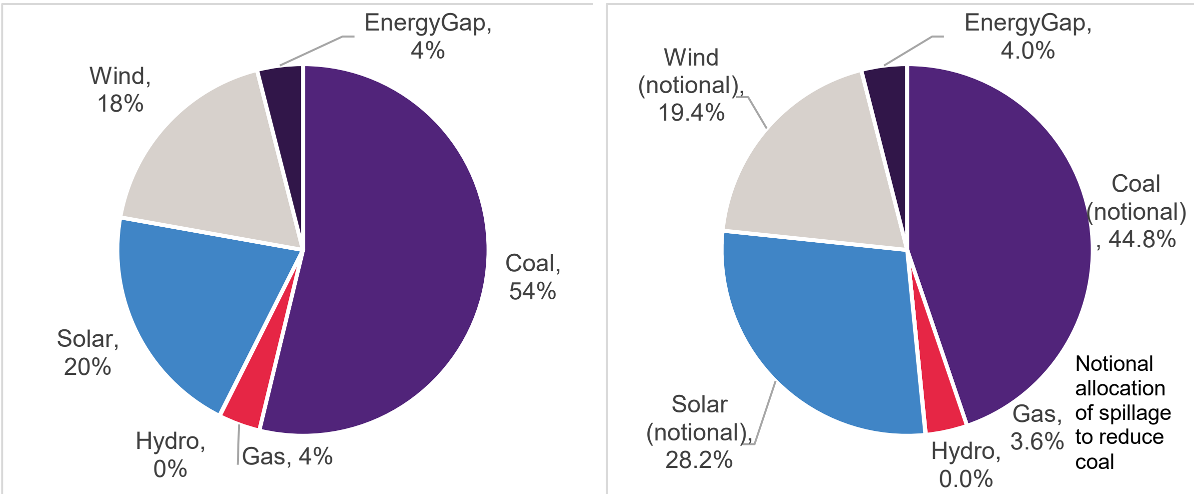


Figure 2: Fuel source of electricity generated, 2030, Pipeline Baseline N Scenario

Figure 2 details the source of energy for electricity generation in the Pipeline Baseline scenario with wind and solar constituting 38% of electricity generated in the National Electricity Market. The premise behind the modelling for the Pipeline Scenarios is that coal plant closure can reduce surplus capacity and reduce spilled solar energy facilitating achievement of QRET, as shown in Figure 2. Closure of coal units leads to 2% of energy dispatched not from existing and identified new generation, but from unidentified generators. This unidentified capacity required to balance supply and demand intermittently at each node is referenced in Table 2 as the Energy-Gap. Further detail on complexities associated with the Energy-Gap can be found in the discussion in Section 4 of this report.

In addition, iterations of the Pipeline Scenario considered the following closures:

- Pipeline Scenario A
  - Unit 1 Stanwell; Units 1,2,5,6 Gladstone; Unit 1 Tarong; (Units 1-4 Liddell; Units 1-2 Eraring; Units 5-6 Vales Point)
- Pipeline Scenario B
  - Units 1,2 Stanwell; Units 1,2,5,6 Gladstone; Units 1,2 Tarong; (Units 1-4 Liddell; Units 1-4 Eraring, Units 5-6 Vales Point)
- Pipeline Scenario C
  - Units 1,2,5,6 Gladstone; Units 1-4 Tarong; (Units 1-4 Eraring, Units 1-4 Liddell; Units 5-6 Vales Point)

The Pipeline Scenarios are contingent on investment in wind and solar generation as indicated by planning permission already awarded to project proponents. It is recognised that this reflects a bias towards solar generation of 8,736 MW by 2030, against 4,820 MW of wind. However, investor preference for solar PV supports predictions of ongoing cost decreases over the next 5 years, and thus underpins lowest cost dispatch. In considering the impact of different generation mix, Australian Energy Market Operator's (AEMO)

Integrated System Plan 2020 (ISP) scenarios were also modelled. These scenarios were associated with the following differences to the Pipeline Scenarios:

- ISP 2030 Step Change Scenario
  - 3080 MW coal plant closures (Pipeline Scenario B & C: 2520MW) [difference to Pipeline C is Gladstone Units 3-4 closed]
  - 2030 solar capacity of 3278 MW (Pipeline: 8736 MW)
  - 2030 wind capacity of 7118 MW (Pipeline: 4820 MW)
- ISP 2040 Central Scenario
  - 3650 MW coal plant closures (Pipeline Scenario B & C: 2520MW) [difference to Pipeline C is Gladstone Units 3-4 and Tarong N closed]
  - Solar capacity of 7243 MW (Pipeline: 8736 MW)
  - Wind capacity of 5651 MW (Pipeline: 4820 MW)

Scenario analysis of renewable energy percentage of QLD supply in 2030

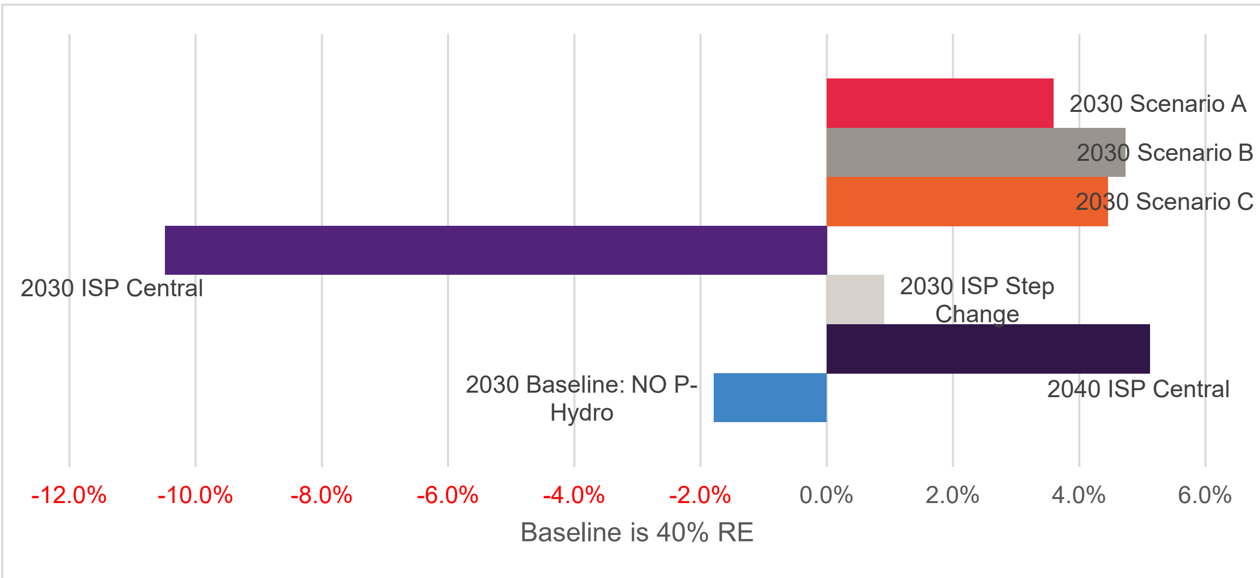


Figure 3: Change to 2030 Pipeline Baseline renewable energy percentage

Figure 3 details the variation (in additional RE %) in the outcomes from modelling of each scenario to the Pipeline Baseline scenario, which achieves 40% renewable energy in QLD NEM supply. Scenario B and ISP 2040 Central generate the highest level of renewable energy in QLD supply.

2030 Fuel source for electricity generated, Scenario B (Closures: 2 Units Stanwell, 4 units Gladstone, 2 Units Tarong)	**Fuel source for electricity generated, ISP 2040 Central** (Closures: 6 units Gladstone, 5 Units Tarong)

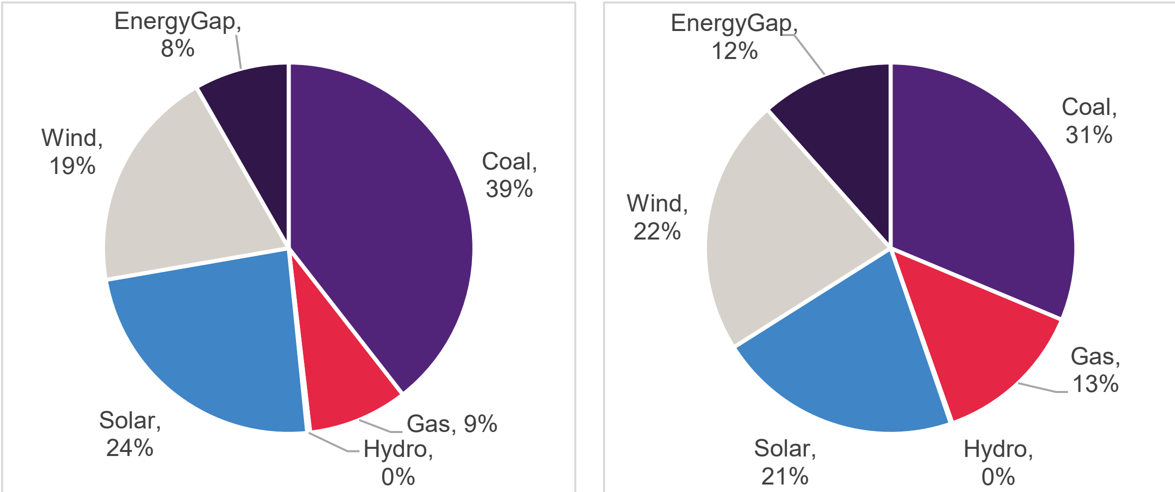


Figure 4: 2030 Pipeline Scenario B and ISP 2040 Central N Scenarios

Modelling 2030 Pipeline Scenario B and ISP 2040 Central indicates that wind and solar contribute 43% to total electricity generation although with slightly different proportions from wind and solar in each scenario. Figure 4 shows the forecast increase in energy deficit to 8% in Scenario B and 12% in 2040 ISP Central as coal plant is removed from supply.

Modelling of ISP 2040 Central Scenario shows that coal plant closures of all of Gladstone Power Station (GPS) and all of Tarong Power Station (TPS) reduces generation from coal to 31%, increases gas to 13% and if QRET is to be achieved, the Energy-Gap would have to be plugged with additional renewable energy capacity.

The modelling conducted shows that transmission has a very large impact on the achievement of QRET, spillage of VRE, resolving the Energy-Gap and the incidence of congestion. In particular, modelling for this report included 2 transmission scenarios for each of the Pipeline and ISP generation scenarios. The first transmission scenario (N) sought to apply existing MW thermal limits in the group of transmission lines connecting 2 nodes. This approach effectively assumes no line outages occur, and that the transmission lines are always operational - it provides an ideal setting for maximising VRE potential within the network. The second transmission scenario (N-1) involved subtracting the largest individual line from the group of transmission lines connecting nodes. This approach more closely matches transmission planning frameworks and how AEMO manages the grid in practice, being linked to reliability and security considerations if the largest single line is lost.

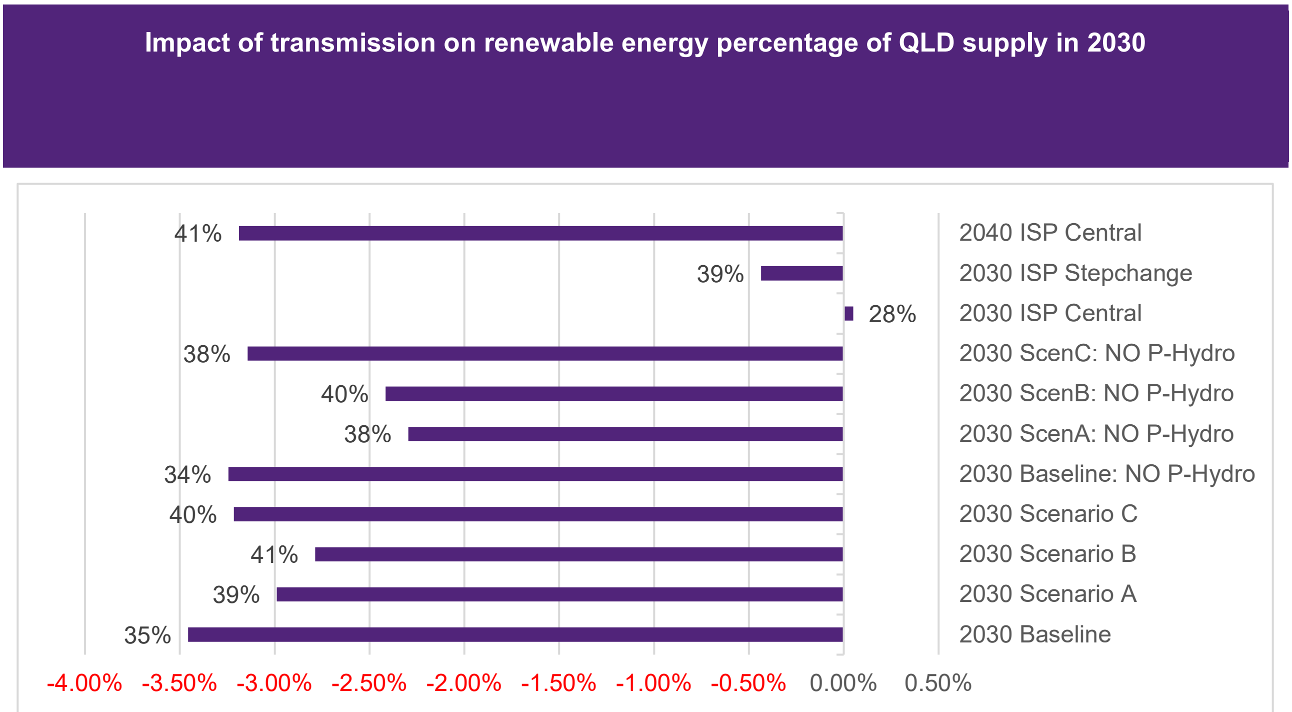


Figure 5: Achievement of QRET, impact of transmission (N v N-1)

Figure 5 provides a synopsis of the impact on QRET of reducing the capacity of the transmission network to the operational level of N-1. The VRE percentage of each of the scenarios under the N-1 transmission scenario is listed against each of the series in the graph. The 2030 Pipeline Baseline Scenario's VRE contribution to electricity generation reduces to 35%, Scenario B's VRE contribution reduces to 41%, ISP 2030 Central Scenario VRE contribution increases slightly and ISP 2040 Central Scenario VRE contribution reduces to 41%.

The energy and capacity deficits vary significantly between scenarios and across the nodes, but there are increasing requirements for capacity and energy to balance the system under N-1 in the Pipeline Scenarios, exacerbated by increasing coal plant closures. Retirement of GPS and TPS, in particular, imposes severe balancing requirement particularly at the Gladstone, Wide Bay and Moreton North nodes.

The large energy and capacity deficits that emerge under N-1, indicate that achievement of QRET is as much about transmission network adequacy as it is about coal plant closure. It is therefore pertinent to focus on the transmission network and its adequacy for maximising VRE dispatch.

Pipeline Scenarios	ISP Scenarios

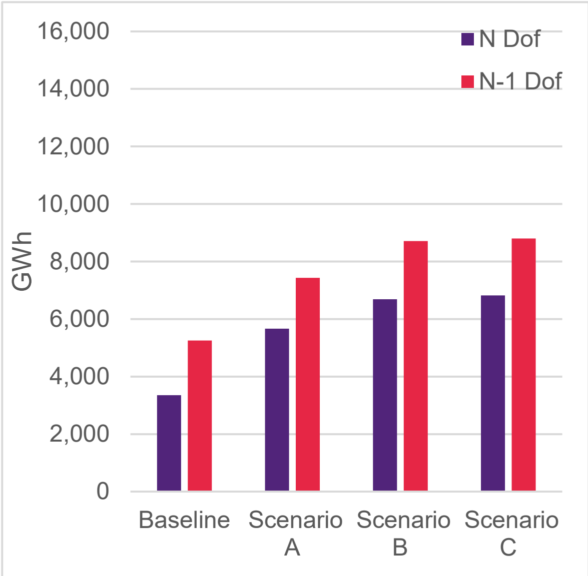


Figure 6: Energy-Gap for Pipeline and ISP Scenarios

Before moving on to a more detailed discussion, it is useful to summarise the outcomes of the scenarios that come closest to reaching QRET under constrained network (N-1) scenarios. Table 1 provides this summary.

Table 1: Salient statistics for scenarios that achieve highest Renewable Energy Proportion

	Pipeline B	Pipeline C	ISP 2040 Central
Solar MW	8736	8736	7243
Wind MW	4820	4820	5651
Ren Energy % (N)	44%	43%	44%
(N-1)	41%	40%	41%
Spillage (N-1) Solar	28%	30%	27%
Wind	12%	13%	14%
EnergyGap (N-1)	8707 GWh (11%)	8796 GWh (11%)	14925 GWh (18%)
Notional RE % with spilled and Energy-Gap reallocated (N-1)	56%	56%	57%

The final line in Table 1 suggests that if spilled electricity can be eliminated and the Energy-Gap filled with renewable energy, nearly 57% of electricity generated could be from renewable sources. The difference in the size of the Energy-Gap between dispatch under N versus dispatch under N-1 and between the Pipeline B and C scenarios, points to the important role that transmission plays in the transport of renewable energy to the load centres.

4. Energy generation adequacy

Energy generation adequacy in each node varies across the scenarios. As this roadmap considers transition to high levels of electricity from VRE, analysis is restricted to the 2 scenarios that project the highest level of renewable generation by 2030, Pipeline Scenario B (sB) and ISP 2040 Central (2040C).

First, consider the generation capacity in each of the scenarios as listed in Table 2. Queensland current generation capacity is 8059MW of coal-fired power stations, with 3076MW of gas turbines, 958MW of wind and solar, 148MW of hydro and 570MW of PHES. Pipeline scenarios project an increase in wind and solar to 13556MW and 2860MW of PHES. In order to avoid excess VRE, pipeline scenarios consider the increasing withdrawal of coal units until 4839MW of coal generator capacity remains. The ISP high VRE scenarios include more ambitious withdrawal of coal plant, to 3836MW in 2040C. The removal of 4223MW from existing capacity in 2040C is counterbalanced by an increase of 10469MW of wind and solar.

It should be noted that approximately 400MW of generation from bagasse is not included in this analysis. These generators are located on or near sugar cane farms and generate approximately 1200GWh a year, about half of which is sent-out. The location of the generators places them in the distribution network, not on the transmission network, so they are not included in the modelling nor in the discussion.

Table 2: Queensland generation capacity for scenarios modelled

Queensland Generation	Existing (MW)	Pipeline Scenarios	ISP 2030 Central	ISP 2030 Step Change	ISP 2040 Central
Coal	8059	7359 (BL) 5539 (sA) 4839 (sB) 4839 (sC)	7359	4279	3836
Gas	3076	2691	2691	2555	2555
Wind	641	4820	3083	7118	5652
Solar	1784	8736	4768	3278	7242
Hydro	148	148	148	148	148
PHES	570	2860	2860	2860	2860
Total	14242	26614 (BL) 24794 (sA) 24094 (sB) 24094 (sC)	20909	20238	22293

Table 3: Energy-Gap by node for 2040C and sB (full year)

Node	ISP 2040C N		ISP 2040C N-1		Pipeline sB N		Pipeline sB N-1	
	MAX (12378MW)	SUMMER EvPk Avg	**MAX** (10826MW)	SUMMER EvPk Avg	**MAX** (4572MW)	SUMMER EvPk Avg	**MAX** (7720MW)	SUMMER EvPk Avg
FNQ	302 (Winter WD 4:30pm)	34	297 (Winter WD 4:30pm)	22	250 (lots overnight)	31	250 (lots overnight)	20
ROSS	487 (Winter WD 5:30pm)	5	310 (Winter WD 5:30pm)	1	423 (lots overnight)	26	423 (lots overnight)	20
NQ	1250 (Winter WE 0:00am)	134	1273 (Autmn WD 4:30pm)	93	1110 (lots overnight)	116	1110 (lots overnight)	64
CWQ	987 (Autmn WE 5:30pm)	11	902 (Winter WD 4:30pm)	6	-	-	774 (Summ WE 4:30pm)	1
GLAD	1664 (Summ WD 4:30pm)	277	1404 (Summ WE 7:30pm)	829	235 (Summ WE 5:00pm)	1	792 (Autmn WD 6:30pm)	26
WB	1250 (Autmn WD 4:30pm)	116	1353 (Winter WD 4:30pm)	233	516 (Summ WE 7:30pm)	5	770 (Summ WE 0:00am)	7
TAR	746 (Winter WD 4:30pm)	5	1946 (Summ WD 7:00pm)	97	94 (Summ WD 4:30pm)	1	700 (Summ WD 4:00pm)	5
SWQ	2822 (Winter WD 4:30pm)	38	463 (Winter WD 4:30pm)	6	-	-	23 (Winter WD 3:30pm)	-
NM	1993 (multiple 3-5:00pm)	282	1993 (lots 3:00 - 5:00pm)	404	1944 (multiple overnight)	205	1993 (multiple 3-5:00pm)	399
SM	885 (multiple 3-5:30pm)	21	885 (lots 3:00 - 5:30pm)	618	-	-	885 (multiple 3-5:30pm)	47
GC	-	-	-	-	-	-	-	-

In both 2040C and sB, the generation capacity by 2030 is assumed to change significantly from 2020. Electricity generation will become increasingly reliant on variable wind and solar power. Solar power is perhaps more predictable than wind power, but the change to a primary reliance on these variable resources requires storage to shift electricity generated during periods of excess energy to periods of excess demand.

Pump hydro energy storage (PHES) is generally accepted as the most affordable form of storage, and is premised on the notion of excess energy from all sources during periods of low demand being used to pump water into reservoirs, which can be released during periods of high demand.

Modelling of PHES must prioritise dispatch at peak demand periods, and pumping action at periods of low demand. The assumptions underpinning the modelling conducted for this report were that PHES is available for dispatch during morning peak (6:30 – 10:00am) and Evening Peak (17:30 -22:00), and that pumping would be directed to periods of excess solar energy from 10:00-17:00 and excess wind energy from 23:00 – 1:00 and 5:30-6:30. As will be discussed in the sub-sectors following, the pumping strategy proved to complicate the supply-demand balance in the nodes where the PHES is located, leading to energy deficits.

Modelling included three network scenarios: the 'N' scenario, which assumes that networks operate at full capacity and the "N-1" scenario, which assumes that networks operate without the largest transmission line between nodes. A third scenario, "N+1", was introduced for the Pipeline Scenario B and the ISP 2040 Central scenarios in the form of augmentation assumed to transmission lines between CWQ-GLAD, WB-NM, and SWQ-SM.

Table 3 provides detail of the maximum Energy-Gap in each node over the course of the whole year and the period during which the maximum occurs for 2040C and sB N and N-1 scenarios. The average Summer Evening Peak Energy-Gap indicates the extent of the Energy-Gap during the periods of higher demand.

Energy-Gaps in 2040C scenarios are very large totalling 12378MW across all nodes (6251MW coincident), decreasing under restricted network to a total of 10826MW (7341MW coincident), but remaining high in the large load centre nodes. Although still large, sB scenarios show significantly lower Energy-Gaps of 7720MW (6286MW coincident) in N-1 scenarios and decreasing further to 4572MW (4034MW coincident) under unrestricted network conditions. The size and persistence of the Energy-Gaps are best examined in the major load centres of North Moreton (NM), South Moreton and Gold Coast combined (as GC is predominantly reliant on energy from SM), and Gladstone and Wide Bay combined (as WB is predominantly reliant on GLAD for energy).

The analysis that follows focusses on Summer Weekdays as the periods with the highest challenges in meeting demand through increased load from air-conditioning and decreased transmission through lower summer thermal limits.

a. ISP 2040 Central Scenario (2040C)

At a state level, Queensland is assumed to consume 60,628 GWh of energy in 2040C, 10,528GWh over Summer Weekdays, 5,289GWh over summer weekends/public holidays – 26% of the annual total. In winter, energy consumed over weekdays totals 10,509GWh and 4,235 GWh over weekends/public holidays – 24% of the annual total. Maximum demand occurs in summer, 11,237MW during a weekday and 11,187 during a weekend/public holiday. Minimum demand occurs in winter, 3177MW during a weekday.

Figure 7 details the ANEM model's Queensland nodal structure including transmission lines, transmission thermal limits (summer) and electricity generation capacity at each node in MW for 2040C. The number of lines comprising transmission between each node are evident from the pink lines.

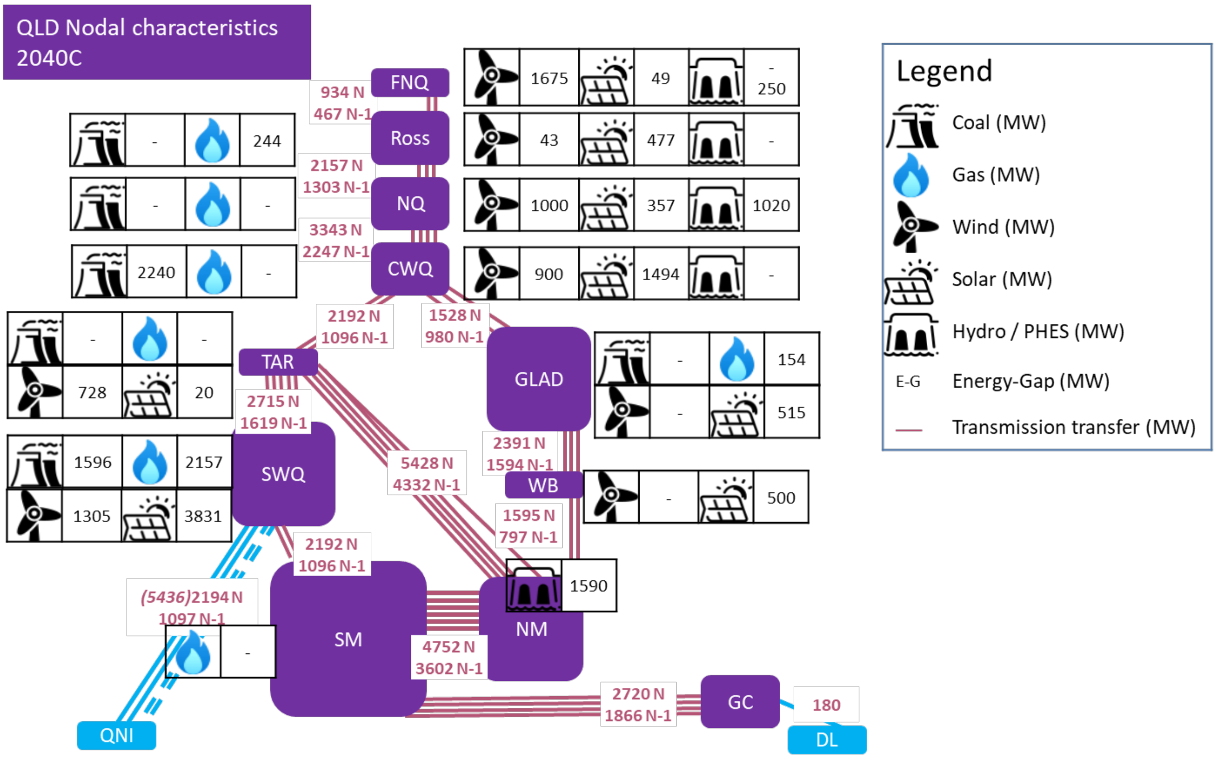


Figure 7: Queensland nodal structure with transmission lines and generation capacity for 2040C

Demand increases with losses from increased network flows and with pumping action for PHES. Table 4 details the average Summer Weekday Energy Balance, where supply in the form of generation and network flows is compared with demand, to indicate the state supply-demand balance. PHES pumping adds approximately 15% to demand, Energy-Gap decreases between N-1 and N scenarios providing evidence of the benefit of adequate transmission capacity. Assumed augmentation to transmission lines between CWQ-GLAD, WB-NM, and SWQ-SM shows only small benefits at the state level, as greater energy flows to NSW with increased network capacity.

Table 4: 2040C Queensland Summer Weekdays Energy Balance

Queensland Summer Weekdays Ave MW	2040C N-1		2040C N		2040C N+1	
Demand	**(8680)**		**(8866)**		**(9019)**	
Load		(7311)		(7311)		(7311)
Loss		(279)		(465)		(618)
PHES Pump		(1090)		(1090)		(1090)
Supply - Generation	**7910**		**9730**		**9964**	
Coal		2783		3252		3421
Gas		648		1235		1195
Hydro		4		9		15
PHES Dispatch		492		441		497
Solar		1753		2330		2332
Wind		2230		2462		2503
Supply - Network	**(710)**		**(1404)**		**(1491)**	
Exports						
QNI		(831)		(1462)		(1516)
DL		(19)		(44)		(63)
Imports						
QNI		-		-		-
DL		140		102		88
ANEM Energy-Gap	**(1921)**		**(1020)**		**(1052)**	
Balance		(1480)		(540)		(546)
Spillage	**(665)**		**(339)**		**(296)**	
Solar		(379)		(238)		(236)
Wind		(286)		(100)		(60)

Spillage of wind and solar is reduced as transmission capacity increases, although there is still some evidence of spillage even under the augmented transmission conditions, indicating the challenges associated with integrating variable resources into a network.

Note that supply and demand is not balanced, indicating a deficit of available generation. There is also a difference between the Energy Balance that is estimated from average supply and demand of energy and the Energy-Gap derived in modelling. This is attributable to auxiliary use of energy by power stations, losses allocated to energy receiving nodes in NSW, and the use of averages rather than weighted average for the analysis.

Table 5 details the averaged Energy Balance for Queensland during Summer Evening Peak.

Table 5: 2040C Queensland Summer Weekday Evening Peak Energy Balance

Queensland Summer Weekdays Evening Peak Ave MW	2040C N-1		2040C N		2040C N+1	
Demand	**(9937)**		**(10091)**		**(10242)**	
Load		(8989)		(8989)		(8989)
Loss		(384)		(538)		(689)
PHES Pump		(564)		(564)		(564)
Supply - Generation	**9257**		**11236**		**11643**	
Coal		3149		3651		3787
Gas		1124		2144		2163
Hydro		11		26		41
PHES Dispatch		1599		1801		2023
Solar		996		1178		1179
Wind		2379		2436		2450
Supply - Network	**(1087)**		**(1552)**		**(1593)**	
Exports						
QNI		(1129)		(1629)		(1658)
DL		(55)		(36)		(40)
Imports						
QNI		-		-		-
DL		98		113		105
ANEM Energy-Gap	**(2308)**		**(924)**		**(767)**	
Balance		(1766)		(407)		(191)
Spillage	**(517)**		**(20)**		**(5)**	
Solar		(185)		(3)		(2)
Wind		(332)		(17)		(3)

Note how the Energy-Gap across all Summer Weekdays is lower under N-1 but higher under N and N+1 than the Energy-Gap across all Summer Weekdays' Evening Peak. This is primarily the benefit of generators being able to respond to higher demand when there is adequate network capacity to do so. The difference between the Energy-Gap as calculated by ANEM and the Energy-Gap as identified in the Energy Balance table is a result of generator auxiliary use and transmission losses allocated to nodes in New South Wales.

The discussion below will examine both the Energy Balance and the Energy-Gap over Summer Weekdays for the three large load centres, and a shorter discussion on the Energy-Gaps in SWQ, CWQ and NQ.

i. NM Summer Weekdays Energy Balance

Table 6 details the NM Energy Balance for Summer Weekdays as modelled in 2040C. There is a persistently large Energy-Gap of 1046 GW under restricted network conditions, reducing to 659MW under unrestricted network conditions. Under network augmentation there is reduction in Energy-Gap, but relatively modest improvement to 578MW. Spillage declines as transmission capacity increases from N-1 to N, but there is little evidence of significant benefit for dispatch of renewable energy under network augmentation in SEQ. The increase in solar spillage under augmented network conditions is surprising, but the increase is associated with 30 periods of unusual flows. In 21 periods, there is a very large dispatch of VRE from CWQ and GLAD which restricts dispatch of VRE in WB. In 4 periods, there is very low available energy from VRE in all northern nodes which results in energy flowing northwards along the following transmission routes: SM-NM-WB-GLAD; SWQ-TAR-CWQ and CWQ-NQ-ROSS-FNQ resulting in WB solar spillage.

Table 6: 2040C NM Summer Weekday Energy Balance

North Moreton Summer Weekdays Ave MW	2040C N-1		2040C N		2040C N+1	
Demand	**(1801)**		**(1822)**		**(1838)**	
Load		(1170)		(1170)		(1170)
Loss		(51)		(72)		(88)
PHES Pump		(580)		(580)		(580)
Supply - Generation	**417**		**310**		**293**	
Coal		-		-		-
Gas		-		-		-
Hydro		-		-		-
PHES Dispatch		417		310		293
Solar		-		-		-
Wind		-		-		-
Supply - Network	**351**		**867**		**985**	
Exports						
SM		(872)		(668)		(739)
Imports						
WB		499		531		664
TAR		724		1004		1060
ANEM Energy-Gap	**(1046)**		**(659)**		**(578)**	
Balance		(1033)		(645)		(560)
SEQ Spillage	**(727)**		**(195)**		**(217)**	
Solar		(691)		(192)		(211)
Wind		(36)		(3)		(6)

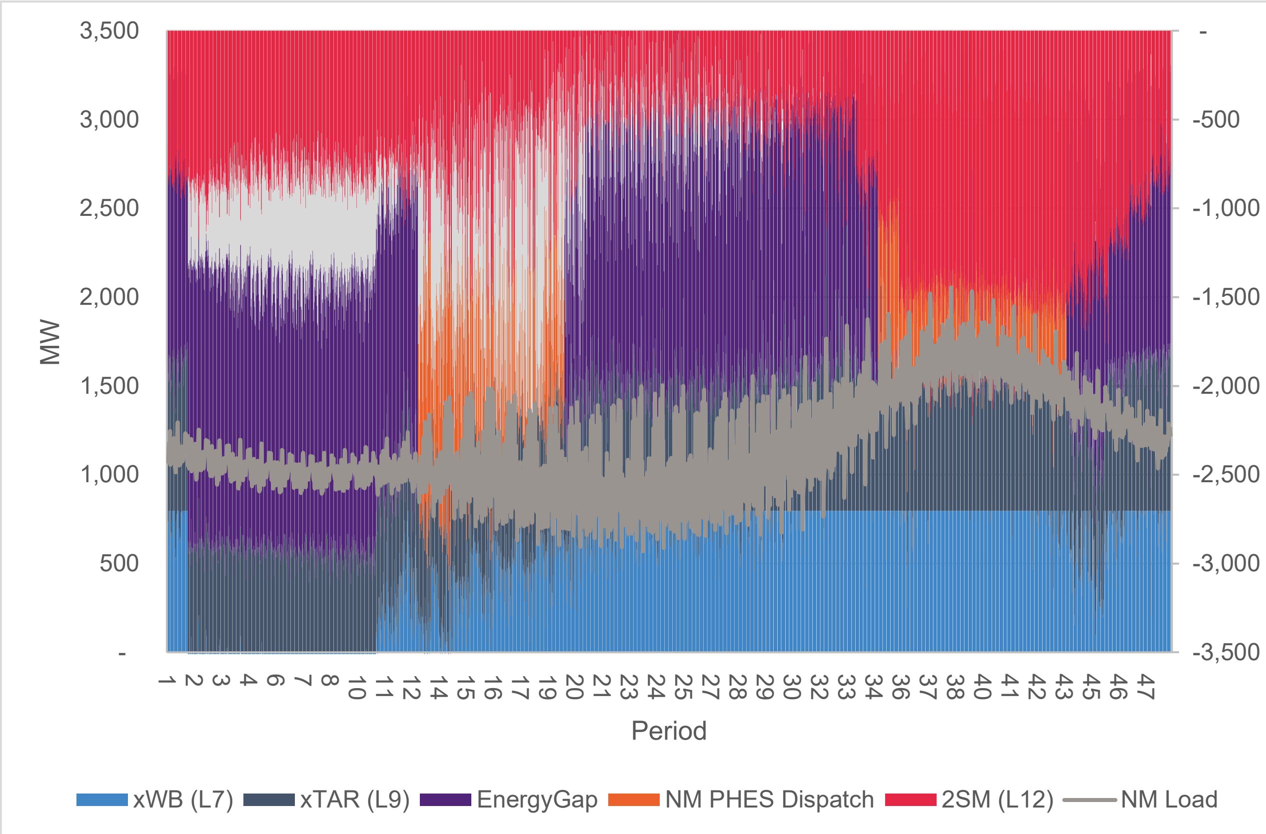
The Energy-Gap during Summer Evening Peak as detailed in Table 7 changes because of the reduction in PHES pumping and increase in PHES available for dispatch. Spillage of wind and solar is also negligible due to the time of day and increased demand to meet Evening Peak.

Table 7: 2040C NM Summer Weekdays Evening Peak Energy Balance

North Moreton Summer Weekdays Evening Peak Ave MW	2040C N-1	2040C N	2040C N+1
Demand	**(1921)**	**(1929)**	**(1935)**
Load	(1548)	(1548)	(1548)
Loss	(73)	(81)	(87)
PHES Pump	(300)	(300)	(300)
Supply - Generation	**1272**	**1235**	**1187**
Coal	-	-	-
Gas	-	-	-
Hydro	-	-	-
PHES Dispatch	1272	1235	1187
Solar	-	-	-
Wind	-	-	-
Supply - Network	**259**	**417**	**515**
Exports			
SM	(1323)	(1234)	(1245)
Imports			
WB	788	624	674
TAR	794	1027	1086
ANEM Energy-Gap	**(404)**	**(282)**	**(254)**
Balance	(390)	(277)	(234)
SEQ Spillage	**(194)**	**(-)**	**(1)**
Solar	(174)	(-)	(1)
Wind	(20)	(-)	(-)

Figure 8 represents 2880 points for each energy series in the NM node under restrictive N-1 network conditions. Note the flows from WB at capacity for many of the periods from 4pm onwards. Also note the periods of Energy-Gaps correspond with periods of PHES pumping. There is little evidence of a marked morning peak, which in effect reduces PHES pumping requirements, although PHES dispatch is strongly in evidence during morning peak. Note the large flows to SM from 4:30pm until 10pm.

Figure 8: 2040C NM Summer Weekday N-1 Energy-Gap with statistics



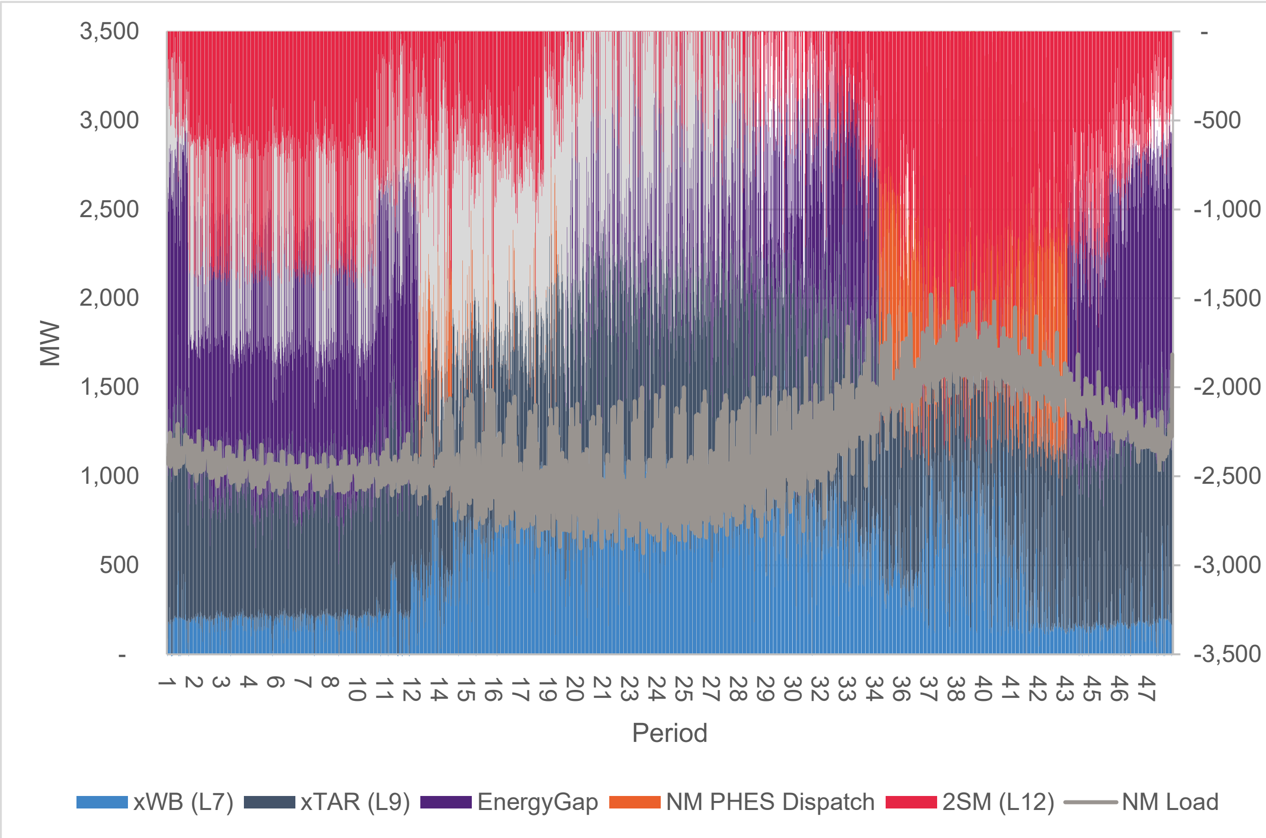
Energy-Gap Statistics and Transmission congestion details

Max: 1993 MW Median: 1590 MW Capacity Factor: 52%	Occurs in 91% of periods >= 498 MW = 66% >= 997 MW = 65% >= 1495MW = 54%	>= 498 MW occurs Evening Peak = 120 (20%) Overnight = 1020 (94%) Daytime = 772 (64%)	Congestion xWB: Day 36%, EvPk 86% xTAR: Day 0%, EvPk 0% 2SM: Day 0%, EvPk 0%

The Energy-Gap in NM is large at 1993MW and persistent, in that the median of all occurrences is 1590 MW and the capacity factor of energy required is 52%. An Energy-Gap occurs in 91% or 2620 periods of the total 2880 periods of Summer Weekdays. Energy-Gaps of 498MW or greater (25% of the maximum) are present in 66% of periods. Energy-Gaps of 997 MW or greater (50% of the maximum) are present in 65% of periods. Energy-Gaps of 1495MW or greater (75% of the maximum) are present in 54% of Summer Weekday periods. 120 incidences (20% of Evening Peak periods), 1020 incidences (94% of Overnight periods) and 772 incidences (64% of periods during the day from 7:00 to 16:30) of Energy-Gaps greater than 498MW occur. Thus a large driver of the Energy-Gap in NM node is PHES pumping which occurs for a few hours overnight and during the day. The only evidence of congestion on the network into and out of NM node, is the line from WB to NM which shows congestion on 86% of Summer Weekdays Evening Peak.

Figure 9 represents 2880 points for each energy series in the NM node under normal N network conditions. Flows from TAR provide the predominant supply of energy into NM, but the Energy-Gap associated with PHES pumping is still marked although not as persistent during the day as under N-1 conditions.

Figure 9: 2040C NM Summer Weekday N Energy-Gap with statistics



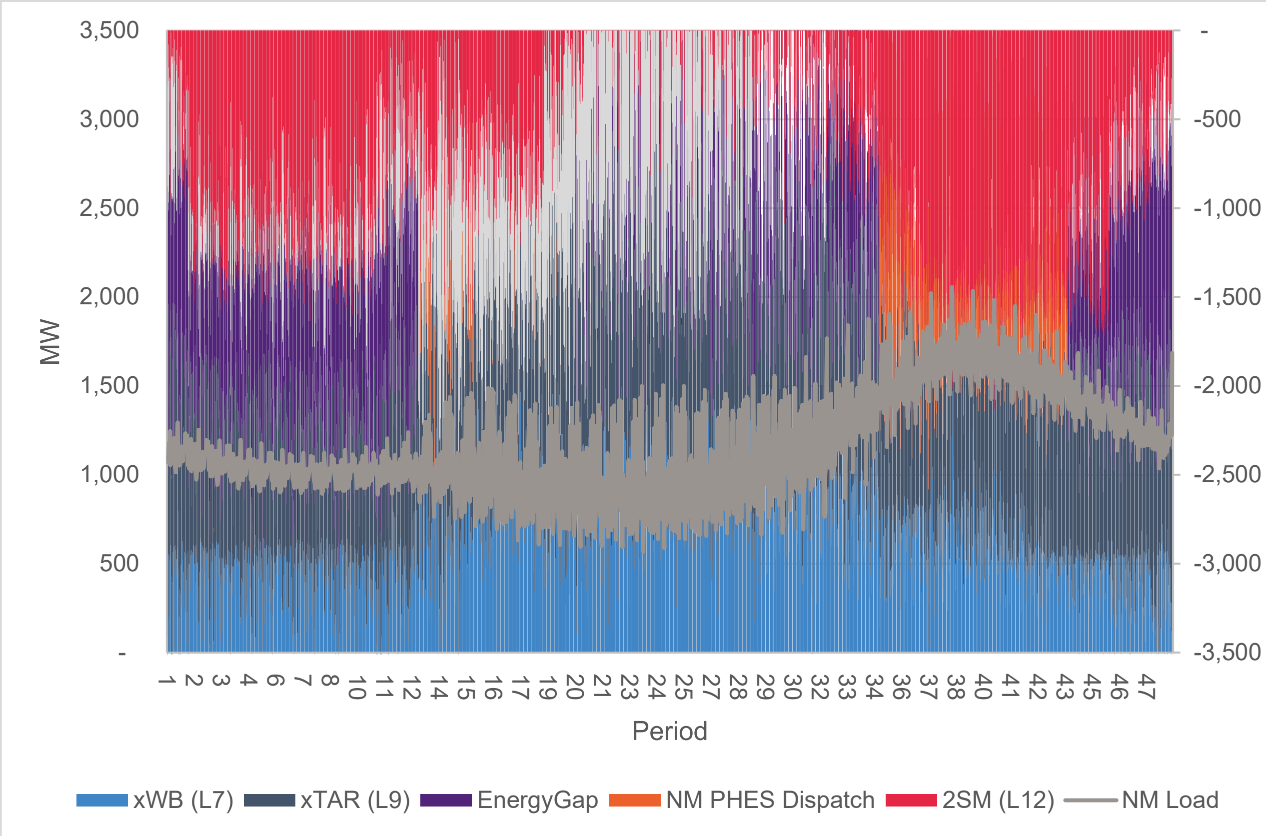
Energy-Gap Statistics and Transmission congestion details

Max: 1993 MW	Occurs in 86% of periods	>= 498 MW occurs	Congestion
Median: 570 MW	>= 498 MW = 53%	Evening Peak = 118 (20%)	xWB: Day 0.3%, EvPk 1.2%
Capacity Factor: 33%	>= 997 MW = 36%	Overnight = 1016 (94%)	xTAR: Day 0%, EvPk 0%
	>= 1495MW = 26%	Daytime = 401 (33%)	2SM: Day 0%, EvPk 0%

The Energy-Gap in NM remains large and persistent, even under normal network conditions. However, the median of all occurrences reduces to 570 MW and the capacity factor of energy required to 33%. An Energy-Gap still occurs in 86% or 2477 periods of the total 2880 periods of Summer Weekdays although higher Energy-Gaps reduce from the N-1 conditions. Overnight Energy-Gaps remain due to a combination of PHES pumping and insufficient VRE capacity. Evidence of congestion on the network into and out of NM node, reduces to negligible levels on the WB-NM line under N conditions.

Figure 10 represents 2880 points for each energy series in the NM node under augmented N+1 network conditions. Recall that modelling for N+1 assumed augmentation on the lines that experience congestion under N conditions (CWQ-GLAD, WB-NM, and SWQ-SM). Outcomes for Energy-Gap at NM, show significant variability in inflows from WB and TAR.

Figure 10: 2040C NM Summer Weekday N+1 Energy-Gap with statistics

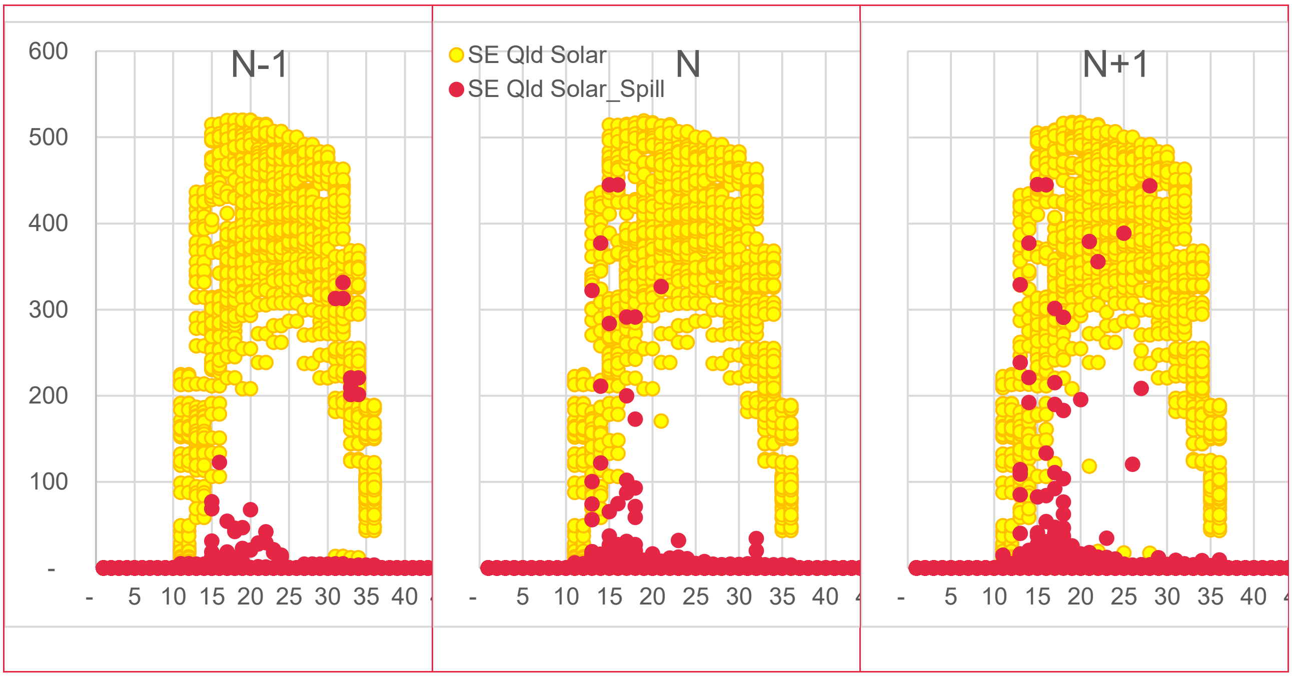


Energy-Gap Statistics and Transmission congestion details			
Max: 1993 MW	Occurs in 85% of periods	>= 498 MW occurs	Congestion
Median: 538 MW	>= 498 MW = 50%	Evening Peak = 118 (20%)	xWB: Day 0%, EvPk 0%
Capacity Factor: 29%	>= 997 MW = 30%	Overnight = 1007 (93%)	xTAR: Day 0%, EvPk 0%
	>= 1495MW = 19%	Daytime = 324 (27%)	2SM: Day 0%, EvPk 0%

Even under augmented network conditions, the Energy-Gap in NM remains large and relatively persistent. The median of all occurrences reduces to 538 MW and the capacity factor of energy required to 29%. An Energy-Gap still occurs in 85% or 2448 periods of the total 2880 periods of Summer Weekdays and higher Energy-Gaps reduce from N conditions. Overnight Energy-Gaps remain due to PHES pumping and a VRE energy deficit. There is no evidence of congestion on the network into and out of NM node under augmented network conditions.

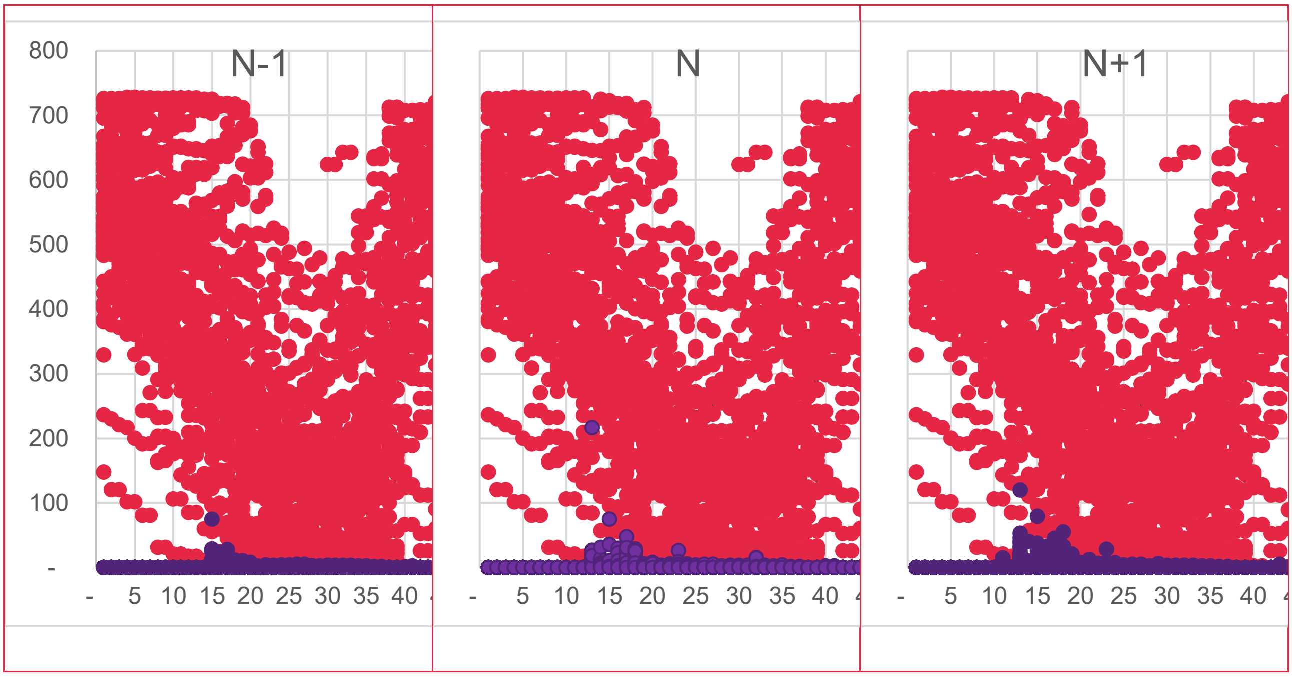
While PHES pumping plays a role in NM Energy-Gaps, the variability of VRE also contributes to the problem.

Figure 11: 2040C SEQ Solar summer dispatch and spill



As a large load centre, NM has limited locations for VRE. The VRE which flows primarily to NM comes from TAR and WB. In 2040C, 500 MW of solar is located in WB node and only 20MW in TAR. Solar resource in WB is generally dispatched even under N-1 conditions, as shown in Figure 11. Solar energy shows reliable resource during summer daylight hours from 6am through to 5pm. However, it should be noted that a total of 520MW is available for dispatch from solar whilst PHES pumping for Mt Byron and Wivenhoe introduces a combined load of 1590MW, which is far in excess of the solar resource available during these periods.

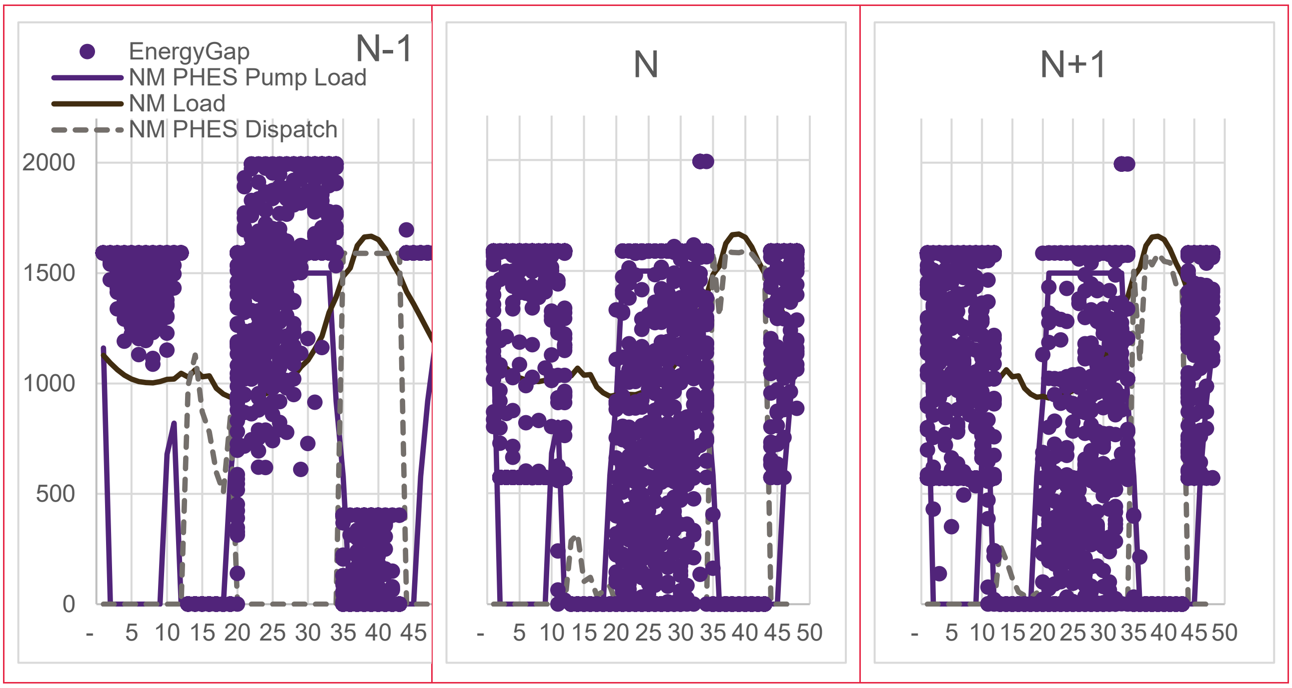
Figure 12; 2040C SEQ Wind summer dispatch and spill



2040C has no wind located in WB but 728MW in TAR. Similarly to solar, wind energy is generally dispatched even under N-1 conditions as shown in Figure 12. The wind resource displays a tendency to drop off steeply during the day from approximately 10am to 6pm. The loss of available wind and sunshine around the beginning of Evening Peak, is also a contributor to the Energy-Gap in NM.

Figure 13 provides a stylised graphic of the incidence of Energy-Gap in NM, together with PHES Pump Load, NM Load and PHES Dispatch. The incidence of very large Energy-Gaps under N-1 reflects the PHES Pump Load, the limits on the capacity of solar from WB to supply PHES Pump Load in NM, and a lack of wind energy close to NM node. Energy-Gaps reduce under N, but remain persistent during PHES Pump Load periods. Under augmented transmission the concentration of Energy-Gap during the day reduces, but otherwise there are few benefits to the transmission augmentation.

Figure 13: 2040C NM Summer Weekdays average Energy-Gap with PHES dispatch and pumping



In summary, modelling indicates that NM has a persistent Energy-Gap in 2040C due to the lack of coal generation in Gladstone and Tarong which reduces schedulable dispatch to fill the gaps that emerge from variable supply from wind energy outside of daylight hours. To address Energy-Gaps in NM, more solar and wind should be considered for TAR, and transmission augmentation and additional solar and wind for WB.

ii. SM+GC Summer Weekdays Energy Balance

Table 8 details the combined SM plus GC Energy Balance for Summer Weekdays as modelled in 2040C. After Swanbank E is closed, neither SM nor GC will have any generation to supply demand. There are however good network connections with TAR and NM and between SM and GC even under network restrictions. The Energy-Gap that emerges under restricted network conditions results from the reduced flow of energy from SWQ where the bulk of energy for SEQ originates. Under unrestricted network conditions, there are no apparent persistent Energy-Gaps.

Table 8: 2040C SM+GC Summer Weekday Energy Balance

South Moreton and Gold Coast combined Summer Weekdays Ave MW	2040C N-1		2040C N		2040C N+1	
Demand	**(2302)**		**(2355)**		**(2355)**	
Load		(2233)		(2233)		(2233)
Loss		(69)		(122)		(122)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**-**		**-**		**-**	
Coal		-		-		-
Gas		-		-		-
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		-		-		-
Wind		-		-		-
Supply - Network	**2087**		**2345**		**2345**	
Exports						
GC		(412)		(476)		(510)
DL		(19)		(44)		(63)
Imports						
NM		872		668		739
SWQ		1094		1619		1581
DL		140		102		88
ANEM Energy-Gap	**(236)**		**(7)**		**(7)**	
Balance		(215)		(10)		10
SWQ Spillage	**(727)**		**(194)**		**(215)**	
Solar		(691)		(192)		(210)
Wind		(36)		(3)		(5)

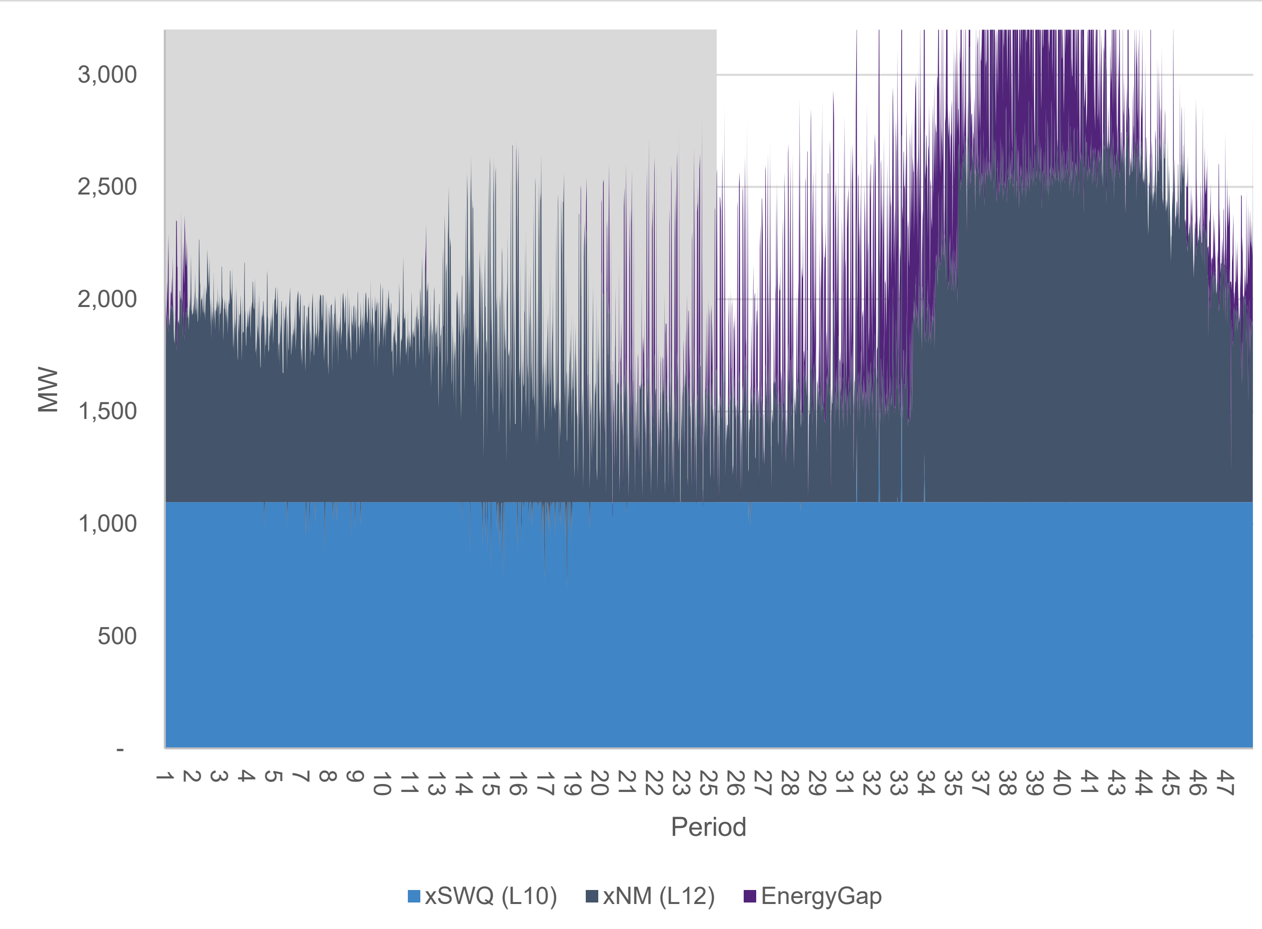
The Energy-Gap during Summer Evening Peak as detailed in Table 9 increases during Evening Peak under restricted network conditions due to the limits of transmission from SWQ where the majority of the energy for SM+GC is located. The Energy-Gap evident under N-1 is no longer a problem under N, and there is no significant benefit for SM+GC from the network augmentation considered under N+1.

Table 9: 2040C SM+GC Summer Weekdays Evening Peak Energy Balance

South Moreton and Gold Coast combined Summer Weekdays Evening Peak Ave MW	2040C N-1	2040C N	2040C N+1
Demand	**(3038)**	**(3102)**	**(3102)**
Load	(2943)	(2943)	(2943)
Loss	(95)	(159)	(159)
PHES Pump	(-)	(-)	(-)
Supply - Generation	**-**	**-**	**-**
Coal	-	-	-
Gas	-	-	-
Hydro	-	-	-
PHES Dispatch	-	-	-
Solar	-	-	-
Wind	-	-	-
Supply - Network	**2465**	**3078**	**3073**
Exports			
GC	(676)	(640)	(653)
DL	(55)	(36)	(40)
Imports			
NM	1323	1233	1244
SWQ	1099	1768	1764
DL	98	113	105
ANEM Energy-Gap	**(618)**	**(21)**	**(25)**
Balance	(573)	(24)	29
SWQ Spillage	**(2)**	**(-)**	**(-)**
Solar	(2)	(-)	(-)
Wind	(-)	(-)	(-)

Figure 14 represents 2880 points for each energy series in the SM and GC nodes under restrictive N-1 network conditions. Note the flows from SWQ at capacity throughout the year and each day. Also note the periods of Energy-Gaps correspond primarily with Evening Peak. Note the variability of flows from NM as the supplier of balancing energy.

Figure 14: 2040C SM+GC Summer Weekday N-1 Energy-Gap with statistics



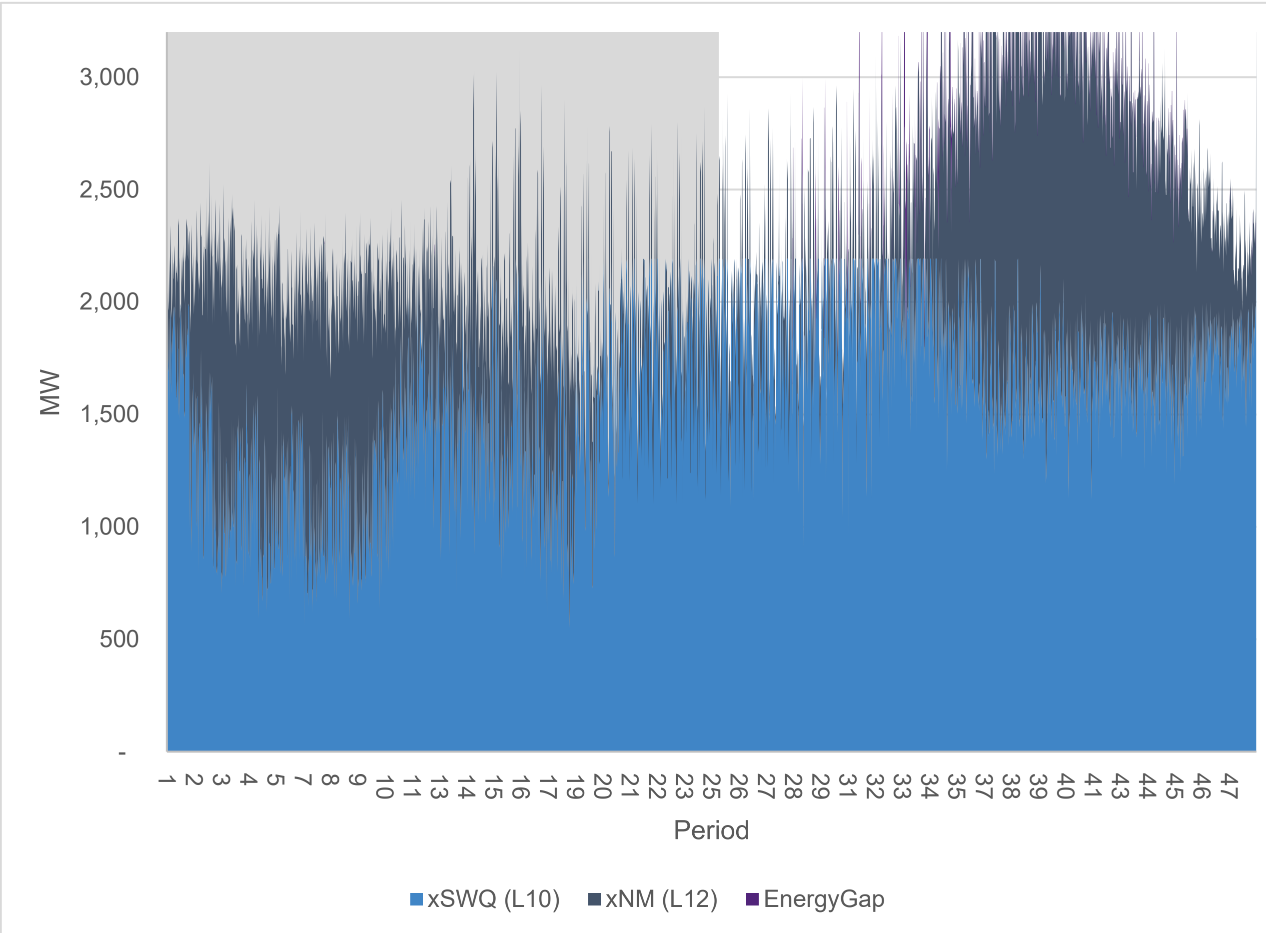
Energy-Gap Statistics and Transmission congestion details

Max: 885 MW Median: 0 MW Capacity Factor: 27%	Occurs in 42% of periods >= 221 MW = 34% >= 443 MW = 27% >= 664MW = 19%	>= 221 MW occurs Evening Peak = 519 (86%) Overnight = 101 (9%) Daytime = 341 (33%)	Congestion: xSWQ: Day 63%, EvPk 93% xNM: Day 0%, EvPk 0% xDL: Day 56%, EvPk 64%

The Energy-Gap in SM is large at 885MW. The median of all occurrences is 0 MW and the capacity factor of energy required is 27%. An Energy-Gap occurs in 42% of the total 2880 periods of Summer Weekdays. Energy-Gaps of 221MW or greater (25% of the maximum) are present in 34% of periods. Energy-Gaps of 443 MW or greater (50% of the maximum) are present in 27% of periods. Energy-Gaps of 664MW or greater (75% of the maximum) are present in 19% of Summer Weekday periods. 519 (86% of Evening Peak periods), 101 (9% of Overnight periods) and 341 (33% of periods between 7:00 to 16:30) periods reflect Energy-Gaps of greater than 221MW.Thus the primary driver of the Energy-Gap in SM node is higher demand during the Evening Peak. The transmission line from SWQ shows significant evidence of congestion into SM especially at Evening Peak when congestion occurs 93% of the time. There is also significant evidence of congestion on the DirectLink connection because of its limited capacity of 180MW and predominant reverse flows from NSW to meet demand. There is no congestion even under restricted network conditions on the transmission link between NM and SM nor the transmission link between SM and GC.

Figure 15 represents 2880 points for each energy series in the SM node under normal N network conditions. Flows from SWQ provide the predominant supply of energy into SM, but flows from NM are important to balance supply and demand at the node.

Figure 15: 2040C SM+GC Summer Weekday N Energy-Gap with statistics

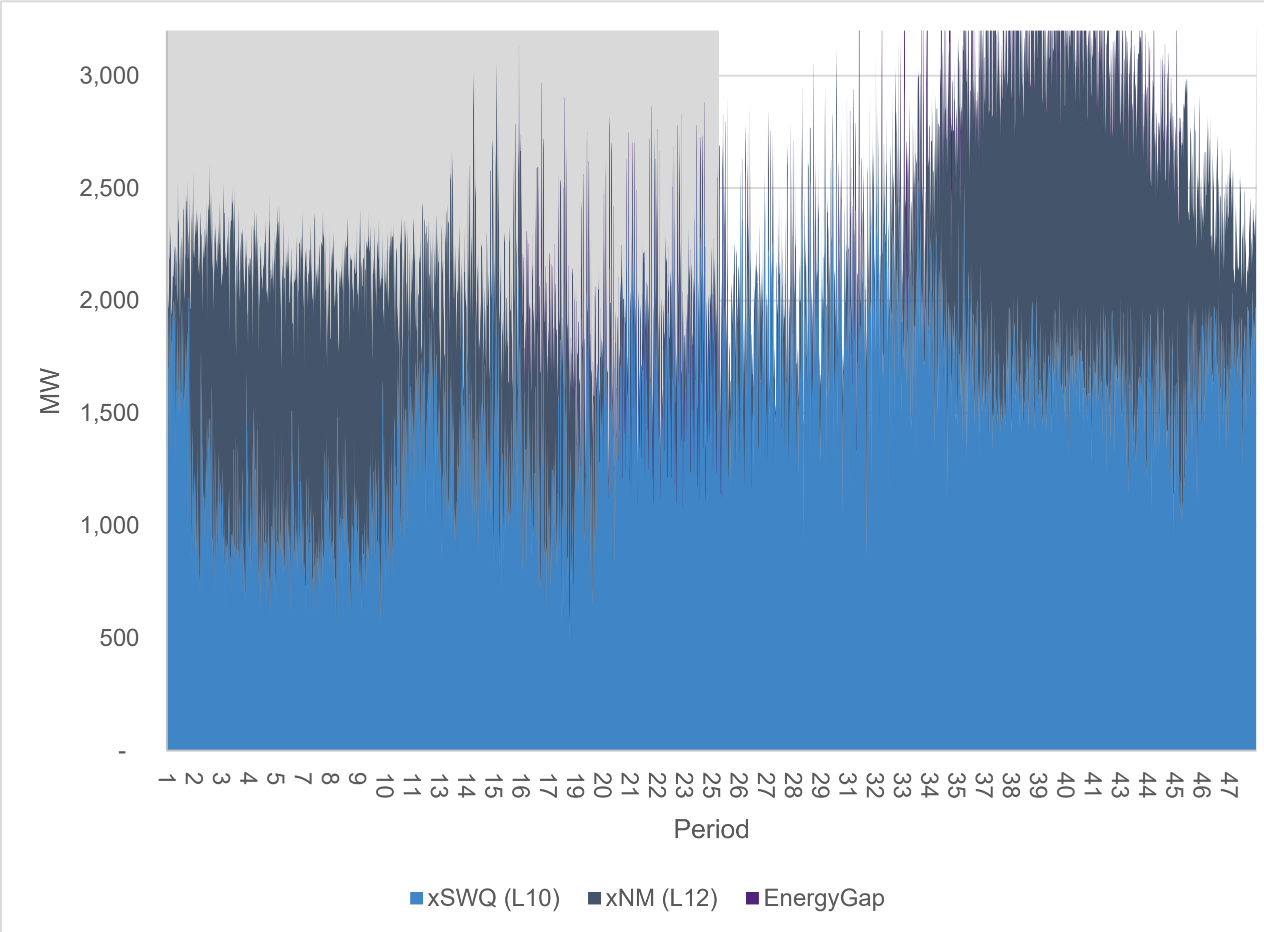


Energy-Gap Statistics and Transmission congestion details			
Max: 885 MW Median: 0 MW Capacity Factor: 1%	Occurs in 6% of periods >= 221 MW = 1% >= 443 MW = 0.8% >= 664MW = 0.4%	>= 221 MW occurs Evening Peak = 20 (3%) Overnight = - Daytime = 12 (1%)	Congestion: xSWQ: Day 4%, EvPk 53% xNM: Day 0%, EvPk 0% xDL: Day 20%, EvPk 47%

The Energy-Gap in SM remains large but very infrequent. The median of all occurrences remains 0 MW but the capacity factor of energy required falls to 1%. An Energy-Gap occurs in only 6% of the total 2880 periods of Summer Weekdays. There are no overnight Energy-Gaps. Evidence of congestion on the network from SWQ reduces to 4% during the day but is elevated during the Evening Peak to 53%. There is less congestion on the DL line than under restricted network conditions but during the Evening Peak it is still high at 47%.

Figure 16 represents 2880 points for each energy series in the combined SM and GC nodes under augmented N+1 network conditions. Modelling for N+1 assumes augmentation on the lines that experience congestion under N conditions (CWQ-GLAD, WB-NM, and SWQ-SM). Outcomes for Energy-Gap at SM, show significant variability in inflows from SWQ and NM with NM providing the primary source of energy to meet elevated demand during Evening Peak.

Figure 16: 2040C SM+GC Summer Weekday N+1 Energy-Gap with statistics

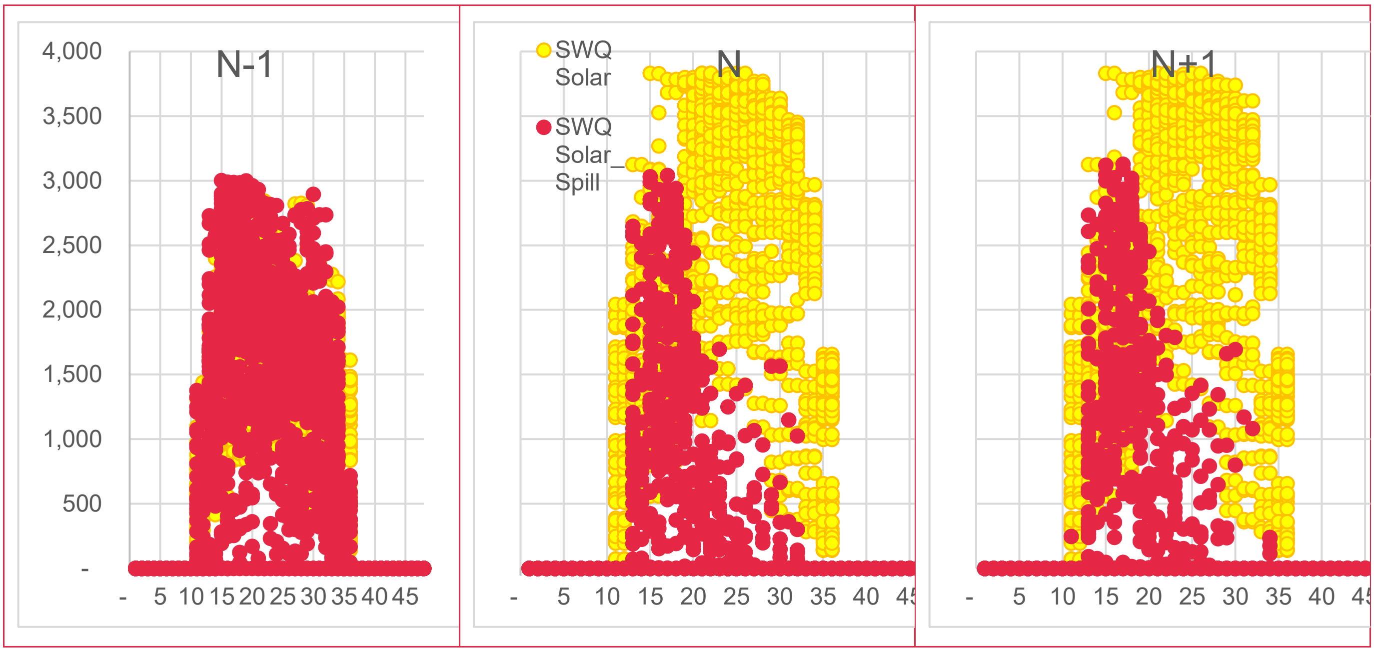


Energy-Gap Statistics and Transmission congestion details			
Max: 885 MW Median: 0 MW Capacity Factor: 1%	Occurs in 17% of periods >= 221 MW = 1.4% >= 443 MW = 1% >= 664MW = 0.6%	>= 221 MW occurs Evening Peak = 39 (6%) Overnight = - Daytime = 2 (1%)	Congestion: xSWQ: Day 0%, EvPk 0% xNM: Day 0%, EvPk 0% xDL: Day 18%, EvPk 37%

Even under augmented network conditions, the Energy-Gap in SM remains, albeit sporadic. The median of all occurrences is 0MW and the capacity factor of energy required is 1%. An Energy-Gap still occurs in 17% of the total 2880 periods of Summer Weekdays. Energy-Gaps are only evident during the Evening Peak on 6% of Evening Peak periods. There is no evidence of congestion on the network into and out of SM node under augmented network conditions, although DL still experiences congestion during 37% of Evening Peak periods.

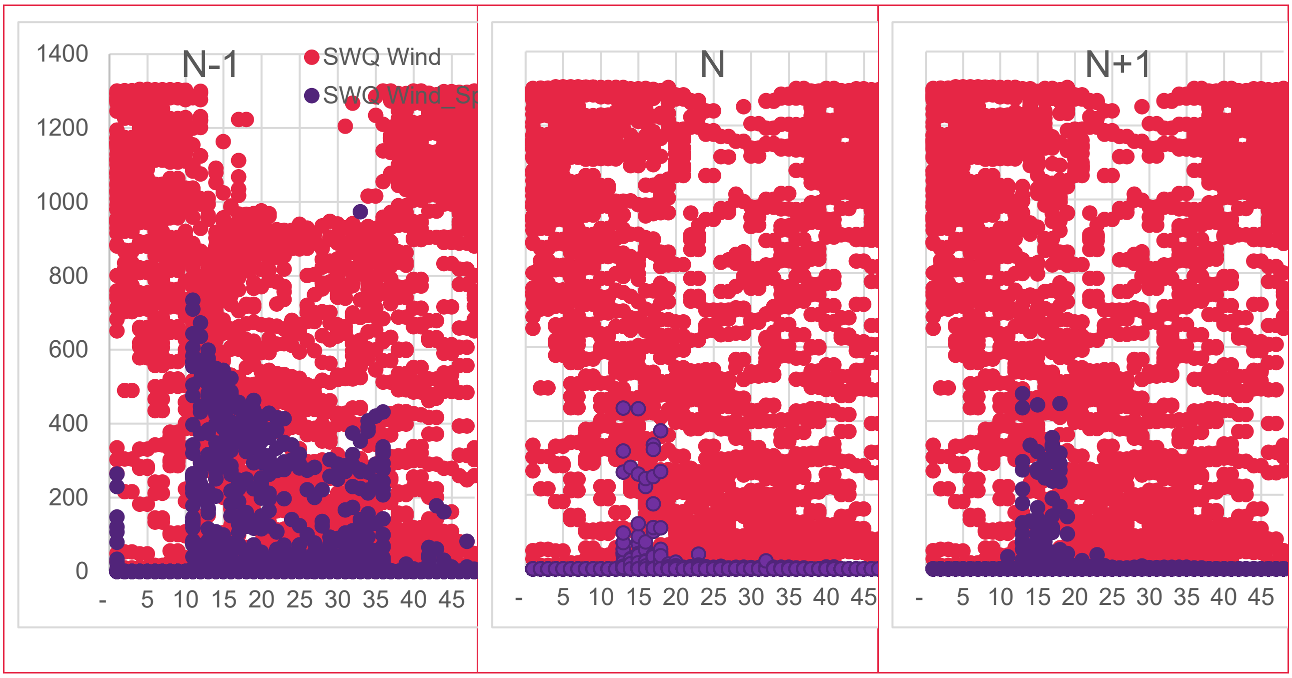
The variability of VRE plays a role in the occurrence of the Energy-Gap.

Figure 17: 2040C SWQ Solar summer dispatch and spill



2040C has 3831MW of solar power allocated to SWQ as shown in Figure 17. Summer thermal limits under N-1 result in 40% of solar spillage in SWQ which in turn increases reliance on flows of energy from NM to SM. Moving to an unrestricted network, ensures that considerably more solar is dispatched with only 14% spilled. This in turn reduces reliance on flows from NM during sunlight, but energy flows between NM and SM remain volatile between midnight and sunrise. There is little apparent benefit to solar dispatch from augmented network capacity between SWQ and SM.

Figure 18; 2040C SWQ Wind summer dispatch and spill



2040C has 1305MW of wind power located in SWQ as shown in Figure 18. Under restricted network conditions, wind spillage occurs mainly during the day when 3831MW of solar is also available for dispatch. Consequently when network restrictions are lifted, wind spillage decreases from 3.5% to negligible levels. It should be noted though that wind resource is irregular during the day and particularly during Evening Peak, similar to the resource available in TAR. This makes meeting demand in SM at the beginning of Evening Peak challenging.

In summary, modelling indicates that SM has an Energy-Gap of up to 885MW in 2040C, primarily during Evening Peak. The Energy-Gaps are persistent under restricted network conditions but sporadic under unrestricted conditions. Energy-Gaps during Evening Peak result from declining solar power in SWQ as sunset approaches, variable wind power in SWQ at the start of the Evening Peak, and PHES pumping in NM node before PHES dispatch is scheduled to start from 17:30. Under the notional augmented network conditions, the Energy-Gap worsens slightly from N conditions as greater flows of energy to SM and GC increase transmission losses. To address Energy-Gaps in SM, augmentation of transmission between SWQ and SM should be considered to facilitate the flow of energy from the high generation capacity node of SWQ to SM and the deferral of closure of Swanbank E in order to balance supply during Evening Peak.

iii. GLAD+WB Summer Weekdays Energy Balance

Table 10 details the combined GLAD plus WB Energy Balance for Summer Weekdays as modelled in 2040C. The scenario includes the total closure of 1680MW of GPS and the addition of 515MW of solar in GLAD node plus a further 500MW of solar in WB node. These additions would not cover the loss of 1680MW coal plant even during the day, and will provide no supply after sundown. WB has never had much generation capacity, and has therefore been reliant on energy flows from GLAD and a transmission corridor of energy from GLAD to NM. As a result of the withdrawal of thermal generation in GLAD, Energy-Gaps emerge within the combined nodes. The Energy-Gaps are large under restricted network conditions but reduce under unrestricted network conditions.

Table 10: 2040C GLAD+WB Summer Weekday Energy Balance

Gladstone and Wide Bay combined Summer Weekdays Ave MW	2040C N-1		2040C N		2040C N+1	
Demand	**(1408)**		**(1474)**		**(1539)**	
Load		(1331)		(1331)		(1331)
Loss		(77)		(143)		(208)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**481**		**455**		**443**	
Coal		-		-		-
Gas		140		116		106
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		341		339		337
Wind		-		-		-
Supply - Network	**480**		**929**		**1050**	
Exports						
WB		(872)		(609)		(771)
NM		(499)		(531)		(662)
Imports						
CWQ		980		1460		1713
ANEM Energy-Gap	**(467)**		**(98)**		**(44)**	
Balance		(447)		(90)		(46)
GLAD+WB Spillage	**(1)**		**(2)**		**(5)**	
Solar		(1)		(2)		(5)
Wind		(-)		(-)		(-)

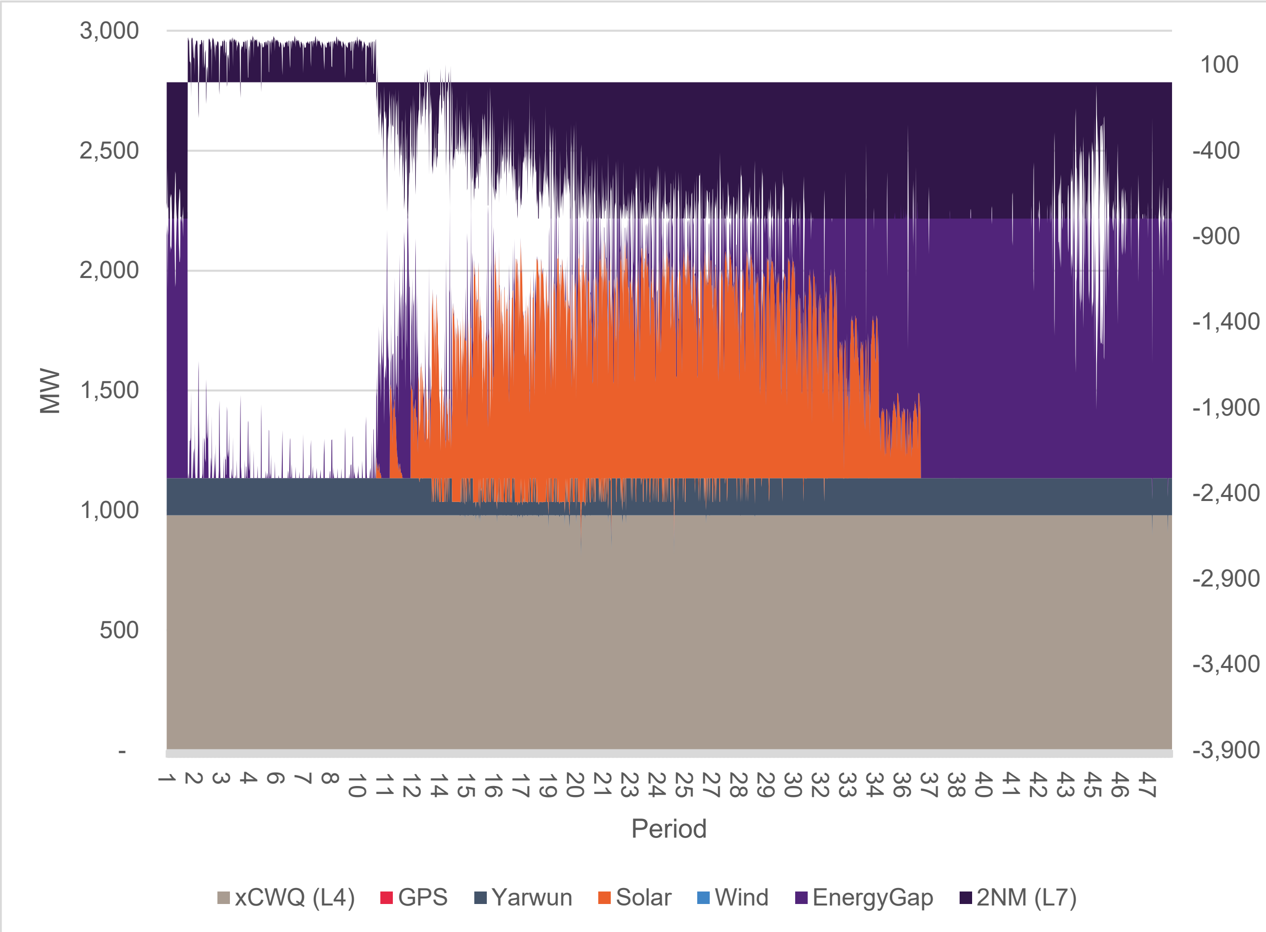
The Energy-Gap during Summer Evening Peak as detailed in Table 11 increases during Evening Peak under restricted network conditions due to a lack of available energy after sundown and the limits of the transmission from CWQ where the majority of the energy for GLAD+WB is located. The Energy-Gap evident under N-1 reduces under N, and still further under the network augmentation considered under N+1.

Table 11: 2040C GLAD+WB Summer Weekdays Evening Peak Energy Balance

Gladstone and Wide Bay combined Summer Weekdays Evening Peak Ave MW	2040C N-1		2040C N		2040C N+1	
Demand	**(1521)**		**(1580)**		**(1651)**	
Load		(1407)		(1407)		(1407)
Loss		(114)		(173)		(244)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**303**		**303**		**298**	
Coal		-		-		-
Gas		154		152		147
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		149		151		151
Wind		-		-		-
Supply - Network	**192**		**884**		**1175**	
Exports						
WB		(841)		(789)		(888)
NM		(788)		(624)		(674)
Imports						
CWQ		980		1508		1849
ANEM Energy-Gap	**(1063)**		**(394)**		**(174)**	
Balance		(1026)		(393)		(178)
GLAD+WB Spillage	**(2)**		**(-)**		**(-)**	
Solar		(2)		(-)		(-)
Wind		(-)		(-)		(-)

Figure 19 represents 2880 points for each energy series in the GLAD+WB nodes under restrictive N-1 network conditions. Note the flows from CWQ at capacity throughout the summer and each day. Also note the periods of Energy-Gaps correspond primarily with Evening Peak. Note the flows to NM at capacity from 10:00am till after midnight, and then reverse flows from NM as energy is required in GLAD for the hours before sunup. Note the significant contribution of solar during the day.

Figure 19: 2040C GLAD+WB Summer Weekday N-1 Energy-Gap with statistics



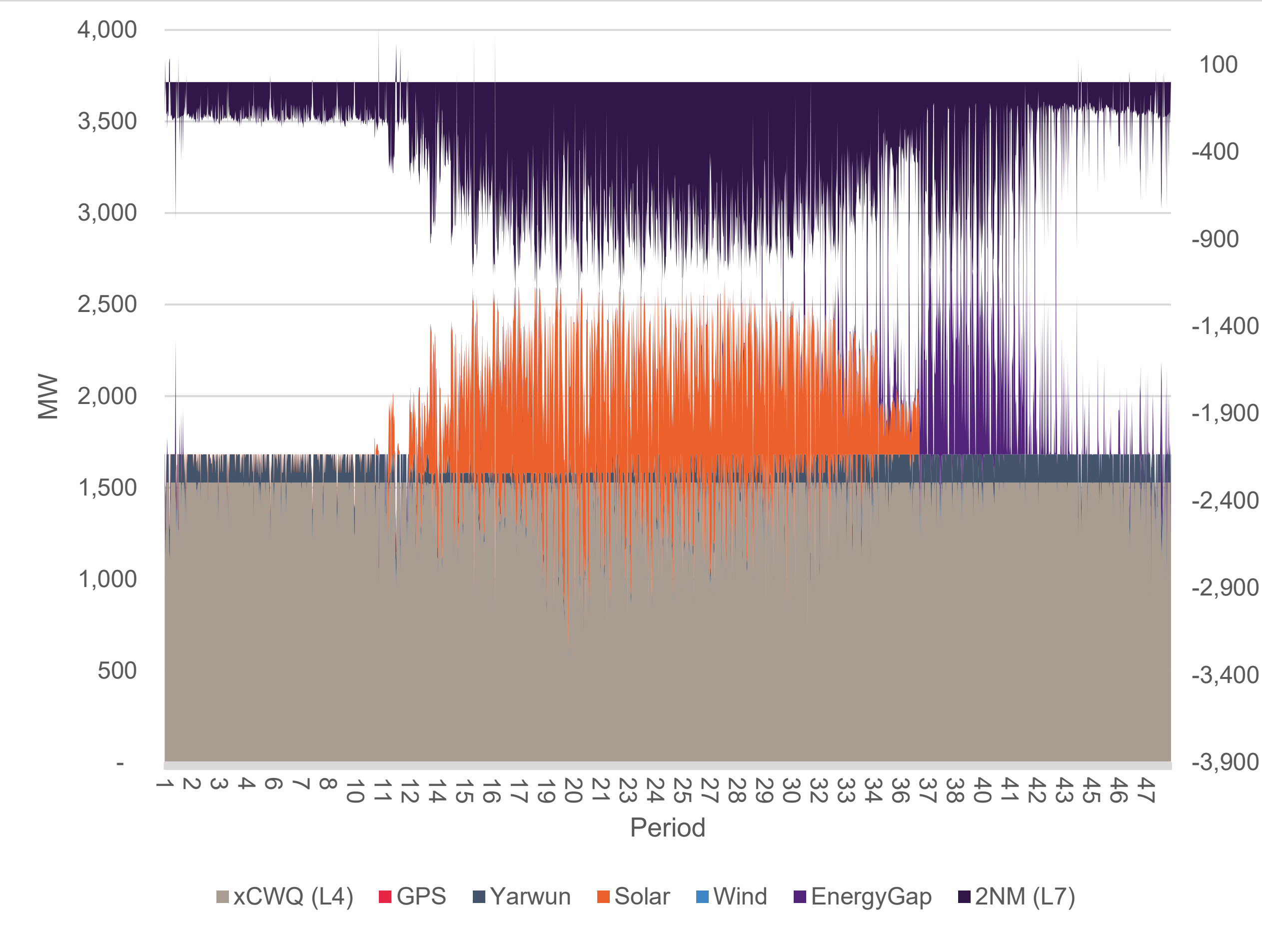
Energy-Gap Statistics and Transmission congestion details			
Max: 1398 + 500 MW Median: 273 + 3 MW Capacity Factor: 25%, 23%	Occurs in 86%, 77% of periods >= 350 MW=46% (24%) >= 699 MW=15% (23%) >= 1049 MW=4% (22%)	>= 350 MW occurs Evening Peak = 597 (99%) Overnight = 443 (41%) Daytime = 213 (18%)	Congestion: xCWQ: Day 63%, EvPk 93% 2WB: Day 0%, EvPk 0% 2NM: Day 36%, EvPk 86%

The Energy-Gaps in GLAD and WB are large at 1398MW and 500MW although the median of all occurrences is 273MW in GLAD and 3MW in WB. The capacity factor of energy required is 25% in GLAD and 23% in WB. An Energy-Gap occurs in 86% in GLAD and 77% in WB of the total 2880 periods of Summer Weekdays. Energy-Gaps of 350MW or greater (25% of the maximum) are present in 46% of periods (24% in WB). Energy-Gaps of 699 MW or greater (50% of the maximum) are present in 15% of periods (23% in WB). Energy-Gaps of 1049MW or greater (75% of the maximum) are present in 4% of Summer Weekday periods (22% in WB). 597 (99% of Evening Peak periods), 443 (41% of overnight periods) and 213 (18% of periods between 7:00 and 16:30 incidences of Energy-Gaps of greater than 350MW in GLAD occur during Summer Weekdays. Thus the primary driver of the Energy-Gap in GLAD and WB nodes is demand during the Evening Peak which cannot be served by solar. The transmission line from CWQ shows significant evidence of congestion into GLAD especially at Evening Peak when congestion occurs 93% of the time. There is also significant evidence of congestion on the transmission line to NM from

WB of 86% over Evening Peak. There is no congestion even under restricted network conditions on the transmission link between GLAD and WB.

Figure 20 represents 2880 points for each energy series in the GLAD and WB nodes under normal N network conditions. Flows from CWQ provide the majority of energy into GLAD, but there are still occurrences of Energy-Gap during the Evening Peak after sundown although not as persistent as under N-1 conditions.

Figure 20: 2040C GLAD+WB Summer Weekday N Energy-Gap with statistics



Energy-Gap Statistics and Transmission congestion details

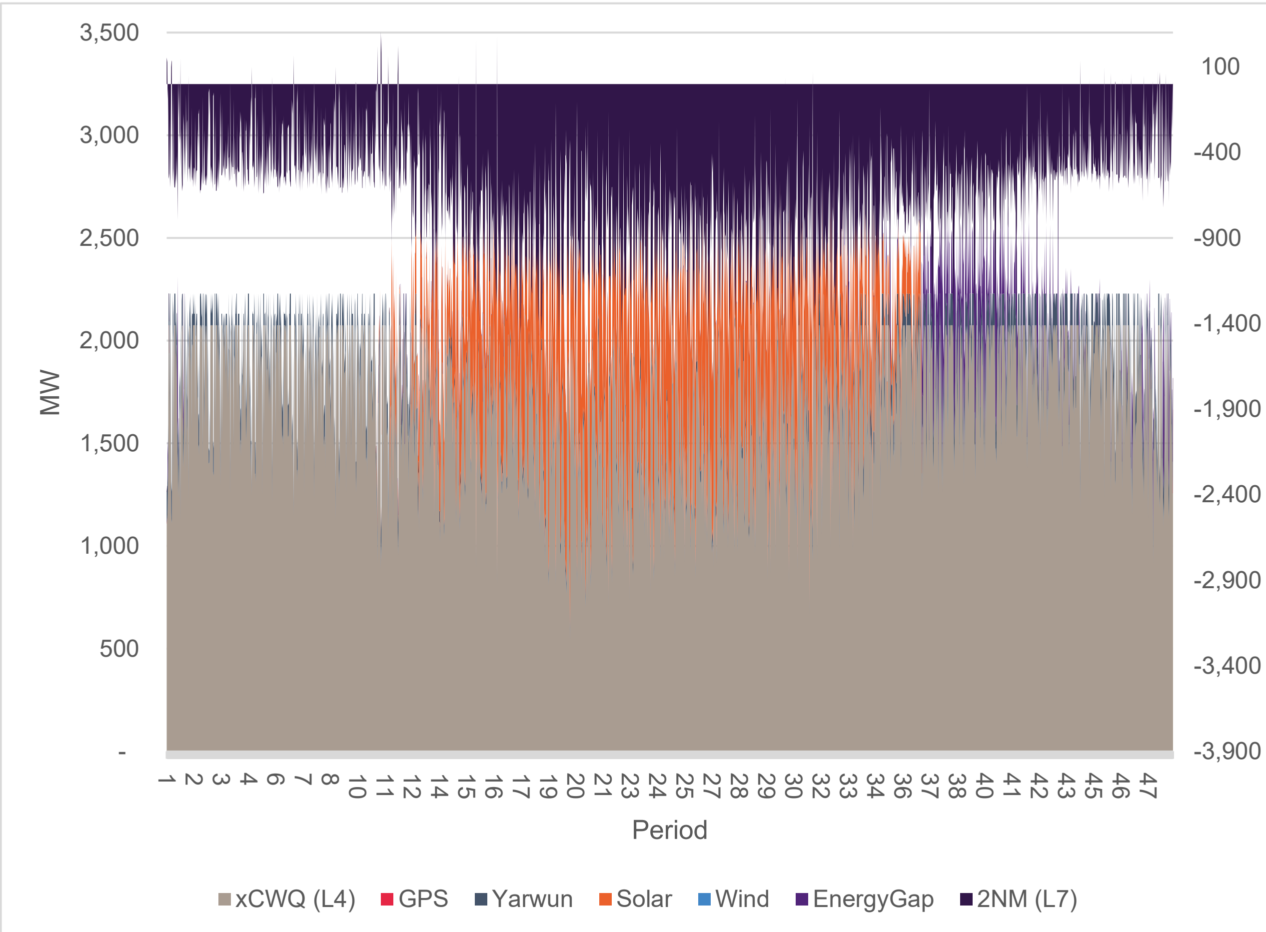
Max: 1664 + 857 MW Median: 2 + 1 MW Capacity Factor: 4%, 3%	Occurs in 60%, 56% of periods >= 416 MW=8% (6%) >= 832 MW=0.9% (4%) >= 1248 MW=.3% (-%)	>= 416 MW occurs Evening Peak = 217 (36%) Overnight = 8 (0.7%) Daytime = 4 (0.3%)	Congestion: xCWQ: Day 10%, EvPk 59% 2WB: Day 0%, EvPk 0% 2NM: Day 0.3%, EvPk 1%

The Energy-Gap in GLAD+WB remains under N transmission conditions. The median of all occurrences are 2 and 1 MW but the capacity factor of energy required falls to 4% and 3%. An Energy-Gap occurs in 60% of the total 2880 periods of Summer Weekdays. Energy-Gaps of greater than 416MW occur in 8% of periods but this decreases to 0.9% for Energy-Gaps of greater than 832MW and 0.3% for Energy-Gaps of greater than 1248MW. Where the Energy-Gap is greater than 416MW in GLAD, 217 incidents (36% of Evening

Peak periods) occur. Incidences of Energy-Gap overnight and during the day are very infrequent. Evidence of congestion on the network from CWQ reduces to 10% during the day but is elevated during the Evening Peak to 59%. There is little congestion on the line to NM from WB.

Figure 21 represents 2880 points for each energy series in the combined GLAD and WB nodes under augmented N+1 network conditions. Modelling for N+1 assumes augmentation on the lines that experience congestion under N conditions (CWQ-GLAD, WB-NM, and SWQ-SM). Outcomes for Energy-Gap at GLAD, show significant variability in inflows from CWQ and significant variability on the lines from WB to NM, but WB-NM flows are elevated during the day to service PHES pump load.

Figure 21: 2040C GLAD+WB Summer Weekday N+1 Energy-Gap with statistics

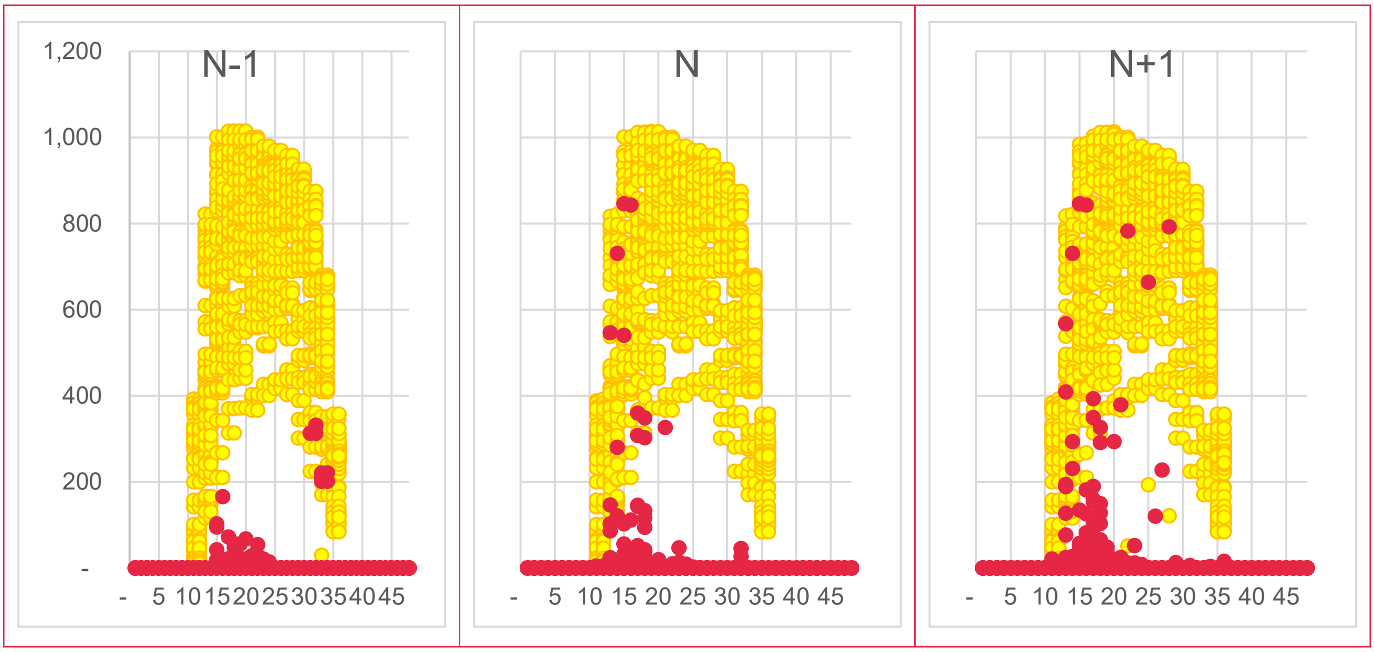


Energy-Gap Statistics and Transmission congestion details			
Max: 591 + 859 MW Median: 0 + 0 MW Capacity Factor: 3%, 3%	Occurs in 53%, 53% of periods >= 148 MW=5% (5%) >= 296 MW=3% (3%) >= 443 MW=1% (-%)	>= 148 MW occurs Evening Peak = 126 (21%) Overnight = 7 (0.6%) Daytime = 1 (-%)	Congestion: xCWQ: Day 1%, EvPk 17% 2WB: Day 0%, EvPk 0% 2NM: Day 0%, EvPk 0%

Even under augmented network conditions, the Energy-Gap in GLAD+WB remains, albeit sporadic. The median of all occurrences is 0MW and the capacity factor of energy required is 3%. An Energy-Gap still occurs in 53% of the total 2880 periods of Summer Weekdays, although Energy-Gaps of greater than

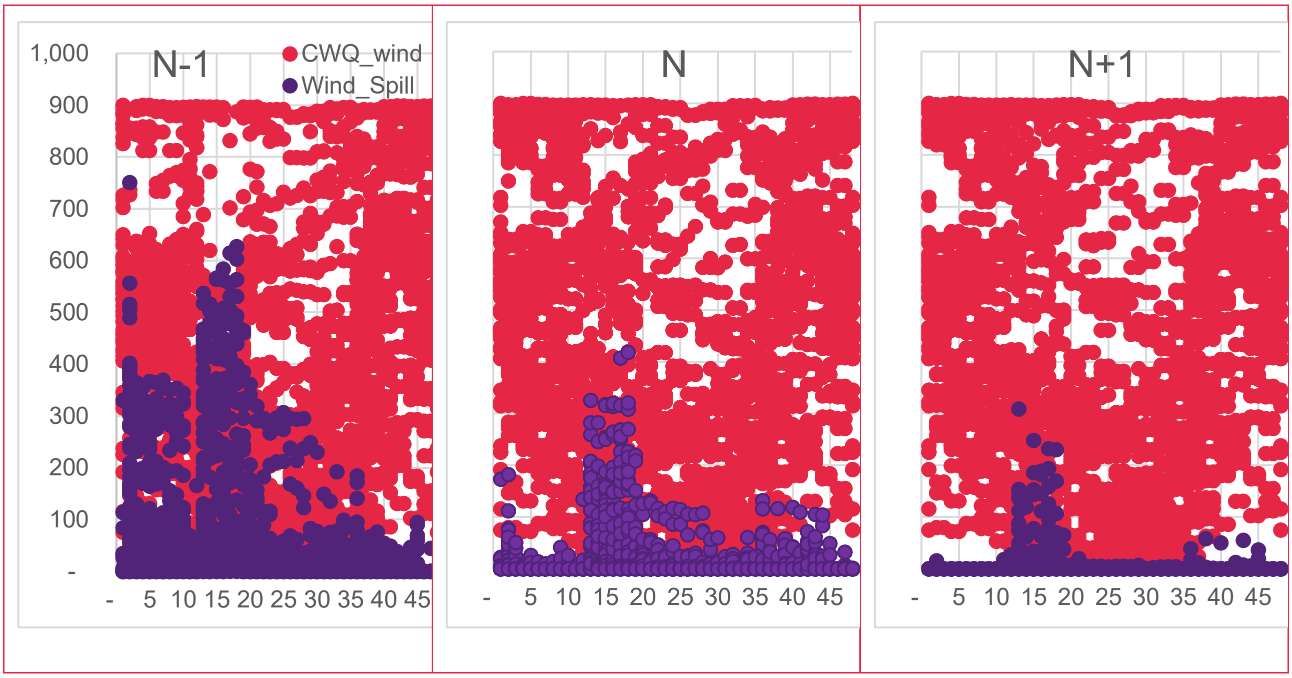
148MW are only evident in 5% of periods. Energy-Gaps are evident during the Evening Peak on 21% of Evening Peak periods. There is a little evidence of congestion on the transmission line from CWQ, increasing to 17% during Evening Peak but other than that there is no evidence of congestion.

Figure 22: 2040C GLAD+WB Solar summer dispatch and spill



2040C has 515MW solar power allocated to GLAD and 500MW to WB. With little generation within the nodes, there is only incidental evidence of spillage even under N-1 summer thermal limits. There is no apparent benefit to solar dispatch from augmented network capacity between CWQ and GLAD and between WB and NM.

Figure 23; 2040C CWQ Wind summer dispatch and spill



2040C has no wind located in GLAD and WB nodes. It is however pertinent to consider the wind resource in CWQ where 2040C includes 900MW of wind power which is likely to flow, at least in part, to GLAD. Under restricted network conditions, 10% wind spillage occurs, mainly during the day when solar is also available for dispatch. Consequently when network restrictions are lifted, wind spillage decreases to 3%, although still predominantly during sunlight hours. It should be noted though that wind resource is irregular during the day and in to Evening Peak, although not as unreliable as the resource in SWQ. This makes meeting demand in GLAD and WB at the beginning of Evening Peak challenging.

In summary, modelling indicates that GLAD and WB have persistent Energy-Gaps of up to 1664MW in GLAD and 857MW in WB in 2040C, primarily during Evening Peak and as a result of the complete closure of GPS. The Energy-Gaps are persistent under restricted network conditions but sporadic under unrestricted conditions. Energy-Gaps during Evening Peak result from declining solar power in GLAD and WB as sunset approaches, and no wind power within the GLAD and WB nodes, at the start of the Evening Peak. There is a significant reduction to the maximum Energy-Gap in GLAD under the notional augmented network conditions, but additional wind power within the nodes would also reduce the Energy-Gaps. To address Energy-Gaps in GLAD +WB, augmentation of transmission between CWQ and GLAD should be initiated to facilitate the flow of energy from CWQ to GLAD, and increase wind generation in both GLAD and WB to balance supply during Evening Peak.

iv. SWQ Summer Weekdays Energy Balance

Table 12 details the SWQ Energy Balance for Summer Weekdays Evening Peak as modelled in 2040C. SWQ node hosts 3753MW of thermal generation, 1305MW of wind and 3831 of solar generation, providing the bulk of capacity to supply SM+GC demand. There are fair network connections with SM but also connections to TAR and NSW through QNI.

Table 12: 2040C SWQ Summer Weekdays Evening Peak Energy Balance

South West Queensland Summer Weekdays Evening Peak Ave MW	2040C N-1		2040C N		2040C N+1	
Demand	**(1014)**		**(1011)**		**(1011)**	
Load		(1010)		(1010)		(1010)
Loss		(4)		(1)		(1)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**3167**		**4682**		**4657**	
Coal		1227		1577		1583
Gas		875		1846		1816
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		447		622		620
Wind		618		637		637
Supply - Network	**(2026)**		**(3528)**		**(3494)**	
Exports						
SM		(1099)		(1768)		(1764)
QNI		(1129)		(1629)		(1658)
TAR				(176)		(122)
Imports						
TAR		202		45		50
ANEM Energy-Gap	**(6)**		**(38)**		**(30)**	
Balance		127		143		152
SWQ Spillage	**(194)**		**(-)**		**(1)**	
Solar		(174)		(-)		(1)
Wind		(20)		(-)		(-)

Energy-Gap statistics for Summer Weekdays, detailed in Table 13, show that under restrictive N-1 conditions, maximum Energy-Gap is 26MW and the median Energy-Gap is 2MW but fairly persistent, occurring during 1746 periods (61%) of Summer Weekdays. An Energy-Gap of greater than 7MW emerges in 64% of Overnight periods and 44% of Evening Peak, but only 7% of Daytime periods.

Without restrictions, under N conditions, sporadic but large Energy-Gaps emerge in SWQ, from a maximum of 1770MW on 1 occasion to 5 periods of greater than 1327MW, 7 periods of greater than 885MW and 11 periods of greater than 442MW. All in there are 19 periods of greater than 45MW of Energy-Gap, 18 of which occur during Evening Peak when all coal and gas generation in SWQ are at full capacity. In 8 of the periods, wind generation of less than 10% is evidence. In all the periods of Energy-Gaps above 44MW, large flows are supplied to QNI, SM and TAR. These SWQ Energy-Gaps result from large system-wide energy deficits.

The maximum Energy-Gap under augmented network conditions reduces to 1093MW. Energy-Gaps of greater than 820MW occur in 2 periods and gaps of greater than 100MW occur in 28 periods, all during Evening Peak.

Table 13: 2040C SWQ Energy-Gap Statistics and Transmission congestion details

Energy-Gap incidence during Summer Weekday periods	N-1	N	N+1
Max capacity (MW)	26	1770	1093
Median capacity (MW)	2	11	11
Capacity factor (%)	18%	1%	2%
Count of EGs: All	61%	91%	90%
• **EG >= 25%Max**	7MW (38%)	442MW (0.4%)	273MW (0.5%)
• **EG >= 50%Max**	13MW (3%)	885MW (0.2%)	546MW (0.2%)
• **EG >= 75%Max**	20MW (1%)	1327MW (0.2%)	820MW (0.1%)
Where EG >= occurs in % of	7MW	442MW	273MW
• **Evening Peak**	44%	2%	2%
• **Overnight**	64%	-	-
• **Daytime**	7%	-	-
TRANSMISSION CONGESTION			
SWQ-SM			
• **Daytime**	63%	4%	-
• **Evening Peak**	93%	5%	-
QNI	-	-	-
TAR	-	-	-

While SWQ has 8889MW of generation capacity, there is evidence of sporadic large Energy-Gaps as a result of low wind resource and/or system-wide energy deficits in 2040C.

v. CWQ Summer Weekdays Energy Balance

Table 14 details the CWQ Energy Balance for Summer Weekdays Evening Peak as modelled in 2040C. CWQ node has 3140MW of thermal, 900 MW of wind and 1494MW of solar generation, and thus the bulk of generation capacity to supply Gladstone and Central Queensland demand. There are fair network connections with TAR but connections to GLAD under restricted N-1 conditions are inadequate to supply GLAD without GPS in operation.

Table 14: 2040C CWQ Summer Weekdays Evening Peak Energy Balance

Central West Queensland Summer Weekdays Evening Peak Ave MW	2040C N-1		2040C N		2040C N+1	
Demand	**(573)**		**(591)**		**(632)**	
Load		(569)		(569)		(569)
Loss		(3)		(22)		(63)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**2632**		**2790**		**2924**	
Coal		1922		2074		2204
Gas		-		-		-
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		248		251		252
Wind		462		465		468
Supply - Network	**(1822)**		**(1960)**		**(2063)**	
Exports						
GLAD		(980)		(1508)		(1849)
TAR		(722)		(710)		(861)
NQ		(212)		(96)		(59)
Imports						
NQ		92		354		706
ANEM Energy-Gap	**(6)**		**(11)**		**(28)**	
Balance		**237**		**239**		**229**
CWQ Spillage	**(11)**		**(5)**		**(-)**	
Solar		(5)		(2)		(-)
Wind		(6)		(4)		(-)

Energy-Gap statistics for Summer Weekdays are included in Table 15 and show that under restrictive N-1 conditions, maximum Energy-Gap is 22MW and the median Energy-Gap is 4MW but fairly persistent, occurring during 1877 periods (65%) of Summer Weekdays. An Energy-Gap of greater than 6MW becomes evident in 52% of Evening Peak, 44% of Daytime periods and 25% of Overnight periods.

Without restrictions, under N conditions, sporadic but fairly large Energy-Gaps become evident in CWQ, from a maximum of 330MW on 1 occasion to 3 periods of greater than 165MW and 14 periods of greater than 82MW. These 14 periods of elevated Energy-Gap generally correspond with the periods of high Energy-Gaps in SWQ, resulting from a combination of Evening Peak and low wind generation.

Table 15: 2040C CWQ Energy-Gap Statistics and Transmission congestion details

Energy-Gap incidence during Summer Weekday periods	N-1	N	N+1
Max capacity (MW)	22	330	1201
Median capacity (MW)	4	6	7
Capacity factor (%)	22%	2%	1%
Count of EGs: All	65%	84%	93%
• **EG >= 25%Max**	6MW (40%)	82MW (0.5%)	300MW (0.3%)
• **EG >= 50%Max**	11MW (17%)	165MW (0.1%)	601MW (0.2%)
• **EG >= 75%Max**	17MW (2%)	247MW (0.01%)	901 MW (0.1%)
Where EG >= occurs in % of	6MW	82MW	300MW
• **Evening Peak**	52%	2%	1%
• **Overnight**	25%	-	-
• **Daytime**	44%	-	-
TRANSMISSION CONGESTION			
CWQ-GLAD			
• **Daytime**	63%	10%	1%
• **Evening Peak**	93%	10%	16%
CWQ-TAR			
• **Daytime**	-	-	-
• **Evening Peak**	-	-	-
NQ-CWQ			
• **Daytime**	-	-	-
• **Evening Peak**	-	-	-

vi. NQ Summer Weekdays Energy Balance

Table 16 details the NQ Energy Balance for Summer Weekdays Evening Peak as modelled in 2040C. NQ node has no thermal generation but includes 1020MW Urannah PHES for storing surplus energy to dispatch at peak demand, 1000MW of wind and 357MW of solar generation. There are reasonable network connections with ROSS and CWQ.

Table 16: 2040C NQ Summer Weekdays Evening Peak Energy Balance

North Queensland **Summer Weekdays Evening Peak Ave MW**	**2040C** **N-1**	**2040C** **N**	**2040C** **N+1**
Demand	**(660)**	**(655)**	**(656)**
Load	(445)	(445)	(445)
Loss	(11)	(6)	(7)
PHES Pump	(204)	(204)	(204)
Supply - Generation	**783**	**972**	**1196**
Coal	-	-	-
Gas	-	-	-
Hydro	-	-	-
PHES Dispatch	254	440	659
Solar	56	57	57
Wind	473	476	480
Supply - Network	**(179)**	**(394)**	**(544)**
Exports			
CWQ	(92)	(354)	(706)
ROSS	(308)	(174)	(-)
Imports			
ROSS	9	39	103
CWQ	212	96	59
ANEM Energy-Gap	**(93)**	**(134)**	**(190)**
Balance	**(56)**	**(77)**	**(4)**
NQ Spillage	**(10)**	**(5)**	**(5)**
Solar	(2)	(1)	(1)
Wind	(8)	(4)	(4)

The Energy-Gap in NQ as detailed in Table 17 is directly related to PHES pump load. With only solar and wind generation located in NQ in 2040C, pump load after dark when wind resources are reduced, will result in an Energy Deficit of approximately 1GW. There are more incidences of Energy-Gap under N conditions than under N-1 due to increased flows of energy. Under N there are 239 periods when the Energy Deficit is 1000MW or greater, and 922 periods when an Energy-Gap of greater than 50MW is evident. 28% of overnight periods have an Energy-Gap of greater than 287MW, 12% of daytime periods and 11% of Evening Peak periods. With 922 periods with an Energy-Gap of greater than 50MW, the Energy-Gap is relatively persistent. The results generally reinforce the need to investigate nodal positioning and sizing of PHES relative to available VRE and transmission linkages. The emergence of Energy-Gaps in PHES nodes is evidence of the complexities of modelling PHES pumping and dispatch, but also the complexities of developing a strategy for PHES management that does not increase demand to the extent that it results in energy deficits.

Table 17: 2040C NQ Energy-Gap Statistics and Transmission congestion details

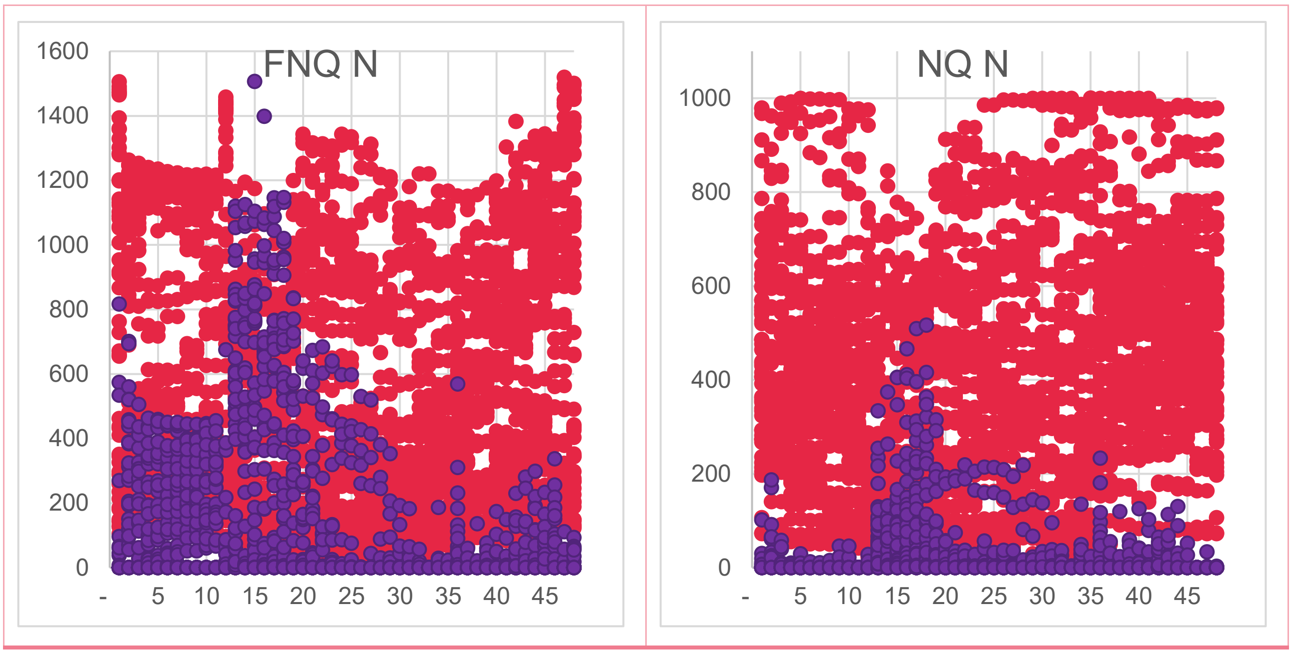
Energy-Gap incidence during Summer Weekday periods	N-1	N	N+1
Max capacity (MW)	1117	1149	1195
Median capacity (MW)	4	6	10
Capacity factor (%)	9%	15%	25%
Count of EGs: All	86%	90%	93%
• **EG >=25%Max**	279MW (11%)	287MW (18%)	299MW (30%)
• **EG >= 50%Max**	558MW (7%)	575MW (13%)	598MW (25%)
• **EG >= 75%Max**	838MW (5%)	862MW (10%)	896MW (21%)
Where EG >= occurs in % of	279MW	287MW	299MW
• **Evening Peak**	9%	11%	14%
• **Overnight**	18%	28%	55%
• **Daytime**	6%	12%	14%
TRANSMISSION CONGESTION			
NQ-CWQ	-	-	-

vii. Conclusions on energy generation adequacy in 2040C

2040C reduces coal generation in Queensland by 4223MW from current levels. It replaces this generation with 5011MW of wind and 6925MW solar. Nearly 50% of Queensland wind generation in 2040C is located in NQ (1000MW) and FNQ (1675MW). Average summer dispatch from wind in FNQ during Evening Peak is 519MW and 476MW from NQ. Thus wind generated in the northern nodes does not appear to contribute significantly to meeting Evening Peak in central and southern nodes. Figure 24 shows detail of northern wind dispatch.

2040C also locates 55% of solar generation in SWQ. This competes with coal, gas and wind for dispatch and transmission capacity during the day, and makes little contribution to Evening Peak. Location of the wind and solar resource matter, but also the ability to connect with the transmission network to replace coal generators. Careful consideration of existing capacity and location should be given to the award of planning permissions. The concept of Renewable Energy Zones (REZ) is sound, but the REZ's should be accompanied by clear plans for transmission infrastructure and potential for PHES storage capacity and location available for each REZ. These details will become more pressing as more coal plant closes which is why the Energy-Gap for 2040C is greater than in any of the Pipeline scenarios.

Figure 24: 2040C FNQ and NQ wind generation and spillage under N



Analysis of Queensland's Energy Balance over the full 2880 periods of Summer Weekdays under N network conditions, shows the extent of the challenges associated with periods of low wind availability. Firstly, co-incident low wind generation is compared to Energy-Gap in Figure 25 for 2040C under N conditions. Note that the 7 periods of highest Energy-Gap are within periods when wind is low but also during the early Evening Peak from 4:30pm onwards.

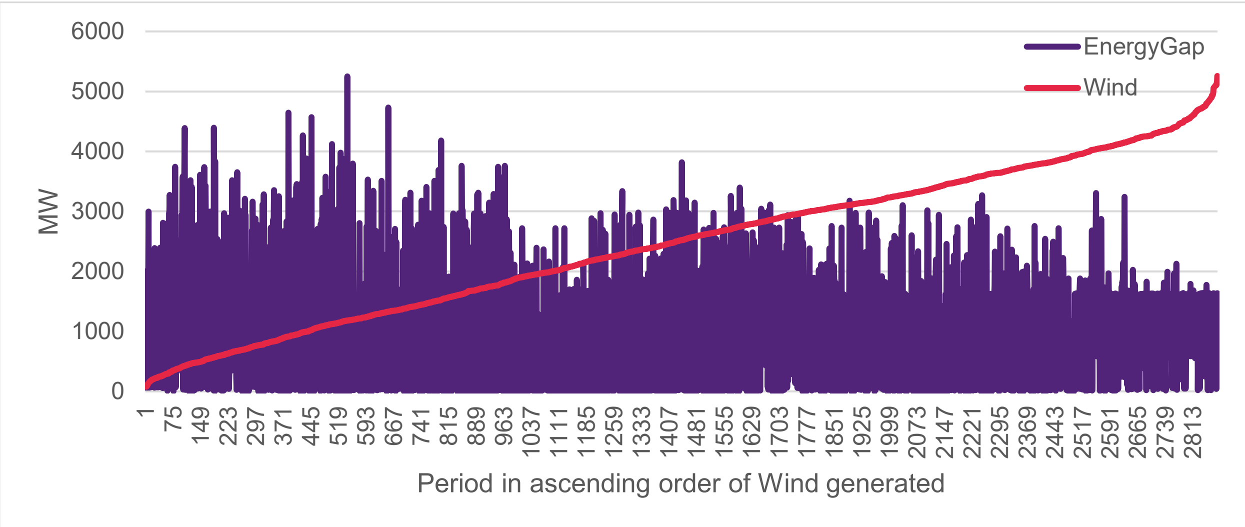


Figure 25: 2040C N Queensland comparison of low wind to Energy-Gap periods

Table 18 provides further detail on the periods with the 7 largest co-incident Energy-Gaps during Summer Weekdays. All of these periods fall between 4:30 and 5:00pm when load is elevated coupled with some PHES pumping before switching to PHES dispatch. Coal and gas generation is generally at capacity, solar generation is evident but tailing off. Similar conditions will be present in NSW because flows to QNI continue at average levels.

Table 18: 2040C N 7 periods of highest co-incident Energy-Gap during Summer Weekdays

Energy-Gap	Max	5250MW	4733MW	4545MW	4571MW	4395MW	4389MW	4181MW
Period		46-33	45-33	46-34	47-33	53-33	363-33	45-34
Load	**-11192**	-10414	-9488	-10536	-10248	-8422	-8723	-9891
PHES Pu	**-2760**	-2760	-2760	-1840	-2760	-2760	-2760	-1840
Coal	**3836**	**3836**	**3836**	**3836**	**3836**	**3836**	**3836**	**3836**
Gas	**2555**	2484	2487	2400	2096	2487	2487	2487
Wind	**5652**	1180	1328	912	1024	568	424	1530
Solar	**7242**	2983	2632	2983	4341	1836	2363	2630
QNI	**-2628**	-1598	-1280	-1523	-1831	-1216	-1216	-1408
DL	**+180**	+180	+180	+180	+180	+180	+180	+179
Spill_W	**-2067**	-	-	-	-	-	-	-
Spill_S	**-4580**	-	-	-	-	-	-	-

Incidences of lower than 400MW of wind generation were selected and analysed. In total those 97 incidences occurred on 15 days, with periods of low wind extending from 7 hours in a day to half an hour in a day. The events occurred between period 18 (9am) and 35 (5:30pm). Periods 26-29 recorded the most frequent occurrence of less than 400MW of wind generation (10) and also the four lowest wind generation (79-96MW) for Summer Weekdays.

ISP 2040C is linked with PHES of 3.4GW of storage which is more than the PHES of 2.8GW included in the modelling here. However, there is no indication given of where that PHES might be located nor what impact it might have on supply-demand balance with its substantial increase to demand, as has been found to be a driver of Energy-Gaps in the modelling here.

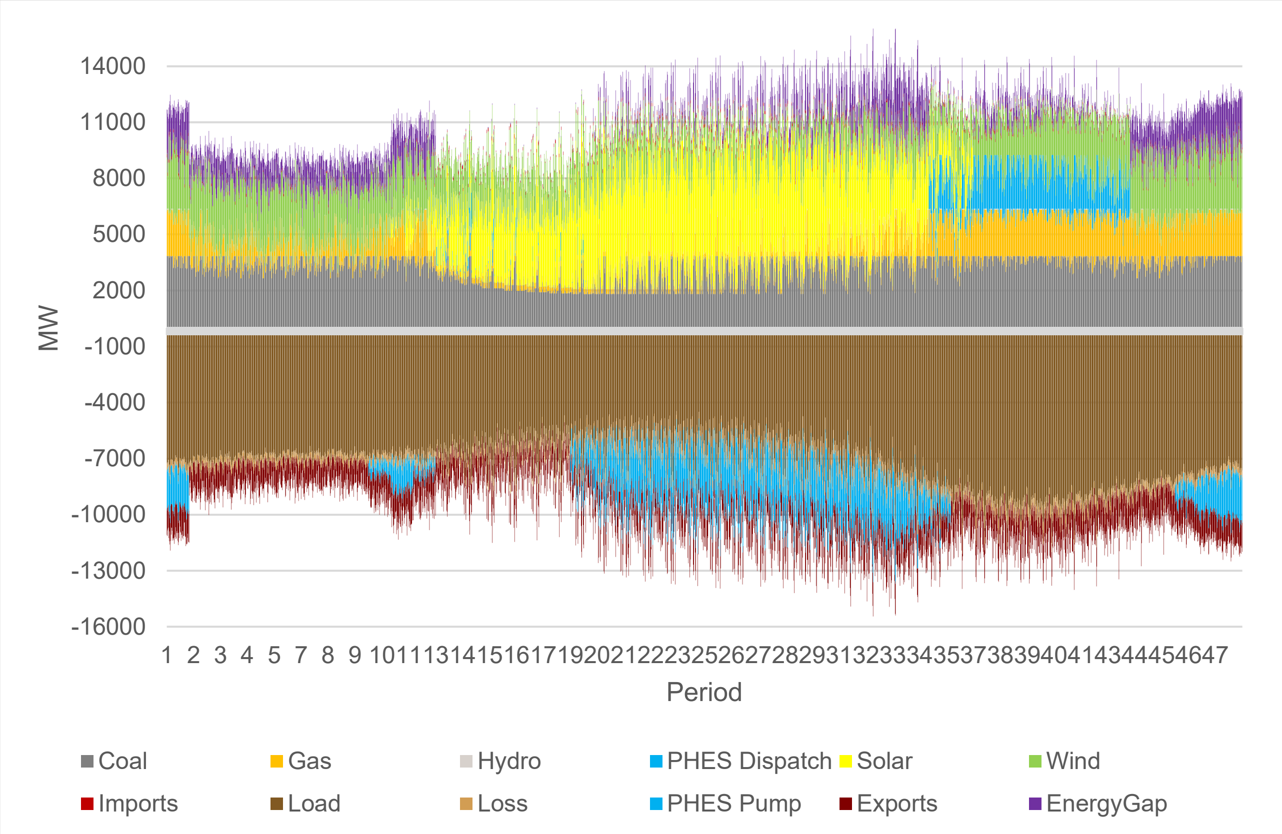


Figure 26: Queensland Summer Weekdays Energy Flows 2040C N

Figure 26 details the energy flows for all Queensland nodes as modelled for 2040C under N transmission conditions for all Summer Weekdays. Cumulative native load, losses, PHES pump load and exports through QNI are represented as negative flows while generation, PHES dispatch and imports are depicted as positive flows. Energy flowing from Energy-Gap is shown as a positive flow. Coal generation forms the foundation of the energy flows with the other sources contributing as possible under transmission capacities. The effect of PHES pump load on total demand is evident and the ongoing flow of energy to NSW despite Energy-Gaps within Queensland. Forthcoming analysis of NSW Energy-Gaps will contribute to further understanding of the nature of Energy-Gaps throughout the NEM and their impact on Queensland supply-demand balance.

b. Pipeline Scenario B (sB)

sB has different VRE assumptions to 2040C and also moderately different native demand estimates. At a state level, Queensland is estimated to consume 58,866 GWh of energy in sB (3% less than in 2040C) 10,233GWh over Summer Weekdays, 5,209GWh over summer weekends/public holidays – 26% of the annual total. In winter, energy consumed over weekdays totals 10,154GWh and 4,123 GWh over weekends/public holidays – 24% of the annual total. Maximum demand occurs in summer, 10,519MW during a weekday and 10,574 during a weekend/public holiday. Minimum demand occurs in winter, 3955MW during a weekday. The difference in native demand between the 2 scenarios may affect the results, but is relatively small compared to the larger differences in assumptions regarding coal generation closures and VRE generation additions.

Figure 27 details the ANEM model's Queensland nodal structure including transmission lines, transmission thermal limits (summer) and electricity generation capacity at each node in MW for sB. The number of lines comprising transmission between each node are evident from the pink lines.

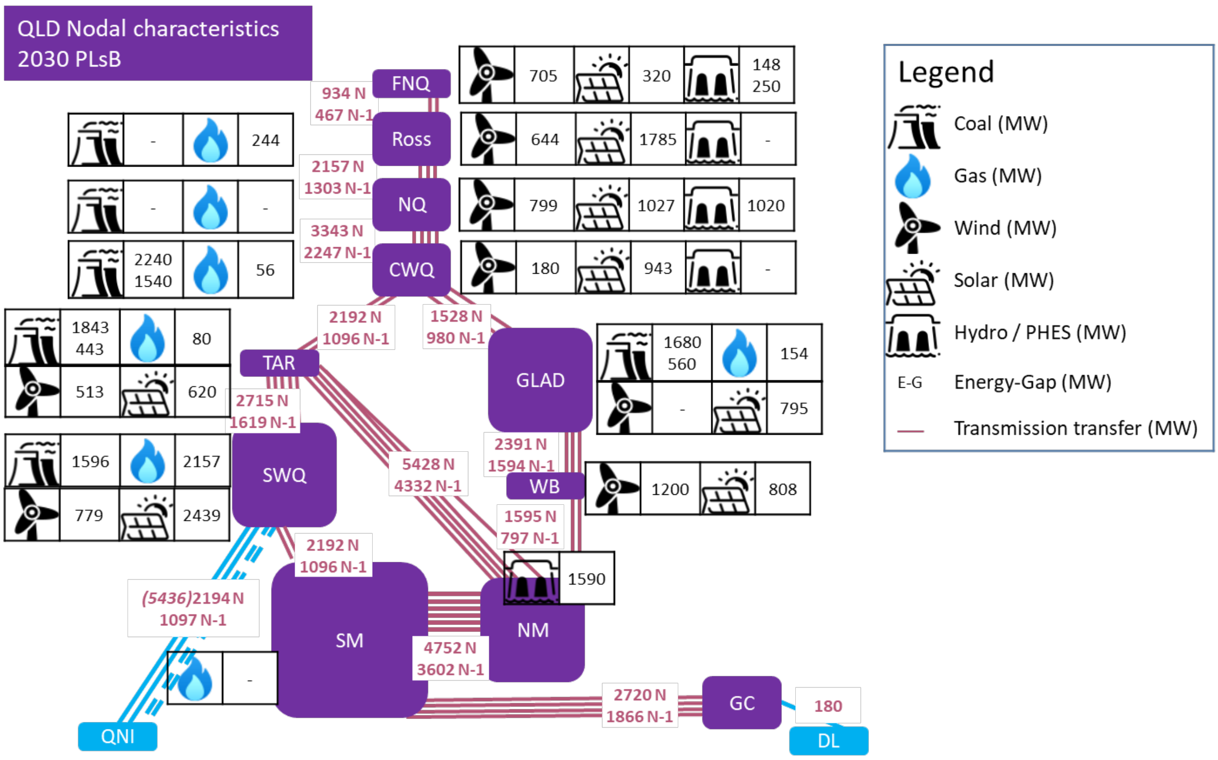


Figure 27: Queensland nodal structure with transmission lines and generation capacity for sB

Demand increases with losses from increased network flows and with pumping action for PHES. Table 19 provides detail on the average Summer Weekday Energy Balance, where supply in the form of generation and network flows is compared with demand to indicate the state supply-demand balance. PHES pumping adds approximately 15% to demand, Energy-Gap decreases from N to N-1 scenarios providing evidence of the benefit of adequate transmission capacity. Assumed augmentation to transmission lines between CWQ-GLAD, WB-NM, and SWQ-SM shows only small benefits at the state level, although it does provide greater energy security.

Table 19: sB Queensland Summer Weekdays Energy Balance

Queensland Summer Weekdays Ave MW	sB N-1		sB N		sB N+1	
Demand	**(8511)**		**(8671)**		**(8714)**	
Load		(7106)		(7106)		(7106)
Loss		(315)		(475)		(518)
PHES Pump		(1090)		(1090)		(1090)
Supply - Generation	**8471**		**9258**		**9309**	
Coal		3833		3934		3943
Gas		603		816		818
Hydro		25		23		24
PHES Dispatch		453		358		357
Solar		2033		2411		2411
Wind		1524		1717		1756
Supply - Network	**(634)**		**(905)**		**(912)**	
Exports						
QNI		(753)		(989)		(987)
DL		(17)		(33)		(37)
Imports						
QNI		-		-		-
DL		136		117		75
ANEM Energy-Gap	**(1159)**		**(767)**		**(750)**	
Balance		(674)		(318)		(317)
Spillage	**(1114)**		**(543)**		**(504)**	
Solar		(838)		(460)		(460)
Wind		(276)		(83)		(44)

Spillage of wind and solar is reduced as transmission capacity increases, although there is still some evidence of spillage even under the augmented transmission conditions, indicating the challenges associated with integrating variable resources into nodal supply.

Note that supply and demand is not balanced, indicating a deficit of available generation. There is also a difference between the Energy Balance that is estimated from average demand and supply of energy and the Energy-Gap derived in modelling. This is attributable to auxiliary use of energy by power stations, losses allocated to energy receiving nodes in NSW and the use of averages not weighted average for the analysis.

Table 20 details the averaged Energy Balance for Queensland during Summer Evening Peak.

Table 20: sB Queensland Summer Weekday Evening Peak Energy Balance

Queensland **Summer Weekdays Evening Peak Ave MW**	**sB** **N-1**	**sB** **N**	**sB** **N+1**
Demand	**(9439)**	**(9588)**	**(9624)**
Load	(8531)	(8531)	(8531)
Loss	(344)	(493)	(529)
PHES Pump	(564)	(564)	(564)
Supply - Generation	**10106**	**10851**	**10896**
Coal	4553	4781	4810
Gas	860	1436	1438
Hydro	44	46	49
PHES Dispatch	1793	1505	1509
Solar	914	948	948
Wind	1943	2136	2143
Supply - Network	**(690)**	**(1090)**	**(1104)**
Exports			
QNI	(833)	(1182)	(1190)
DL	(7)	(32)	(34)
Imports			
QNI	-	-	-
DL	149	123	120
ANEM Energy-Gap	**(589)**	**(385)**	**(378)**
Balance	(23)	173	168
Spillage	**(244)**	**(17)**	**(9)**
Solar	(36)	(2)	(1)
Wind	(208)	(15)	(8)

The discussion below will examine both the Energy Balance and the Energy-Gap over Summer Weekdays for the three large load centres as derived by the ANEM model and a shorter discussion on SWQ, CWQ and NQ nodes.

i. NM Summer Weekdays Energy Balance

Table 21 details the NM Energy Balance for Summer Weekdays as modelled in sB. There is a persistently large Energy-Gap of 831 MW under restricted network conditions, reducing to 453MW under unrestricted network conditions. Under network augmentation there is a reduction in Energy-Gap, but a relatively modest improvement to 427MW. Spillage decreases as transmission capacity increases from N-1 to N, and there is a modest benefit of 53MW of dispatch of renewable energy under network augmentation in SEQ.

The Energy-Gap for NM in sB is 215MW lower under N-1, 206MW lower under N and 151MW lower under N+1 from the NM Energy-Gap in 2040C. The primary reason for this improvement is the added flows of energy from TAR (where 2 units at TPS continue to operate in sB as opposed to complete closure in 2040C) and WB+GLAD (where 1603MW solar and 1200MW wind energy is located in sB as opposed to 1015MW of solar energy only in 2040C). The added flows of energy into NM in sB facilitate similarly increased flows to SM in sB over 2040C to meet demand in SM too. Thus, the continued availability of coal power from TPS and increased supply of VRE from GLAD+WB play a significant role in reducing the Energy-Gap in NM.

Table 21: sB NM Summer Weekday Energy Balance

North Moreton Summer Weekdays Ave MW	sB N-1	sB N	sB N+1
Demand	**(1786)**	**(1854)**	**(1874)**
Load	(1121)	(1121)	(1121)
Loss	(85)	(153)	(173)
PHES Pump	(580)	(580)	(580)
Supply - Generation	**305**	**210**	**210**
Coal	-	-	-
Gas	-	-	-
Hydro	-	-	-
PHES Dispatch	305	210	210
Solar	-	-	-
Wind	-	-	-
Supply - Network	**661**	**1187**	**1230**
Exports			
SM	(1071)	(969)	(1001)
Imports			
WB	632	950	1028
TAR	1100	1206	1203
ANEM Energy-Gap	**(831)**	**(453)**	**(427)**
Balance	(820)	(457)	(434)
SEQ Spillage	**(421)**	**(109)**	**(56)**
Solar	(163)	(33)	(18)
Wind	(257)	(76)	(37)

The Energy-Gap during Summer Evening Peak as detailed in Table 22 reduces from Summer Weekday average because of the reduction in PHES pumping and increase in PHES available for dispatch. Spillage of wind and solar are significantly reduced from N-1 to N conditions, providing evidence of the benefits of greater network access.

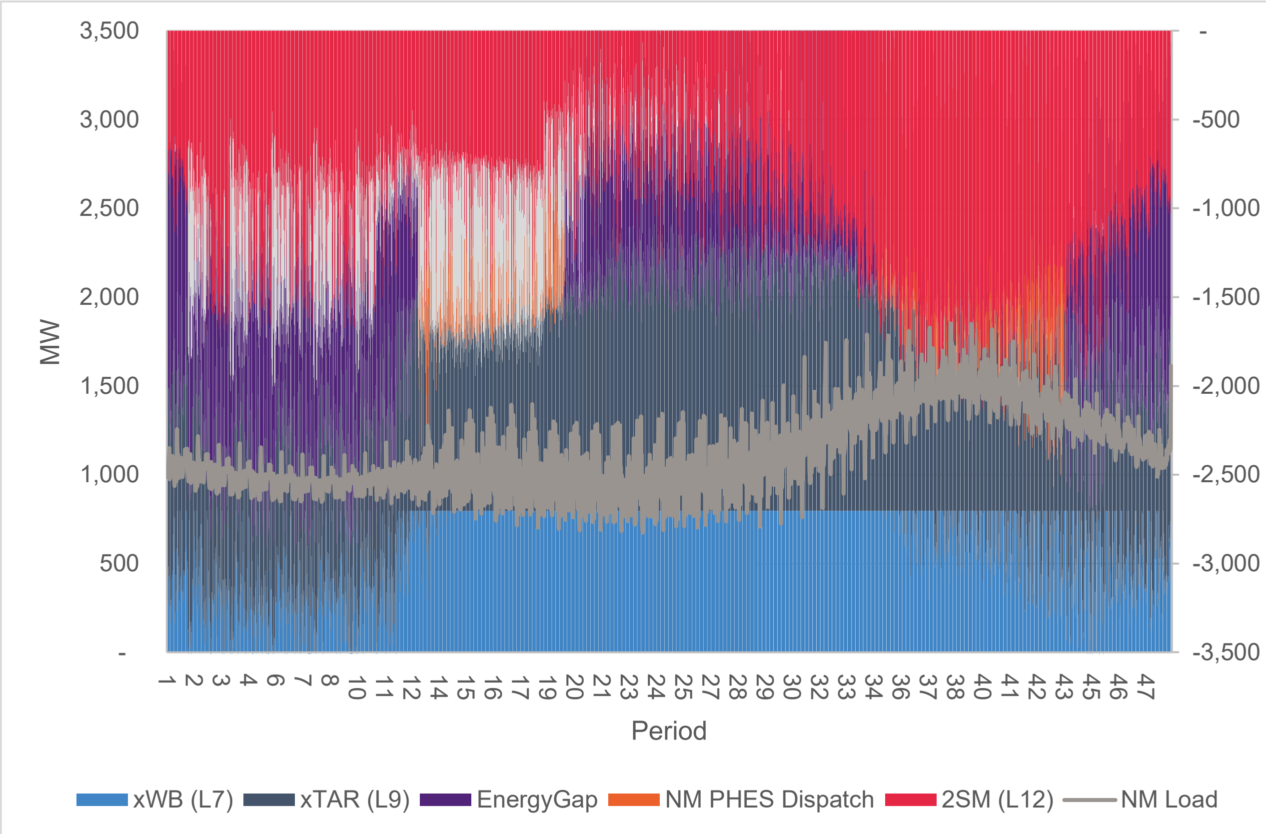
Table 22: sB NM Summer Weekdays Evening Peak Energy Balance

North Moreton Summer Weekdays Evening Peak Ave MW	sB N-1	sB N	sB N+1
Demand	**(1836)**	**(1894)**	**(1904)**
Load	(1443)	(1443)	(1443)
Loss	(93)	(151)	(161)
PHES Pump	(300)	(300)	(300)
Supply - Generation	**1172**	**889**	**888**
Coal	-	-	-
Gas	-	-	-
Hydro	-	-	-
PHES Dispatch	1172	889	888
Solar	-	-	-
Wind	-	-	-
Supply - Network	**279**	**805**	**836**
Exports			
SM	(1576)	(1438)	(1451)
Imports			
WB	718	962	997
TAR	1137	1281	1290
ANEM Energy-Gap	**(399)**	**(205)**	**(182)**
Balance	(385)	(200)	(180)
SEQ Spillage	**(229)**	**(16)**	**(9)**
Solar	(26)	(1)	(1)
Wind	(203)	(15)	(8)

The NM Energy-Gap as derived in sB is slightly lower than that derived in 2040C. The primary decline in Energy-Gap from sB to 2040C is as a result of the benefits achieved under N and N+1 network conditions. The energy flows from TAR and WB are larger in sB than in 2040C due to the greater energy capacity available in those nodes for transmission to other nodes in sB. Wind spillage under N-1 in sB is higher than in 2040C because of the existence of wind in WB in sB, but spillage reduces under N and N+1 reducing concerns about energy loss.

Figure 28 represents 2880 points for each energy series in the NM node under restrictive N-1 network conditions. Note the flows from WB at capacity for daylight hours. Also note the periods of Energy-Gaps correspond with periods of PHES pumping, although they also occur in the early hours of the morning because of an energy deficit. Also note the lack of a marked morning peak. Note the large flows to SM from 4:30pm until 11pm.

Figure 28: sB NM Summer Weekday N-1 Energy-Gap with statistics



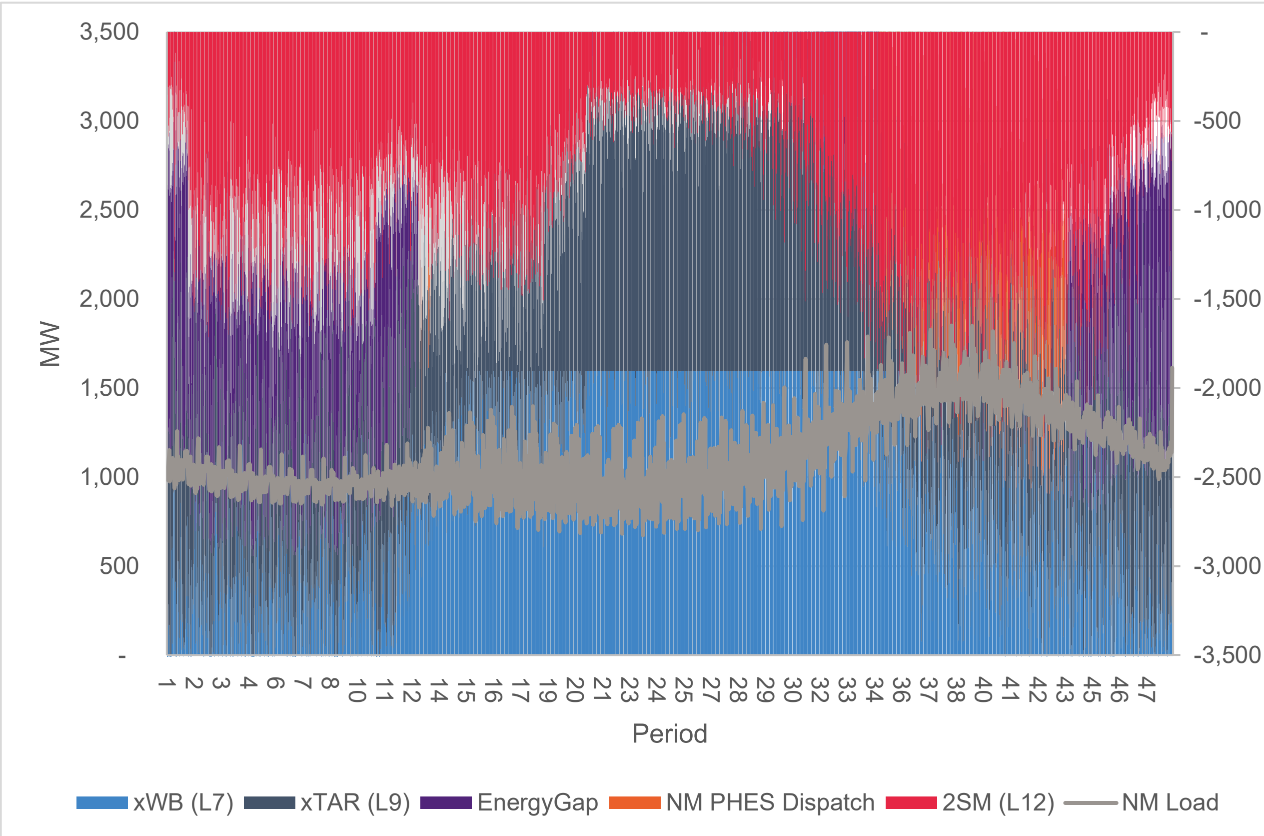
Energy-Gap Statistics and Transmission congestion details			
Max: 1993 MW Median: 805 MW Capacity Factor: 42%	Occurs in 85% of periods >= 498 MW = 64% >= 997 MW = 46% >= 1495MW = 27%	>= 498 MW occurs Evening Peak = 120 (20%) Overnight = 990 (92%) Daytime = 736 (61%)	Congestion xWB: Day 97%, EvPk 54% xTAR: Day 0%, EvPk 0% 2SM: Day 0%, EvPk 0%

The Energy-Gap in NM is large at 1993MW and persistent, in that the median of all occurrences is 1590 MW and the capacity factor of energy required is 42%. An Energy-Gap occurs in 85% of the total 2880 periods of Summer Weekdays. Energy-Gaps of 498MW or greater (25% of the maximum) are present in 64% of periods. Energy-Gaps of 997 MW or greater (50% of the maximum) are present in 46% of periods. Energy-Gaps of 1495MW or greater (75% of the maximum) are present in 27% of Summer Weekday periods. Energy-Gaps of greater than or equal to 498MW occur on 120 (20% of Evening Peak periods), 1020 (94% of overnight periods) and 772 (64% of periods during the day from 7:00 to 16:30) periods. Thus a large driver of the Energy-Gap in NM node is PHES pumping which occurs during the day and for a few hours overnight. The only evidence of congestion on the network into and out of NM node, is the line from WB to NM which shows congestion on 97% of Summer Weekday periods and 54% of Evening Peak periods.

Comparing the NM Energy-Gap in sB to 2040C, the maximum Energy-Gap in both scenarios is equally high, but the median in sB is lower (805MW vs 1590MW), as are the capacity factor (42% vs 52%), occurrence (85% vs 91%), occurrence at greater than 997MW (46% vs 65%), and occurrence at greater than 1495MW (27% vs 54%). Congestion on the WB-NM transmission line occurs in 97% of daytime flows in sB versus only 36% of flows in 2040C which suggests greater flows of solar and wind energy from WB+GLAD to serve PHES pumping loads in NM. Congestion on the WB-NM transmission line occurs in 54% of Evening Peak flows in sB versus 86% of flows in 2040C as energy generated in CWQ flows through GLAD and WB to meet Evening Peak in NM. Greater flows from WB are required in 2040C because of significantly less energy available in TAR with TPS closed, which puts greater demand on energy flows through WB.

Figure 29 represents 2880 points for each energy series in the NM node under normal N network conditions. Flows from WB+GLAD (2803MW solar and wind capacity) and TAR (1143MW TPS and 1133MW solar and wind capacity) provide approximately equal shares of energy into NM, reducing the Energy-Gap during the day to an average of 96MW, despite PHES pump load requirements. The Energy-Gap remains overnight, even when there is no PHES pump load, which raises questions about adequacy of wind generation.

Figure 29: sB NM Summer Weekday N Energy-Gap with statistics

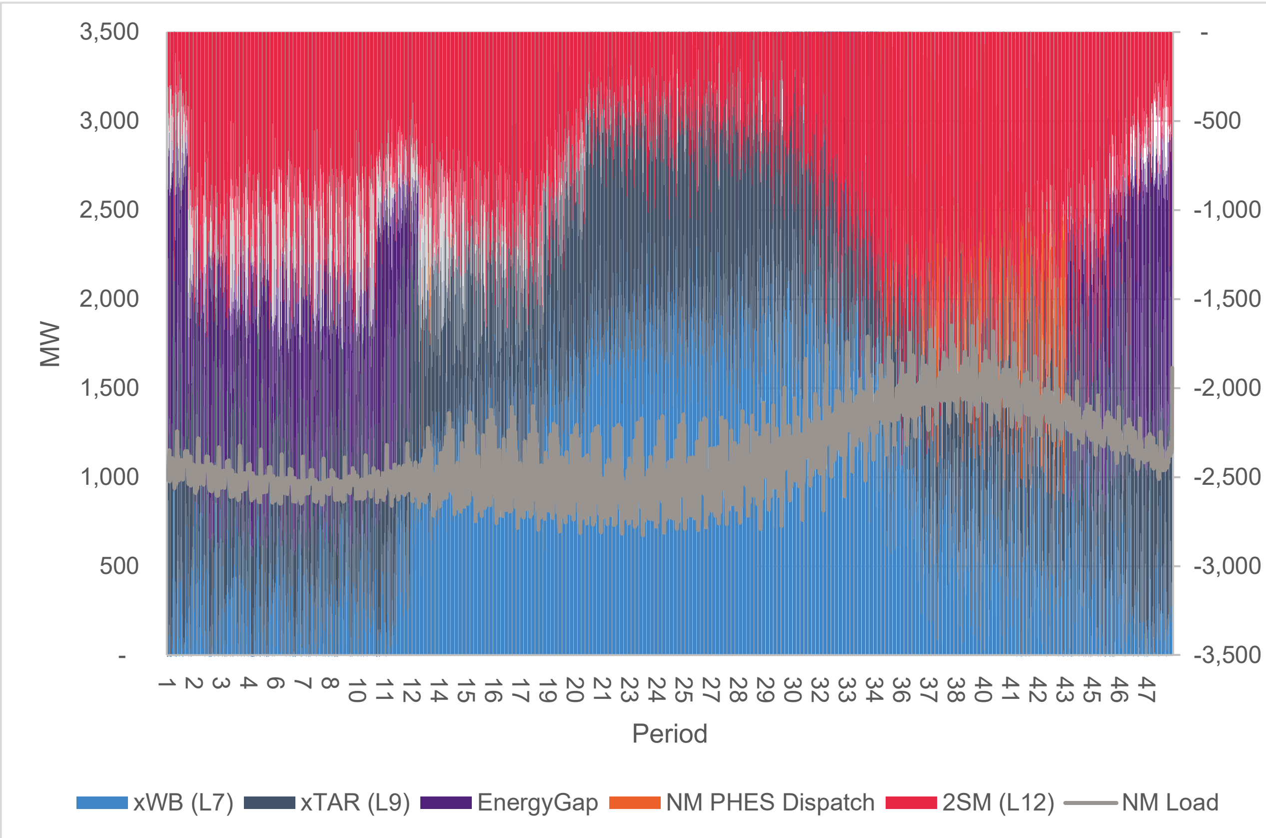


Energy-Gap Statistics and Transmission congestion details			
Max: 1944 MW	Occurs in 63% of periods	>= 486 MW occurs	Congestion
Median: 0 MW	>= 486 MW = 40%	Evening Peak = 112 (19%)	xWB: Day 54%, EvPk 12%
Capacity Factor: 23%	>= 972 MW = 22%	Overnight = 946 (88%)	xTAR: Day 0%, EvPk 0%
	>= 1458MW = 16%	Daytime = 101 (8%)	2SM: Day 0%, EvPk 0%

The Energy-Gap in NM remains large but is less persistent under normal network conditions due to flows of energy from TAR and WB during sunlight hours. The median of all occurrences reduces to 0 MW and the capacity factor of energy required to 23%. An Energy-Gap still occurs in 63% of the total 2880 periods of Summer Weekdays although higher Energy-Gaps reduce from the N-1 conditions. Overnight Energy-Gaps remain the major cause of the energy deficits. Congestion on the WB-NM line under N conditions remains high at 54% during sunlight hours due to flows from WB to serve PHES pump load. Congestion on the WB-NM line reduced to 12% at Evening Peak as less energy is required in NM because of increased flows from TAR and PHES for dispatch.

The Energy-Gap in sB under N conditions is less persistent than in 2040C with the Energy-Gap median in 2040C of 570MW reducing to 0MW in sB. Consequently all statistics in sB are improved over 2040C from capacity factor of 33% in 2040C reducing to 23% in sB, occurrences of Energy-Gap of 86% in 2040C reducing to 63% in sB, and occurrences of Energy-Gaps greater than 1494MW of 26% in 2040C reducing to 16% in sB. Energy-Gaps overnight remain high in both scenarios although they reduce from 1016 incidences in 2040C to 846 in sB.

Figure 30: sB NM Summer Weekday N+1 Energy-Gap with statistics



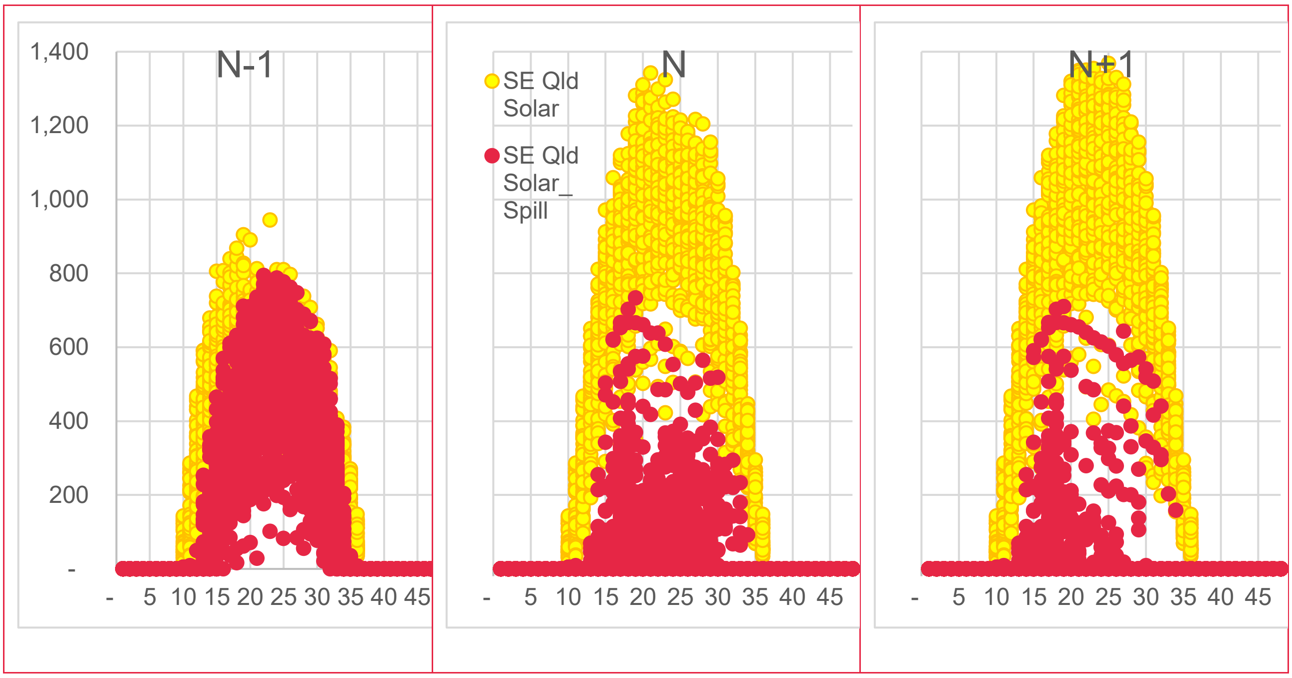
Energy-Gap Statistics and Transmission congestion details			
Max: 1944 MW	Occurs in 58% of periods	>= 486 MW occurs	Congestion
Median: 0 MW	>= 486 MW = 38%	Evening Peak = 99 (17%)	xWB: Day 1%, EvPk 0%
Capacity Factor: 22%	>= 972 MW = 21%	Overnight = 948 (88%)	xTAR: Day 0%, EvPk 0%
	>= 1458MW = 15%	Daytime = 47 (4%)	2SM: Day 0%, EvPk 0%

Figure 30 represents 2880 points for each energy series in the NM node under augmented N+1 network conditions. Modelling for N+1 assumed augmentation on the lines that experience congestion under N conditions (CWQ-GLAD, WB-NM, and SWQ-SM). Outcomes for Energy-Gap at NM, show significant variability in inflows from WB and TAR.

Even under augmented network conditions, the Energy-Gap in NM remains, albeit more sporadic than under N conditions. The median of all occurrences is 0MW and the capacity factor of energy required is 22%. An Energy-Gap still occurs in 58% of the total 2880 periods of Summer Weekdays and higher Energy-Gaps reduce slightly from N conditions. Overnight Energy-Gaps remain due to a deficit of wind energy available at night. There is only slight evidence of congestion on WB-NM transmission line. The Energy-Gap as derived in sB is less persistent than in 2040C, providing evidence of the benefits of greater generation capacity in both WB+GLAD and TAR.

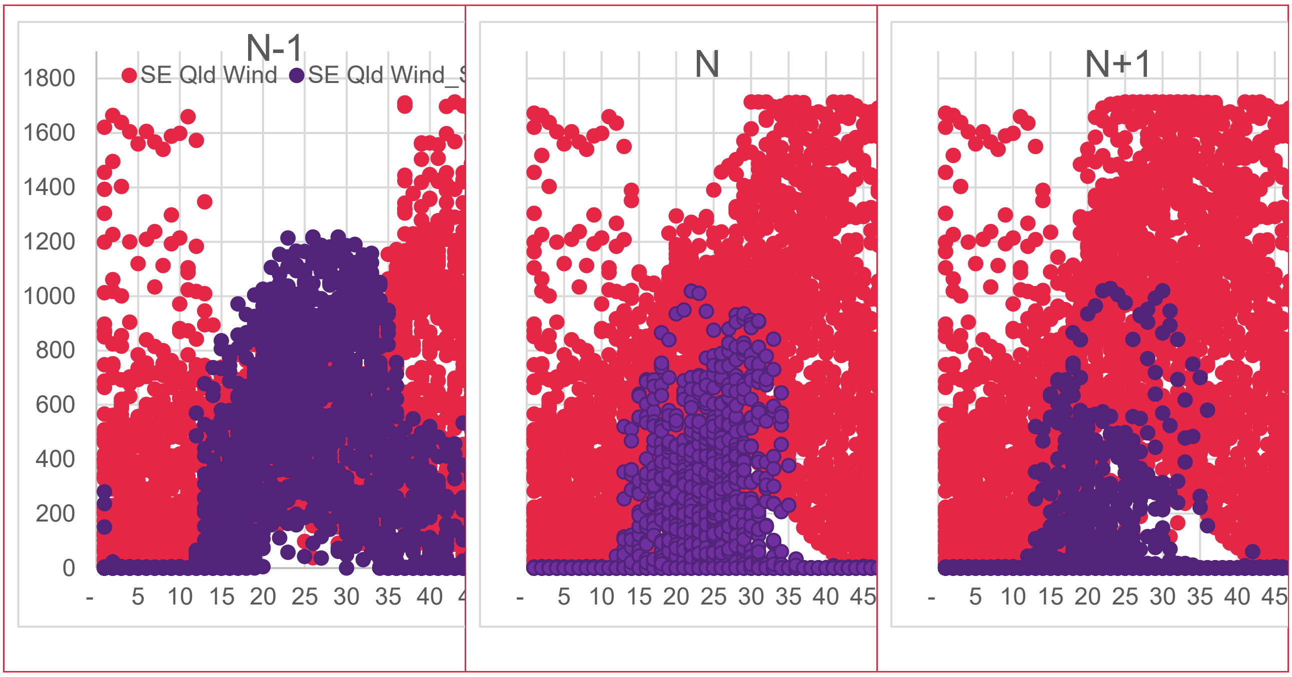
While PHES pumping plays a role in NM Energy-Gaps, the variability of VRE is the primary contributor.

Figure 31: sB SEQ Solar summer dispatch and spill



As a large load centre, NM has limited locations for VRE. The VRE which flows primarily to NM comes from TAR and WB. In sB, 808 MW of solar is located in WB and 620MW in TAR nodes. Solar energy in TAR is generally dispatched but in WB 68% is spilled under N-1 conditions, as shown in Figure 31. Under N conditions solar spillage in WB reduces to 13%. Solar provides a reliable resource during summer daylight hours from 6am through to 5pm. Thus solar in WB and TAR provide much needed energy for PHES pump load during the day. Spillage declines even further under the augmented network conditions modelled to low levels, which almost eliminates much of the Energy-Gap during sunlight hours in NM.

Figure 32; sB SEQ Wind summer dispatch and spill

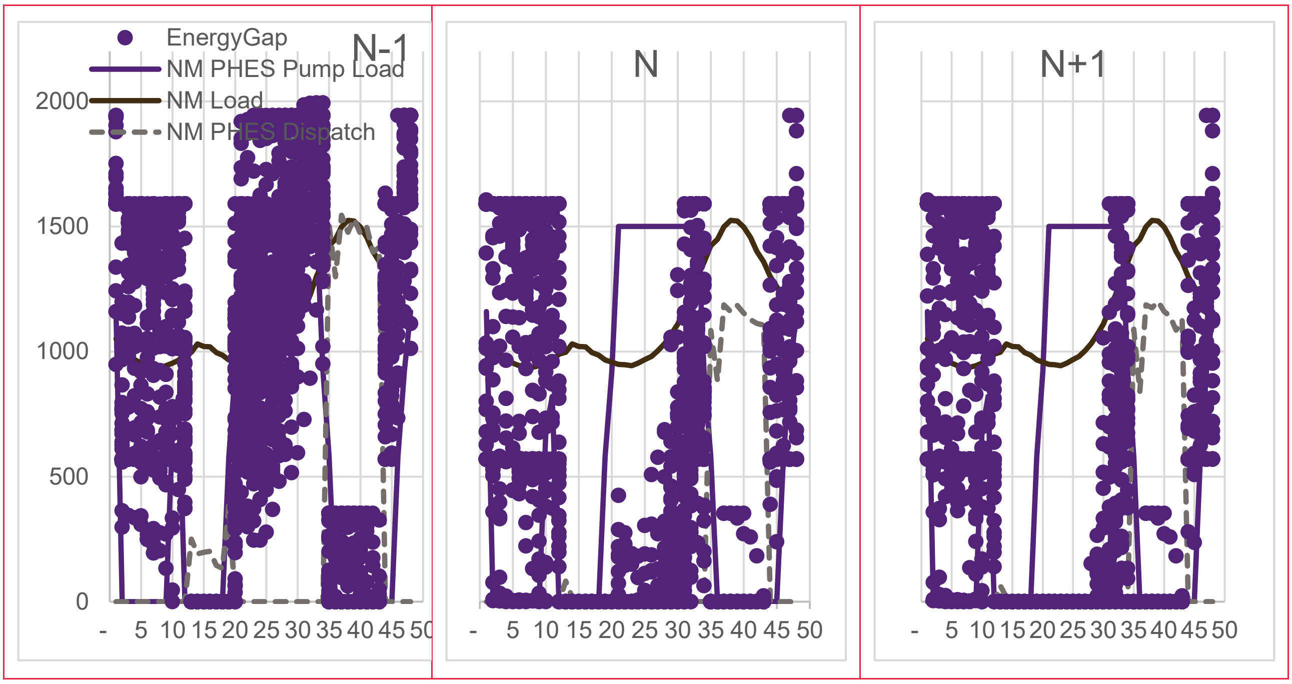


In sB, 513MW of wind power is located in TAR and 1200MW in WB. Similarly to solar, wind energy is generally dispatched even under N-1 conditions in TAR but 50% is spilled in WB as shown in Figure 32. The wind resource displays a tendency to vary significantly from midnight until the early afternoon. This variability in the early hours of the morning creates problems for meeting overnight demand. The wind resource appears to be much more reliable during the afternoon corresponding favourably with Evening Peak. Under unrestricted network conditions, wind spillage in WB reduces to an average of 15% although spillage is elevated during sunlight hours as it conflicts with solar generation and inadequate transmission capacity on the WB-NM line. Under augmented transmission conditions, wind spillage in WB is significantly reduced.

The much larger additions of wind capacity to the TAR and WB nodes contributes significantly to reduced Energy-Gap in NM node in sB compared to 2040C. Greater transmission capacity between WB and NM will enhance the capacity of VRE to meet NM demand and reduce the incidence of an Energy-Gap in the node.

Figure 33 provides a stylised graphic of the incidence of Energy-Gap in NM, together with PHES Pump Load, NM Load and PHES Dispatch. The incidence of very large Energy-Gaps under N-1 reflects the PHES Pump Load, and also the limits on the capacity of solar and wind from WB to supply PHES Pump Load in NM. Energy-Gaps reduce and become less persistent under N, but remain evident. Under augmented transmission the concentration of Energy-Gap during the day reduces and spillage is reduced providing evidence of the benefit of transmission augmentation for NM node.

Figure 33: sB NM Summer Weekdays average Energy-Gap with PHES dispatch and pumping



In summary, modelling indicates that NM has an Energy-Gap in sB due to PHES pumping and unreliable wind resource. Coal generation in Tarong, greater wind energy resource in both TAR and WB reduces the incidence of NM Energy-Gaps in sB from 2040C. Transmission augmentation facilitates the transmission of energy from wind energy generated in WB but does not eliminate the incidence of Energy-Gap. It is thus important to consider carefully the PHES pump strategy to take account of wind resource but also to increase wind capacity to eliminate the incidence of an Energy-Gap overnight. Also pump strategy for early Evening Peak demand should reflect solar and wind resource to avoid contributing to the incidence of Energy-Gap.

ii. SM+GC Summer Weekdays Energy Balance

Table 23 details the combined SM plus GC Energy Balance for Summer Weekdays as modelled in sB. After Swanbank E is shut, neither SM nor GC will have any generation to supply demand. There are however good network connections with TAR and NM and between SM and GC even under network restrictions. The Energy-Gap that emerges under restricted network conditions results from the reduced flow of energy from SWQ where the bulk of energy for SEQ originates. Under unrestricted network conditions, there are no apparent persistent Energy-Gaps.

Table 23: sB SM+GC Summer Weekday Energy Balance

South Moreton and Gold Coast combined Summer Weekdays Ave MW	sB N-1		sB N		sB N+1	
Demand	**(2207)**		**(2220)**		**(2218)**	
Load		(2138)		(2138)		(2138)
Loss		(69)		(82)		(81)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**-**		**-**		**-**	
Coal		-		-		-
Gas		-		-		-
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		-		-		-
Wind		-		-		-
Supply - Network	**2197**		**2218**		**2217**	
Exports						
GC		(391)		(427)		(435)
DL		(17)		(33)		(37)
Imports						
NM		1071		969		1001
SWQ		1006		1166		1140
DL		136		117		112
ANEM Energy-Gap	**(15)**		**(-)**		**(-)**	
Balance		(10)		(2)		(1)
SWQ Spillage	**(324)**		**(195)**		**(226)**	
Solar		(317)		(191)		(221)
Wind		(7)		(4)		(5)

The average SM +GC Energy-Gap under restricted N-1 conditions is considerably smaller in sB at 15MW than in 2040C at 236MW. This primarily as a result of improved energy flows from NM, which in turn experiences improved energy flows from TAR and WB under sB due to greater generation capacity in both TAR and WB in sB than in 2040C. Under unrestricted network conditions and the augmented network conditions both sB and 2040C show little evidence of persistent Energy-Gaps. Solar spillage in SWQ improves from N-1 to N, but shows a slight deterioration in N+1 as greater energy flows from GLAD+WB to NM and SM.

The Energy-Gap during Summer Evening Peak as detailed in Table 24 increases during Evening Peak under restricted network conditions due to the limits of the transmission line from SWQ where the majority of the energy for SM+GC is located. The Energy-Gap evident under N-1 is no longer a problem under N, and there is no significant benefit for SM+GC from the network augmentation considered under N+1.

The SM+GC Energy-Gap during Evening Peak under restrictive N-1 conditions for sB of 47MW is considerably improved from 618MW in 2040C. This is primarily as a result of increased flows of energy from

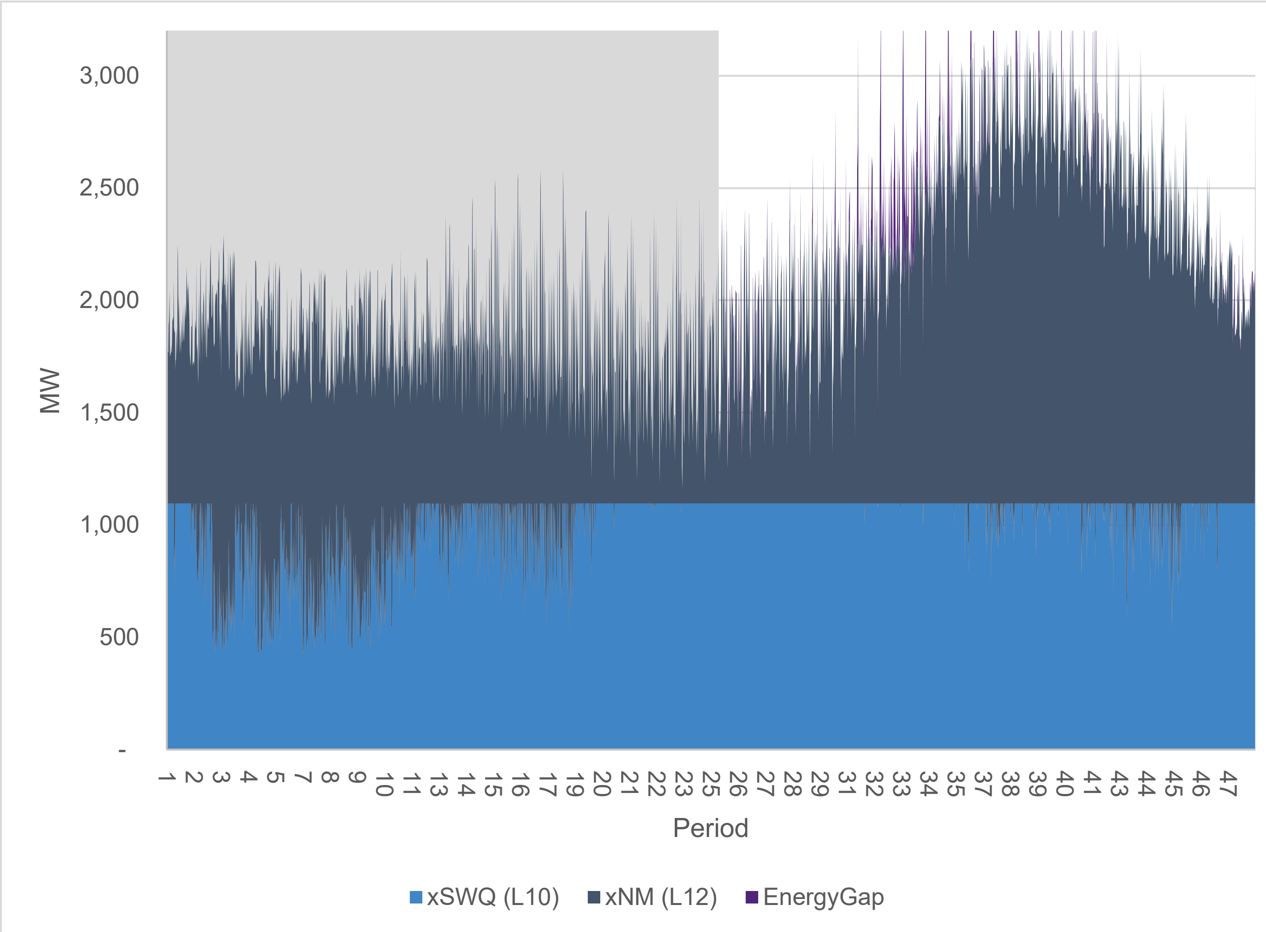
NM and DL aided by generation available from TPS in sB, but also 2040C assumptions of slightly higher demand in SM+GC.

Table 24: sB SM+GC Summer Weekdays Evening Peak Energy Balance

South Moreton and Gold Coast combined Summer Weekdays Evening Peak Ave MW	sB N-1		sB N		sB N+1	
Demand	**(2842)**		**(2860)**		**(2860)**	
Load		(2743)		(2743)		(2743)
Loss		(99)		(117)		(117)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**-**		**-**		**-**	
Coal		-		-		-
Gas		-		-		-
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		-		-		-
Wind		-		-		-
Supply - Network	**2801**		**2855**		**2855**	
Exports						
GC		(524)		(576)		(582)
DL		(7)		(32)		(34)
Imports						
NM		1576		1438		1451
SWQ		1082		1325		1318
DL		149		123		120
ANEM Energy-Gap	**(47)**		**(21)**		**(-)**	
Balance		(41)		(5)		(5)
SWQ Spillage	**(6)**		**(-)**		**(-)**	
Solar		(4)		(-)		(-)
Wind		(1)		(-)		(-)

Figure 34 represents 2880 points for each energy series in the SM and GC nodes under restrictive N-1 network conditions. Note the flows from SWQ at capacity throughout the year and each day. Also note the very few periods of Energy-Gaps and when they do occur they correspond primarily with Evening Peak. Also note the lack of a marked morning peak. Note the variability of flows from NM as the source of energy balancing.

Figure 34: sB SM+GC Summer Weekday N-1 Energy-Gap with statistics



Energy-Gap Statistics and Transmission congestion details

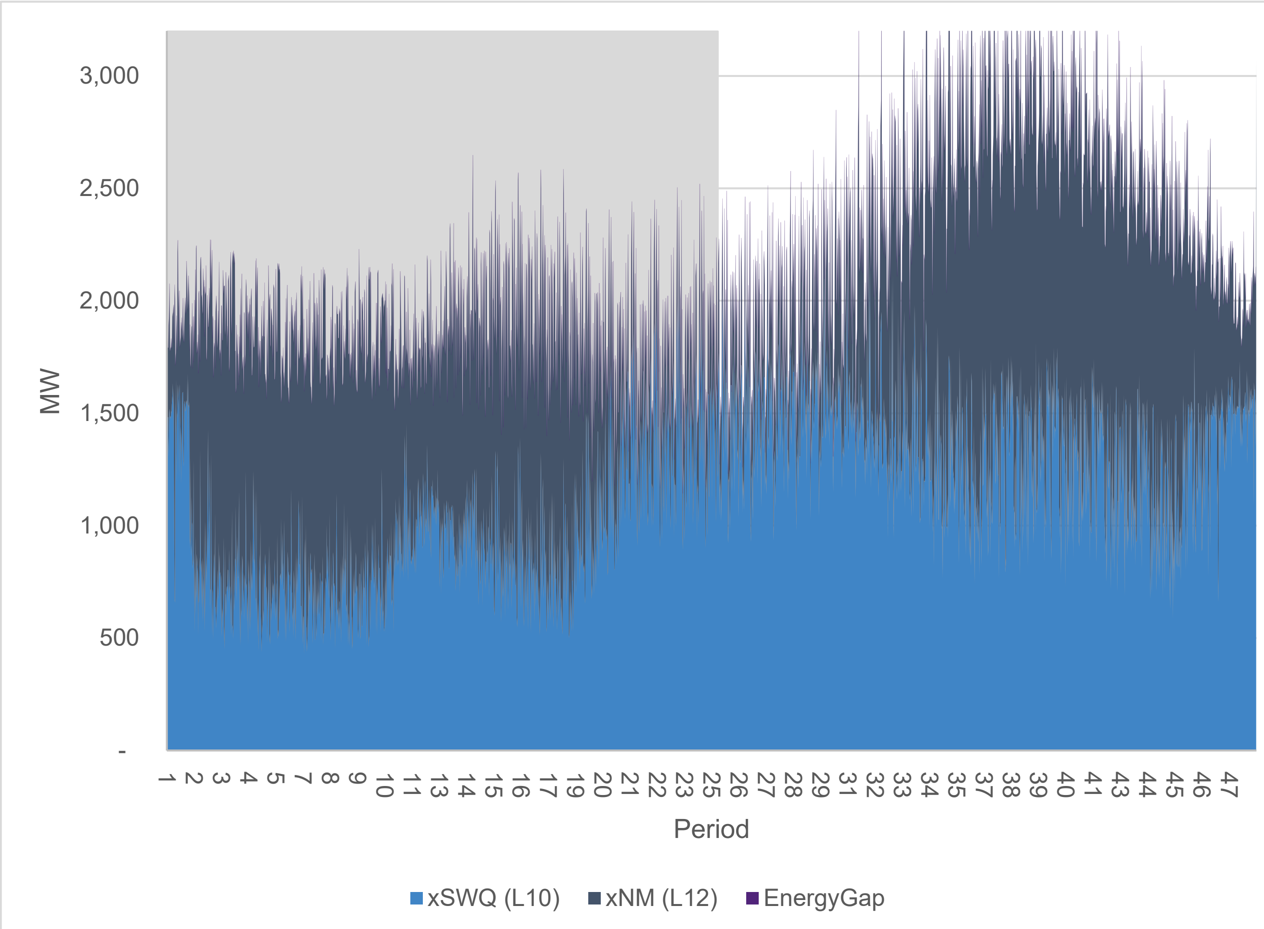
Max: 885 MW	Occurs in 6% of periods	>= 221 MW occurs	Congestion:
Median: 0 MW	>= 221 MW = 3%	Evening Peak = 48 (8%)	xSWQ: Day 82%, EvPk 69%
Capacity Factor: 2%	>= 443 MW = 1%	Overnight = 4 (0%)	xNM: Day 0%, EvPk 0%
	>= 664MW = 1%	Daytime = 22 (2%)	xDL: Day 68%, EvPk 58%

The Energy-Gap in SM is large at 885MW. The median of all occurrences is 0 MW and the capacity factor of energy required is 2%. An Energy-Gap occurs in 6% of the total 2880 periods of Summer Weekdays. Energy-Gaps of 221MW or greater (25% of the maximum) are present in 3% of periods. Energy-Gaps of 443 MW or greater (50% of the maximum) are present in 1% of periods. Energy-Gaps of 664MW or greater (75% of the maximum) are present in 1% of Summer Weekday periods. 48 (8% of Evening Peak periods), 4 (0.4% of Overnight periods) and 22 (2% of periods between 7:00 to 16:30) periods reflect Energy-Gaps of greater than 221MW.Thus the primary driver of the Energy-Gap in SM node is higher demand during the Evening Peak. The transmission line from SWQ shows significant evidence of congestion into SM especially during the day when congestion occurs 82% of the time reducing to 69% of the time during Evening Peak. There is also significant evidence of congestion on the DirectLink connection because of its limited capacity of 180MW and predominant reverse flows from NSW to meet demand. There is no congestion even under restricted network conditions on the transmission link between NM and SM nor the transmission link between SM and GC.

The SM+GC Energy-Gap under N-1 conditions is considerably less persistent in sB than in 2040C occurring in only 6% of periods during Summer Weekdays compared to 42% of periods in 2040C, across all periods of the day. Congestion on the SWQ-SM transmission line and DL interconnector in sB is higher during the day but lower during Evening Peak than in 2040C.

Figure 35 represents 2880 points for each energy series in the NM node under normal N network conditions. Flows from SWQ provide the predominant supply of energy into SM, but flows from NM are the source of energy balancing.

Figure 35: sB SM+GC Summer Weekday N Energy-Gap with statistics

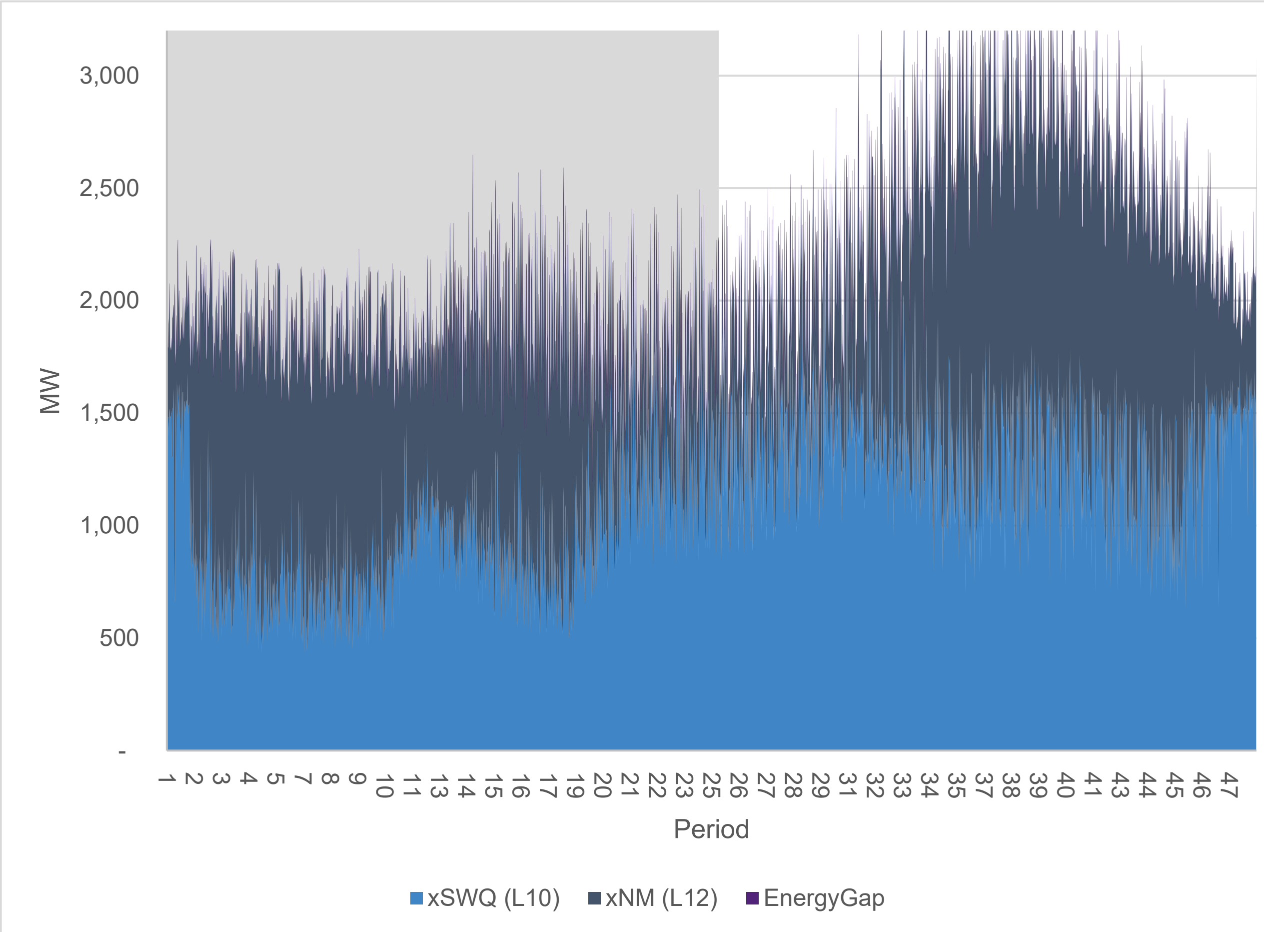


Energy-Gap Statistics and Transmission congestion details			
Max: 0 MW Median: 0 MW Capacity Factor: 0%			Congestion: xSWQ: Day 0.6%, EvPk 0% xNM: Day 0%, EvPk 0% xDL: Day 66%, EvPk 42%

There is no evidence Energy-Gap in SM under unrestricted network conditions in sB. There remains evidence of congestion on the DL interconnector. This is a marked improvement on SM+GC Energy-Gap derived in 2040C which also sporadic still shows high Energy-Gaps of 885MW during some Summer Weekday periods.

Figure 36 represents 2880 points for each energy series in the combined SM and GC nodes under augmented N+1 network conditions. Modelling for N+1 assumed augmentation on the lines that experience congestion under N conditions (CWQ-GLAD, WB-NM, and SWQ-SM). Outcomes for Energy-Gap at SM, show significant variability in inflows from SWQ and NM with NM providing the primary source of increased energy to meet demand during Evening Peak.

Figure 36: sB SM+GC Summer Weekday N+1 Energy-Gap with statistics

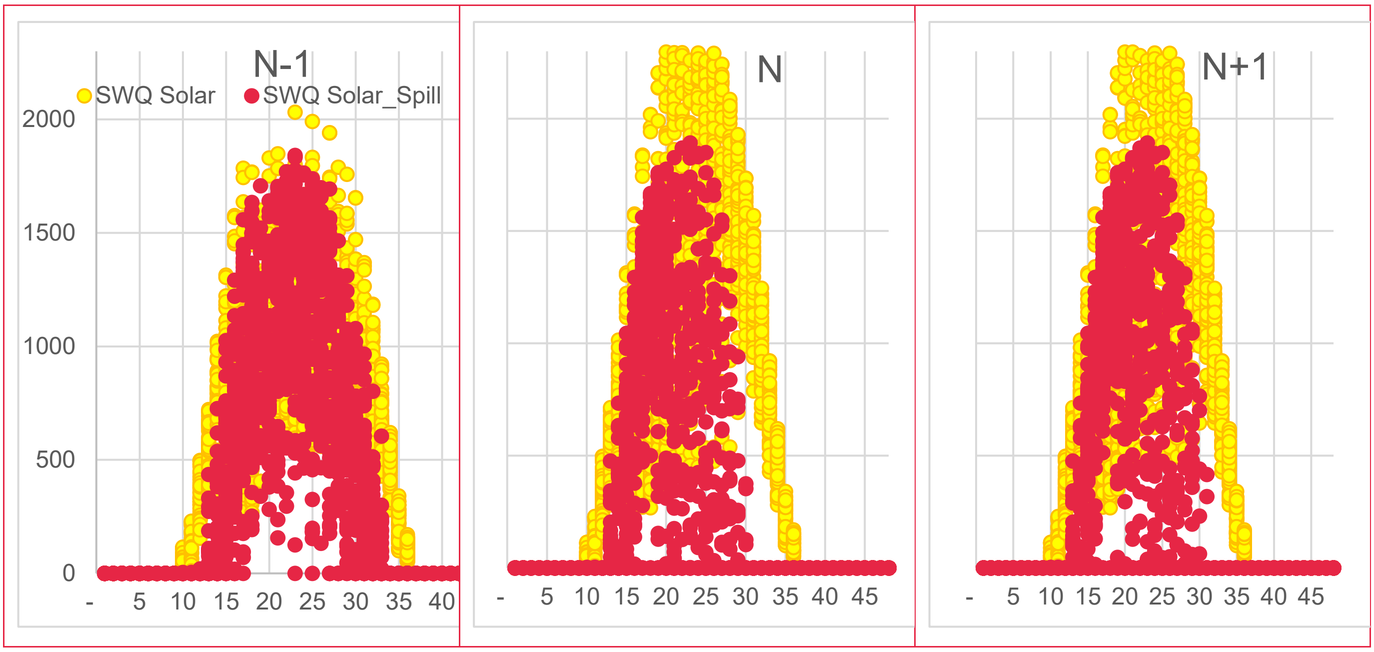


Energy-Gap Statistics and Transmission congestion details			
Max: 0 MW Median: 0 MW Capacity Factor: 0%			Congestion: xSWQ: Day 0%, EvPk 0% xNM: Day 0%, EvPk 0% xDL: Day 67%, EvPk 46%

There is no evidence of congestion on the network into and out of SM node under augmented network conditions, although DL still experiences congestion during 67% of daytime periods and 46% of Evening Peak periods.

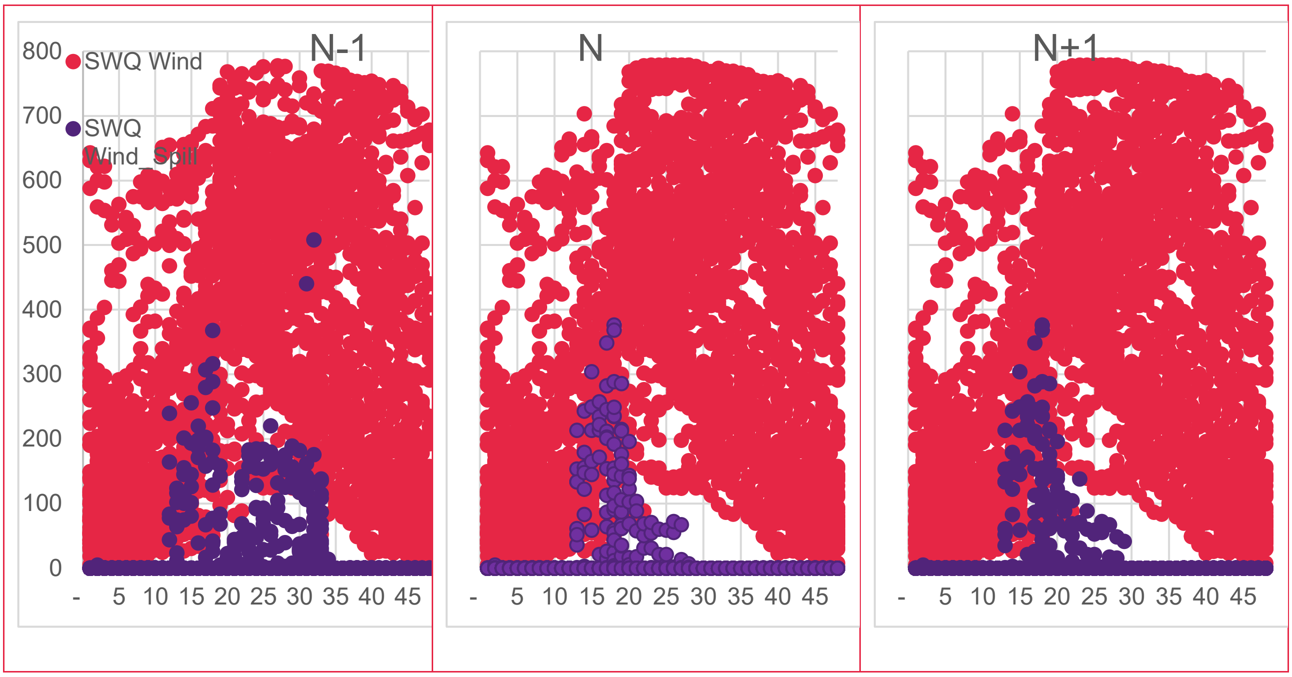
The variability of VRE plays a role in the occurrence of the Energy-Gap.

Figure 37: sB SWQ Solar summer dispatch and spill



sB has 2439MW of solar power allocated to SWQ. Summer thermal limits under N-1 result in 43% of solar spillage in SWQ which in turn increases reliance on flows of energy from NM to SM as shown in Figure 37. Moving to an unrestricted network, ensures that considerably more solar is dispatched with only 26% spilled. This in turn reduces reliance on flows from NM during sunlight, but they remain volatile between midnight and sunrise. There is a small decrease to solar dispatch from augmented network capacity between SWQ and SM.

Figure 38; sB SWQ Wind summer dispatch and spill



sB has 779MW of wind power located in SWQ. Under restricted network conditions, 2% of wind spillage occurs mainly during the day. When network restrictions are lifted, wind spillage decreases to 1% as shown in Figure 38. It should be noted though that wind resource is irregular from midnight to around 10am. This complicates the challenge of meeting demand in SM overnight when PHES pumping at NM increases demand in NM.

In summary, modelling indicates that SM has an Energy-Gap of up to 885MW in sB only under restrictive N-1 network conditions. To address Energy-Gaps in SM, augmentation of transmission between SWQ and SM should be considered to facilitate the flow of energy from the high generation capacity node of SWQ to SM, and the deferral of closure of Swanbank E in order to balance supply during Evening Peak.

iii. GLAD+WB Summer Weekdays Energy Balance

Table 25 details the combined GLAD plus WB Energy Balance for Summer Weekdays as modelled in sB. The scenario includes the closure of 4 units or 1120MW of GPS and the addition of 795MW of solar in GLAD node plus a further 808MW of solar and 1200MW of wind in WB node. These additions could theoretically cover the loss of 1120MW coal plant. As a result of the withdrawal of thermal generation in GLAD, small Energy-Gaps emerge within the combined nodes. The Energy-Gaps reduce to negligible levels under unrestricted network conditions.

Table 25: sB GLAD+WB Summer Weekday Energy Balance

Gladstone and Wide Bay combined Summer Weekdays Ave MW	sB N-1		sB N		sB N+1	
Demand	**(1401)**		**(1414)**		**(1419)**	
Load		(1326)		(1326)		(1326)
Loss		(75)		(87)		(93)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**1154**		**1432**		**1500**	
Coal		466		440		456
Gas		95		87		88
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		336		468		480
Wind		256		437		476
Supply - Network	**276**		**12**		**(53)**	
Exports						
WB		(549)		(564)		(588)
NM		(632)		(951)		(1026)
Imports						
CWQ		906		962		973
ANEM Energy-Gap	**(13)**		**(1)**		**(1)**	
Balance		(29)		(30)		(28)
GLAD+WB Spillage	**(436)**		**(123)**		**(72)**	
Solar		(179)		(47)		(35)
Wind		(257)		(76)		(37)

The Energy-Gap during Summer Evening Peak as detailed in Table 26 increases during Evening Peak under restricted network conditions due to a lack of available energy after sundown and the limits of the transmission from CWQ where the majority of the energy for GLAD+WB is located. The Energy-Gap evident under N-1 reduces under N, and still further under the network augmentation considered under N+1.

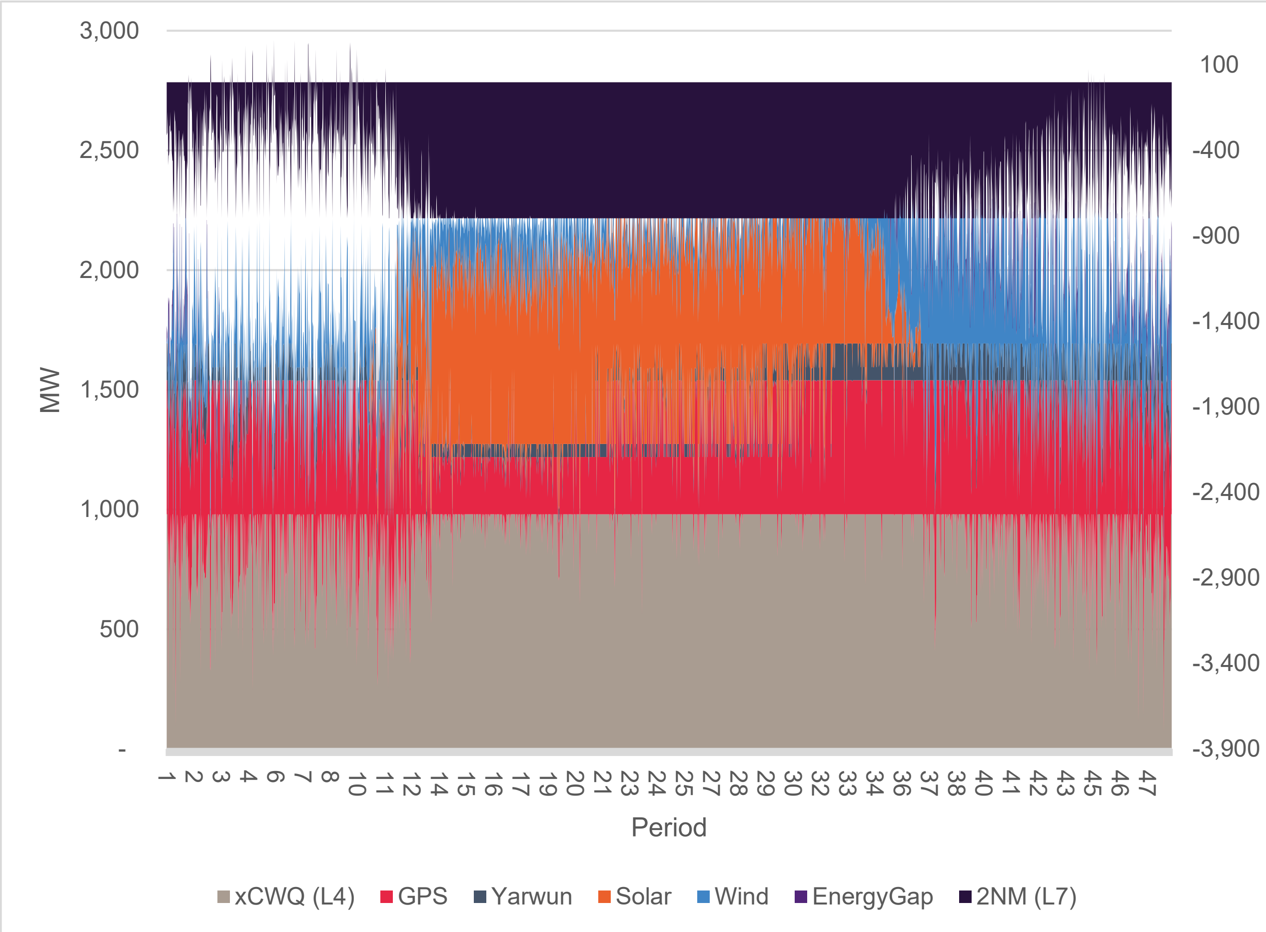
The GLAD+WB Energy-Gap under N-1 network restrictions in sB at 13MW is significantly lower than that in 2040C of 1063MW, and also under N network conditions at 1MW in sB compared to 394MW in 2040C. Once again this is primarily as a result of the larger generation capacity in GLAD and WB in sB over 2040C.

Table 26: sB GLAD+WB Summer Weekdays Evening Peak Energy Balance

Gladstone and Wide Bay combined Summer Weekdays Evening Peak Ave MW	sB N-1		sB N		sB N+1	
Demand	**(1462)**		**(1482)**		**(1490)**	
Load		(1388)		(1388)		(1388)
Loss		(74)		(94)		(102)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**1258**		**1469**		**1487**	
Coal		552		553		560
Gas		125		122		125
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		139		164		165
Wind		442		630		637
Supply - Network	**219**		**49**		**37**	
Exports						
WB		(538)		(579)		(610)
NM		(718)		(962)		(997)
Imports						
CWQ		937		1011		1034
ANEM Energy-Gap	**(33)**		**(5)**		**(5)**	
Balance		15		36		34
GLAD+WB Spillage	**(229)**		**(16)**		**(9)**	
Solar		(26)		(1)		(1)
Wind		(203)		(15)		(8)

Figure 39 represents 2880 points for each energy series in the GLAD+WB nodes under restrictive N-1 network conditions. Note the flows from CWQ generally at capacity throughout the year and each day. Also note the periods of Energy-Gaps are extremely sporadic. Also note the lack of a marked morning peak. Note the flows to NM at capacity from 10:00am till Evening Peak and then sporadically overnight until morning peak. Note the significant contribution of solar during the day.

Figure 39: sB GLAD+WB Summer Weekday N-1 Energy-Gap with statistics



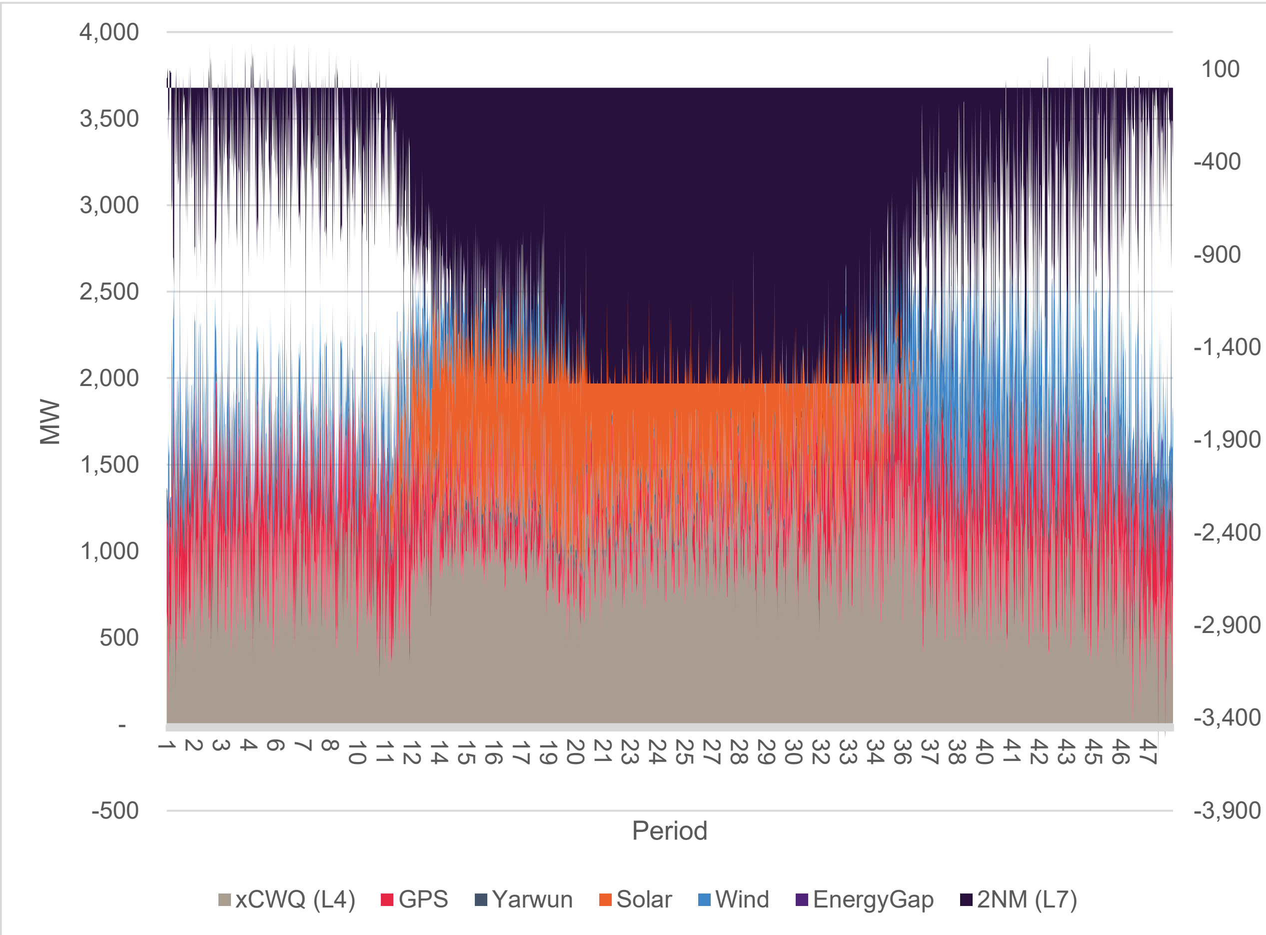
Energy-Gap Statistics and Transmission congestion details			
Max: 657 + 654 MW Median: 0 + 0 MW Capacity Factor: 1%, 1%	Occurs in 29%, 16% of periods >= 164 MW=2% (1%) >= 328 MW=1% (0%) >= 493 MW=0% (0%)	>= 164 MW occurs Evening Peak = 36 (6%) Overnight = 15 (1%) Daytime = 2 (0%)	Congestion: xCWQ: Day 86%, EvPk 63% 2WB: Day 0%, EvPk 0% 2NM: Day 97%, EvPk 54%

The Energy-Gaps in GLAD and WB are large at 657MW and 654MW with the median of all occurrences at 0MW. The capacity factor of energy required is 1%. An Energy-Gap occurs in 29% in GLAD and 16% in WB of the total 2880 periods of Summer Weekdays. Energy-Gaps of 350MW or greater (25% of the maximum) are present in 2% of periods (1% in WB). Energy-Gaps of 328 MW or greater (50% of the maximum) are present in 1% of periods (0% in WB). Energy-Gaps of 493MW or greater (75% of the maximum) are not almost non-existent. 36 (6% of Evening Peak periods), 15 (1% of overnight periods) and 2 (negligible % of periods between 7:00 and 16:30 incidences of Energy-Gaps of greater than 164MW in GLAD occur during Summer Weekdays. Thus the primary driver of the Energy-Gap in GLAD and WB nodes is demand during the Evening Peak which cannot be served by solar. The transmission line from CWQ shows significant evidence of congestion into GLAD especially during the day when congestion occurs 86% of the time. There is also significant evidence of congestion on the transmission line to NM from WB of 97% during the day.

There is no congestion even under restricted network conditions on the transmission link between GLAD and WB.

Figure 40 represents 2880 points for each energy series in the GLAD and WB nodes under normal N network conditions. Flows from CWQ provide the predominant supply of energy into GLAD, and flows to NM from WB are concentrated during sunlight hours to help serve PHES pump load.

Figure 40: sB GLAD+WB Summer Weekday N Energy-Gap with statistics

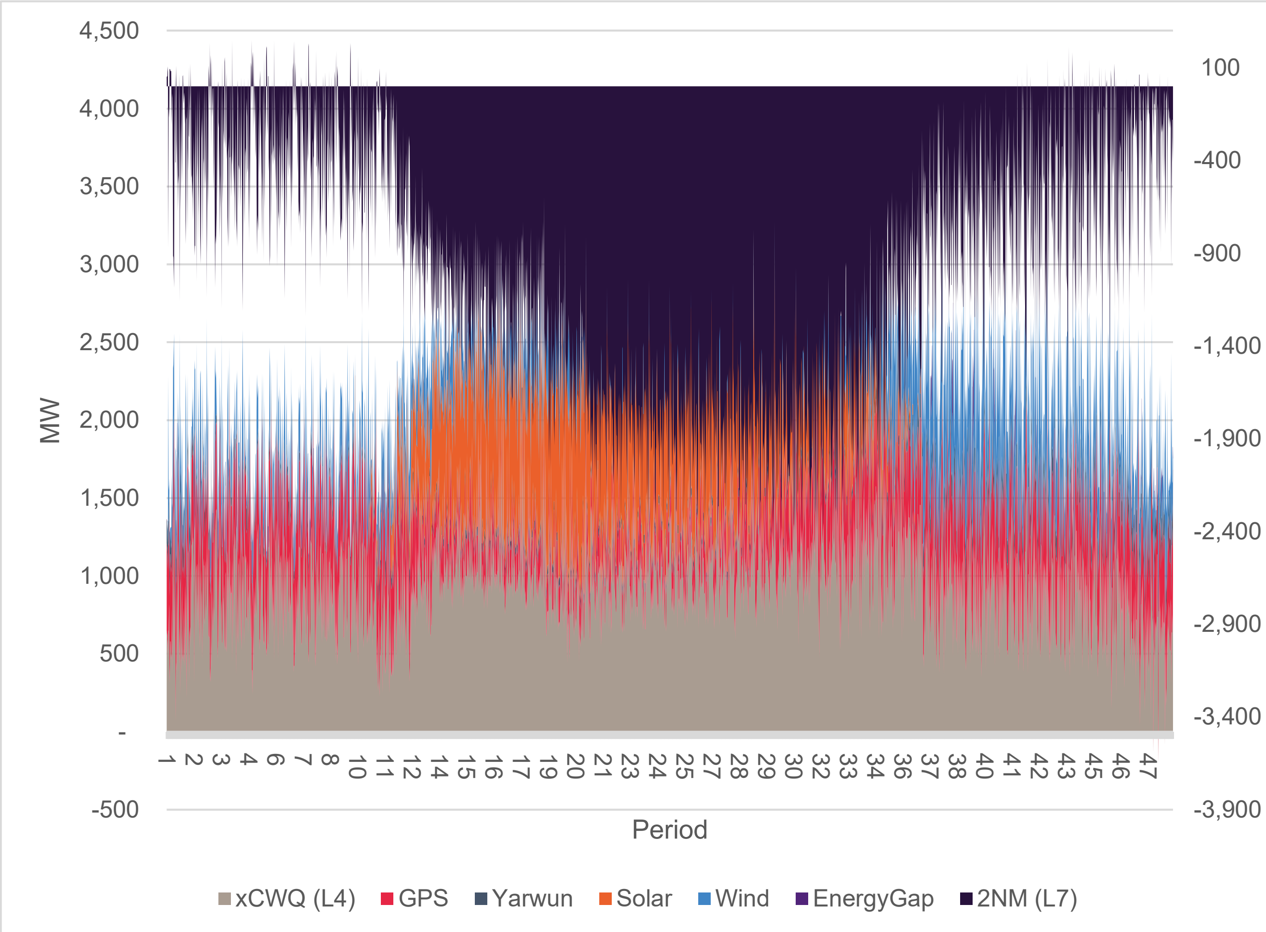


Energy-Gap Statistics and Transmission congestion details			
Max: 181 + 516 MW Median: 0 + 0 MW Capacity Factor: 0%, 0%	Occurs in 22%, 29% of periods >= 129 MW=0% (0%) >= 258 MW=0% (0%) >= 387 MW=0% (0%)	>= 129 MW occurs Evening Peak = 9 (2%) Overnight = 1 (0%) Daytime = 0 (0 %)	Congestion: xCWQ: Day 6%, EvPk 6% 2WB: Day 0%, EvPk 0% 2NM: Day 53%, EvPk 12%

The Energy-Gap in GLAD+WB remains under N transmission conditions, although much smaller than under N-1. The median of all occurrences is 0MW with close to non-extent capacity factor. An Energy-Gap occurs in GLAD in 22% and in WB in 29% of the total 2880 periods of Summer Weekdays. Energy-Gaps of greater than 129MW occur extremely infrequently. Where the Energy-Gap is greater than 129MW in GLAD, 9 incidents (2% of Evening Peak periods) occur. Evidence of congestion on the network from CWQ reduces to 6% during the day and the Evening Peak to 59%. There is notable congestion on the line to NM from WB.

Figure 41 references 2880 points for each energy series in the combined GLAD and WB nodes under augmented N+1 network conditions. Modelling for N+1 assumed augmentation on the lines that experience congestion under N conditions (CWQ-GLAD, WB-NM, and SWQ-SM). Outcomes for Energy-Gap at GLAD, show significant variability in inflows from CWQ and significant variability on the lines from WB to NM, but WB-NM flows are elevated during the day to service PHES pump load.

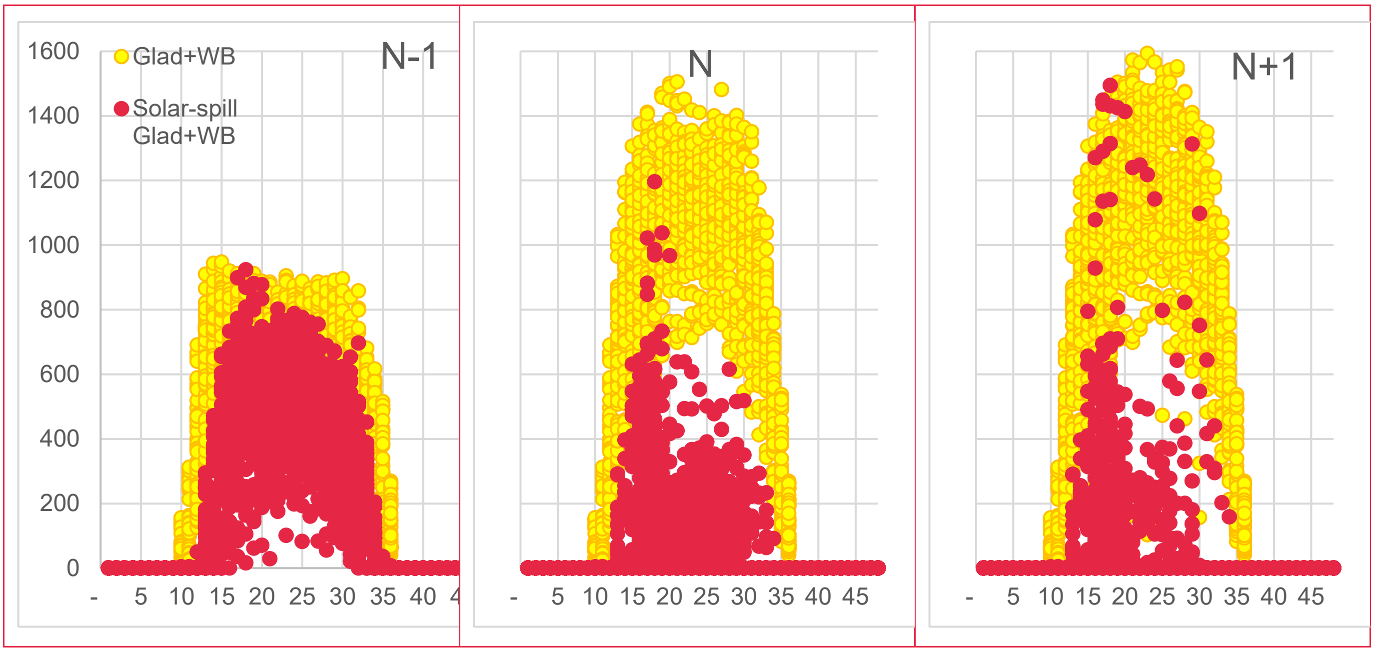
Figure 41: sB GLAD+WB Summer Weekday N+1 Energy-Gap with statistics



Energy-Gap Statistics and Transmission congestion details			
Max: 138 + 516 MW Median: 0 + 0 MW Capacity Factor: 0%, 0%	Occurs in 23%, 37% of periods >= 129 MW=0% (0%) >= 258 MW=0% (0%) >= 387 MW=0% (0%)	>= 129 MW occurs Evening Peak = 9 (2%) Overnight = 1 (0%) Daytime = 0 (0%)	Congestion: xCWQ: Day 1%, EvPk 0.5% 2WB: Day 0%, EvPk 0% 2NM: Day 1%, EvPk 0%

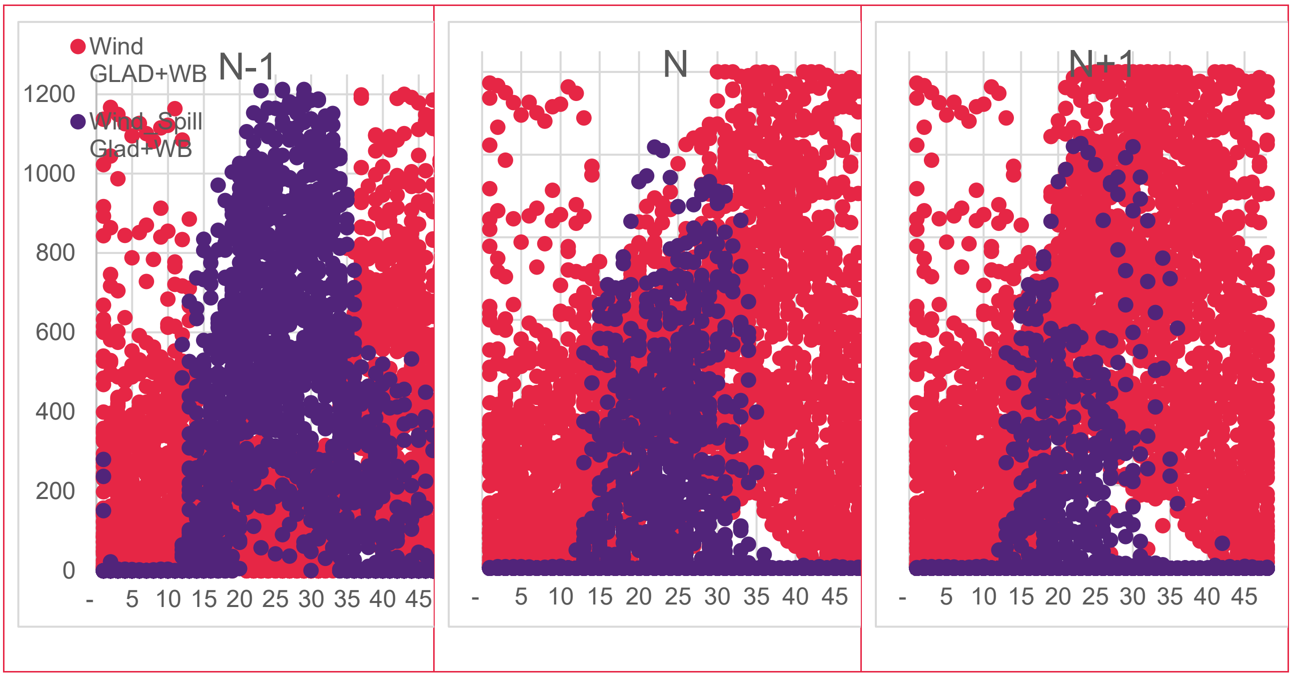
Even under augmented network conditions, the Energy-Gap in GLAD+WB remains, albeit sporadic. The median of all occurrences is 0MW and the capacity factor 0%. An Energy-Gap still occurs in 23% in GLAD and 37% in WB of the total 2880 periods of Summer Weekdays, although Energy-Gaps of greater than 129MW are almost negligible. There is a little evidence of congestion on the transmission line from CWQ, and the WB-NM line.

Figure 42: sB GLAD+WB Solar summer dispatch and spill



sB has 795MW solar power allocated to GLAD and 808MW to WB with 35% spilled under N-1 summer thermal limits. Solar generation and spillage is detailed in Figure 42. Solar spillage declines under N conditions to 9% and under the augmented network to 7%.

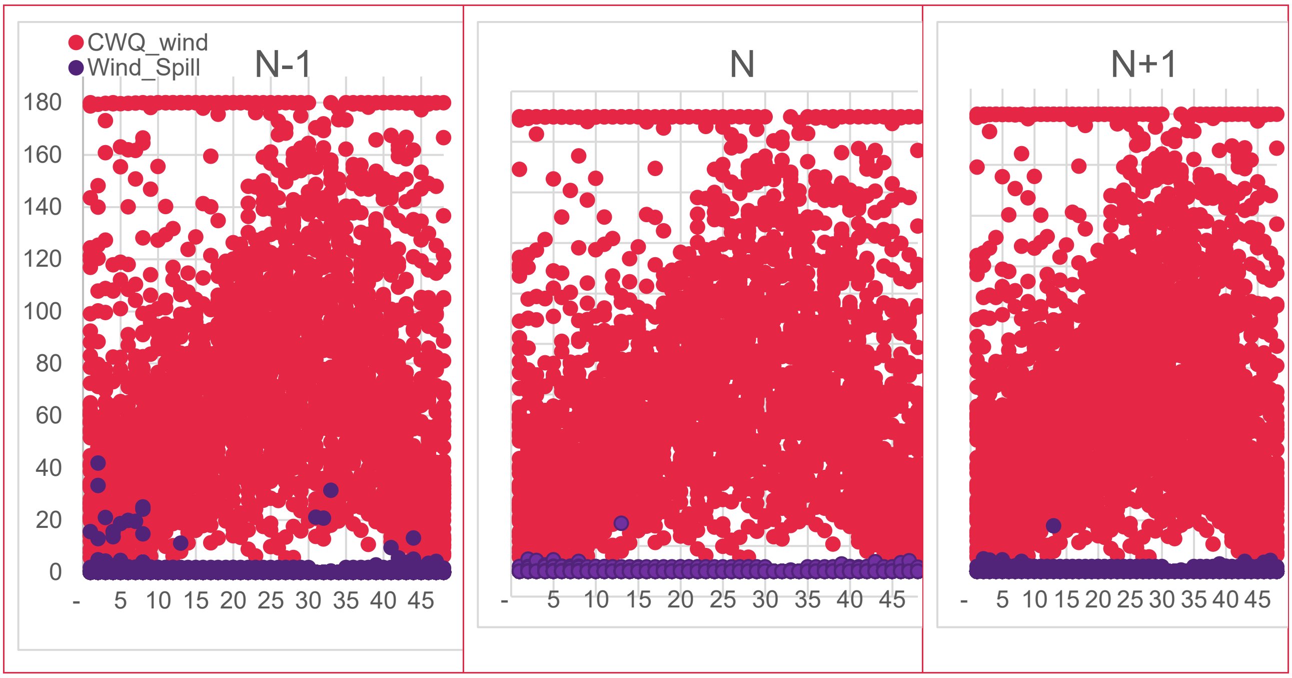
Figure 43; sB WB Wind summer dispatch and spill



sB has 1200MW of wind generation located in WB. Under restrictive N-1 network conditions, 50% of wind is spilled, but this reduces to 14% under N condition and further to 7% under the augmented network. The wind resource in WB appears unreliable from midnight to early morning, which creates some challenges for meeting overnight demand. Figure 43 gives detail.

Figure 44 includes CWQ solar dispatch and spillage as derived for sB. As with the wind resource at WB, there appears to be an unreliable wind resource between midnight and morning peak which will create challenges for meeting overnight demand.

Figure 44: sB CWQ Wind summer dispatch and spill



In summary, modelling indicates that GLAD and WB Energy-Gaps are only of real concern under restrictive N-1 network conditions in sB. Augmenting the network between CWQ-GLAD and WB-NM significantly reduces wind and solar spillage making the increased transmission infrastructure important for stable supply of high levels of VRE.

iv. SWQ Summer Weekdays Energy Balance

Table 27 details the SWQ Energy Balance for Summer Weekdays Evening Peak as modelled in sB. SWQ node hosts 3753MW of thermal generation, 779MW of wind and 2439 of solar generation, providing the bulk of capacity to supply SM+GC demand. There are fair network connections with SM but also connections to TAR and NSW through QNI.

Table 27: sB SWQ Summer Weekdays Evening Peak Energy Balance

South West Queensland Summer Weekdays Evening Peak Ave MW	sB N-1	sB N	sB N+1
Demand	**(1038)**	**(1034)**	**(1035)**
Load	(1018)	(1018)	(1018)
Loss	(19)	(16)	(17)
PHES Pump	(-)	(-)	(-)
Supply - Generation	**2502**	**3211**	**3195**
Coal	1418	1583	1577
Gas	546	1084	1074
Hydro	-	-	-
PHES Dispatch	-	-	-
Solar	144	149	149
Wind	394	395	395
Supply - Network	**(1327)**	**(2015)**	**(1999)**
Exports			
SM	(1082)	(1325)	(1318)
QNI	(833)	(1182)	(1190)
TAR			
Imports			
TAR	588	492	509
ANEM Energy-Gap	**(-)**	**(-)**	**(-)**
Balance	137	162	161
SWQ Spillage	**(5)**	**(-)**	**(-)**
Solar	(4)	(-)	(-)
Wind	(1)	(-)	(-)

Energy-Gap statistics for Summer Weekdays show that under restrictive N-1 conditions, maximum Energy-Gap is 23MW and the median Energy-Gap is 0MW but fairly persistent, occurring during 835 periods (29%) of Summer Weekdays. An Energy-Gap of greater than 6MW emerges in 0.1% of Overnight, Evening Peak and Daytime periods.

Without restrictions, under N and augmented network conditions, Energy-Gaps disappear.

Energy-Gap statistics and transmission congestion details are provided in Table 28.

Table 28: sB SWQ Energy-Gap Statistics and Transmission congestion details

Energy-Gap incidence during Summer Weekday periods	N-1	N	N+1
Max capacity (MW)	23	-	-
Median capacity (MW)	0	-	-
Capacity factor (%)	0%	-	-
Count of EGs: All	29%		
• EG >= 25%Max	6MW (0.1%)		
• EG >= 50%Max	12MW (0.1%)		
• EG >= 75%Max	17MW (0.1%)		
Where EG >= occurs in % of	6MW		
• Evening Peak	0.2%		
• Overnight	0%		
• Daytime	0.2%		
TRANSMISSION CONGESTION			
SWQ-SM			
• Daytime	82%	0.6%	
• Evening Peak	68%	-	
QNI	-	-	-
TAR	-	-	-

There is little concern with Energy-Gap in SWQ as modelled in sB.

v. CWQ Summer Weekdays Energy Balance

Table 29 details the CWQ Energy Balance for Summer Weekdays Evening Peak as modelled in sB. CWQ node has 1596MW of thermal, 180 MW of wind and 943MW of solar generation, and thus the bulk of generation capacity to supply Gladstone and Central Queensland demand. There are fair network connections with TAR but connections to GLAD under restricted N-1 conditions are inadequate to supply GLAD without GPS in operation.

Table 29: sB CWQ Summer Weekdays Evening Peak Energy Balance

Central West Queensland Summer Weekdays Evening Peak Ave MW	sB N-1		sB N		sB N+1	
Demand	**(552)**		**(583)**		**(590)**	
Load		(531)		(531)		(531)
Loss		(22)		(53)		(60)
PHES Pump		(-)		(-)		(-)
Supply - Generation	**1680**		**1753**		**1781**	
Coal		1443		1509		1536
Gas		18		24		25
Hydro		-		-		-
PHES Dispatch		-		-		-
Solar		141		141		141
Wind		79		79		79
Supply - Network	**(936)**		**(985)**		**(1017)**	
Exports						
GLAD		(937)		(1011)		(1034)
TAR		(409)		(495)		(534)
NQ		(14)		(66)		(66)
Imports						
NQ		422		587		617
ANEM Energy-Gap	(-)		(-)		(-)	
Balance		**192**		**185**		**174**
CWQ Spillage	**(1)**		**(-)**		**(-)**	
Solar		(1)		(-)		(-)
Wind		(-)		(-)		(-)

Energy-Gap statistics for Summer Weekdays are included in Table 30 and show that under restrictive N-1 conditions, maximum Energy-Gap is 721MW with a median Energy-Gap of 0MW. Small and fairly persistent Energy-Gaps occur during 1877 periods (38%) of Summer Weekdays. An Energy-Gap of greater than 180MW becomes evident in 0.2% of Evening Peak periods.

Without restrictions, under N conditions, there is little evidence of Energy-Gaps.

Table 30: sB CWQ Energy-Gap Statistics and Transmission congestion details

Energy-Gap incidence during Summer Weekday periods	N-1	N	N+1
Max capacity (MW)	721	-	-
Median capacity (MW)	0	-	-
Capacity factor (%)	0%	-	-
Count of EGs: All	38%		
• EG >= 25%Max	180MW (0.1%)		
• EG >= 50%Max	360MW (0.1%)		
• EG >= 75%Max	540MW (0.1%)		
Where EG >= occurs in % of	180MW		
• Evening Peak	0.2%		
• Overnight	-%		
• Daytime	0.2%		
TRANSMISSION CONGESTION			
CWQ-GLAD			
• Daytime	86%	6%	
• Evening Peak	63%	6%	
CWQ-TAR			
• Daytime	-	-	-
• Evening Peak	-	-	-
NQ-CWQ			
• Daytime	-	-	-
• Evening Peak	-	-	-

vi. NQ Summer Weekdays Energy Balance

Table 31 details the NQ Energy Balance for Summer Weekdays Evening Peak as modelled in sB. NQ node has no thermal generation but includes 1020MW Urannah PHES for storing surplus energy to dispatch at peak demand, 799MW of wind and 1027MW of solar generation. There are reasonable network connections with ROSS and CWQ.

Table 31: sB NQ Summer Weekdays Evening Peak Energy Balance

North Queensland Summer Weekdays Evening Peak Ave MW	sB N-1		sB N		sB N+1	
Demand	**(628)**		**(635)**		**(638)**	
Load		(415)		(415)		(415)
Loss		(9)		(16)		(19)
PHES Pump		(204)		(204)		(204)
Supply - Generation	**955**		**918**		**920**	
Coal		-		-		-
Gas		-		-		-
Hydro		-		-		-
PHES Dispatch		473		474		437
Solar		139		139		139
Wind		343		345		345
Supply - Network	**(339)**		**(347)**		**(356)**	
Exports						
CWQ		(422)		(587)		(617)
ROSS		(108)		(74)		(72)
Imports						
ROSS		177		248		267
CWQ		14		66		66
ANEM Energy-Gap Balance	**(64)**	**(12)**	**(116)**	**(64)**	**(124)**	**(74)**
NQ Spillage	**(2)**		**(-)**		**(-)**	
Solar		(-)		(-)		(-)
Wind		(2)		(-)		(-)

The Energy-Gap in NQ as detailed in Table 32 is directly related to PHES pump load. With only solar and wind generation located in NQ in sB, pump load after dark when wind resources are reduced, will result in an energy deficit of approximately 1GW. Under N there are 459 periods when the energy deficit is 1000MW or greater, and 933 periods when an Energy-Gap of greater than 50MW is evident. 50% of overnight periods have an Energy-Gap of greater than 277MW, 1% of daytime periods and 8% of Evening Peak periods. With 933 periods with an Energy-Gap of greater than 50MW, the Energy-Gap is relatively persistent. Urannah PHES is assumed to have a relatively small upper reservoir providing storage capacity of around 10GWh which is smaller compared to that assumed for Mt Byron of 50GWh. With a sizeable 1020MW capacity and energy requirements for 7-8 hours of dispatch, there is insufficient VRE resources in NQ for a plant of this size. It provides further evidence of the complexities of PHES pumping and discharge modelling assumptions, but also the complexities of developing a strategy for PHES management that does not increase demand and create energy deficits.

Table 32: sB NQ Energy-Gap Statistics and Transmission congestion details

Energy-Gap incidence during Summer Weekday periods	N-1	N	N+1
Max capacity (MW)	1110	1110	1110
Median capacity (MW)	0	0	0
Capacity factor (%)	19%	20%	20%
Count of EGs: All	72%	77%	77%
• EG >=25%Max	277MW (22%)	277MW (21%)	277MW (21%)
• EG >= 50%Max	555MW (18%)	555MW (19%)	555MW (19%)
• EG >= 75%Max	832MW (14%)	832MW (17%)	832MW (18%)
Where EG >= occurs in % of	277MW	277MW	299MW
• Evening Peak	5%	8%	8%
• Overnight	56%	50%	50%
• Daytime	0%	1%	2%
TRANSMISSION CONGESTION			
NQ-CWQ	-	-	-

vii. Conclusions on energy generation adequacy in sB

sB reduces coal generation by 3220MW from current levels. It replaces this generation with 4820MW of wind and 8736MW solar. Both wind and solar projects are fairly equally distributed across the nodes except for a preference for WB for wind generation with 25% of the total and for SWQ for solar generation with 28% of the total. Dispersed VRE and coal generation across the nodes provides more stable energy supply and smaller energy deficits than in 2040C. Large solar generation also assists with supply to PHES pumping to supply Evening Peak.

Analysis of Queensland's Energy Balance over the full 2880 periods of Summer Weekdays under N network conditions, shows a tendency to higher Energy-Gaps during periods of low wind availability. To illustrate this, low wind is compared to Energy Gap in Figure 45 for sB under N conditions. The 7 periods of highest Energy-Gap are within periods when co-incident wind across the state is less than 526MW, 10.9% of wind nameplate capacity.

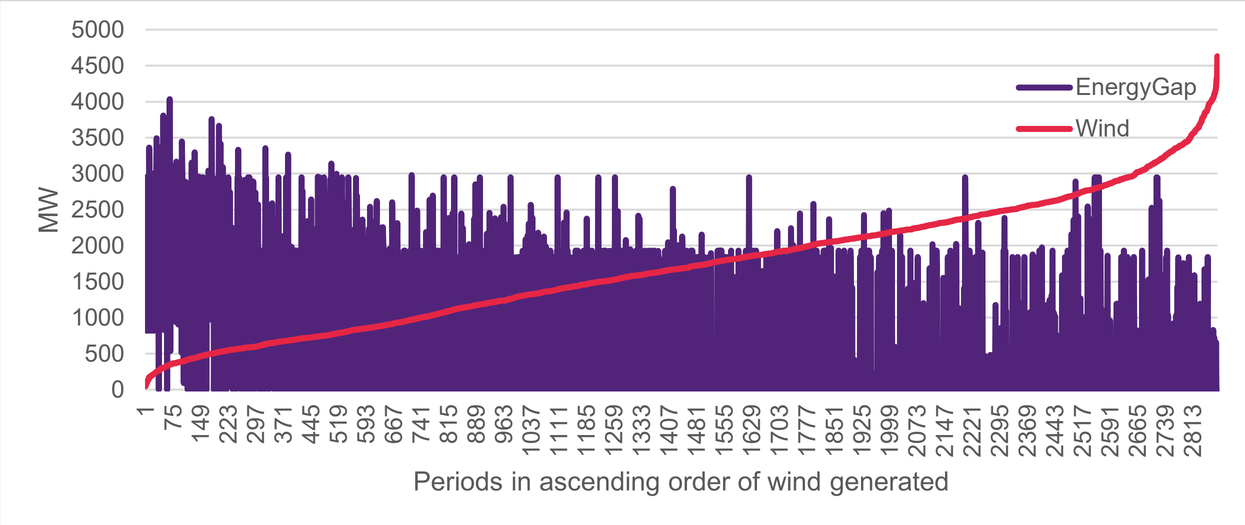


Figure 45: sB N Queensland comparison of low wind to Energy-Gap periods during Summer Weekdays

Unlike 2040C where large Energy-Gaps corresponded with early Evening Peak periods, modelling outcomes for sB indicate that the largest Energy-Gaps are associated with night pump loads because solar is non-existent and there is insufficient alternative generation to sustain pump loads.

Incidences of lower than 400MW of wind generation were analysed for consequences. In total, 107 incidences occurred on 21 days, with periods of low wind extending from 7 hours in a day to half an hour in a day. The events occurred between period 43 (9:30pm) and 13 (6:30am). Period 5 recorded the most frequent occurrence of less than 400MW of wind generation (10) but periods 1-5 also experienced frequent occurrence (7-9) combined with the seven lowest wind generation (46-129MW) for Summer Weekdays. This is in contrast to the low wind conditions indicated in 2040C, and is indicative of the regional variation in wind capacity assumed in the two scenarios.

Table 33: sB N 7 periods of highest co-incident Energy-Gap during Summer Weekdays

Energy-Gap	Max	4034MW	3806MW	3759MW	3665MW	3493MW	3446MW	3414MW
Period		41-48	41-47	11-48	10-48	346-48	42-1	42-48
Load	**-10489**	-7824	-8090	-7729	-7664	-7174	-7593	-7376
PHES Pu	**-2760**	-2420	-1840	-2420	-2420	-2420	-2080	-2420
Coal	**4839**	4839	4839	4839	4839	4839	4839	4839
Gas	**2624**	2624	2624	2624	2624	2624	2624	2624
Wind	**4630**	346	301	500	522	245	393	526
Solar	**8115**	-	-	-	-	-	-	-
QNI	**-2557**	-1063	-1085	-1060	-1053	-1063	-1078	-1063
DL	**180**	180	180	180	180	180	180	180
Spill_W	-1646	-	-	-	-	-3	-4	-
Spill_S	-5078	-	-	-	-	-	-	-

Table 33 provides further detail on the periods with the 7 largest co-incident Energy-Gaps during Summer Weekdays. All of these periods fall between 23:30 and 00:30 when load is elevated coupled with some PHES pumping. Coal and gas generation is generally at capacity, solar generation is non-existent, and wind provides little supply to the state demand. Similar conditions will be present in NSW because flows to QNI continue. Thus for sB, too little wind generation at night, creates the largest Energy-Gaps.

Figure 46 represents the energy flows for all Queensland nodes as modelled for sB under N transmission conditions for all Summer Weekdays. Cumulative native load, losses, PHES pump load and exports through QNI are represented as negative flows while generation, PHES dispatch and imports are depicted as positive flows. Energy flowing from Energy-Gap is shown as a positive flow. Coal generation forms the foundation of the energy flows with the other sources contributing as possible under transmission capacities. The effect of PHES pump load on total demand is evident and the ongoing flow of energy to NSW despite Energy-Gaps within Queensland. Forthcoming analysis of NSW Energy-Gaps will contribute to better understanding of the nature of Energy-Gaps throughout the NEM and their impact on Queensland supply-demand balance.

Comparing Queensland energy flows in sB to 2040C, shows a smaller contribution of PHES dispatch and the gas generators at SWQ node to meet Summer Evening Peak demand. The Energy-Gap is still evident although not as sustained over the full 24 hour periods as evident in 2040C. Also, there is less contribution to meeting demand from wind capacity in sB which creates the Energy-Gap in sB as evidenced in the periods where the largest Energy-Gaps occur, detailed in Table 33.

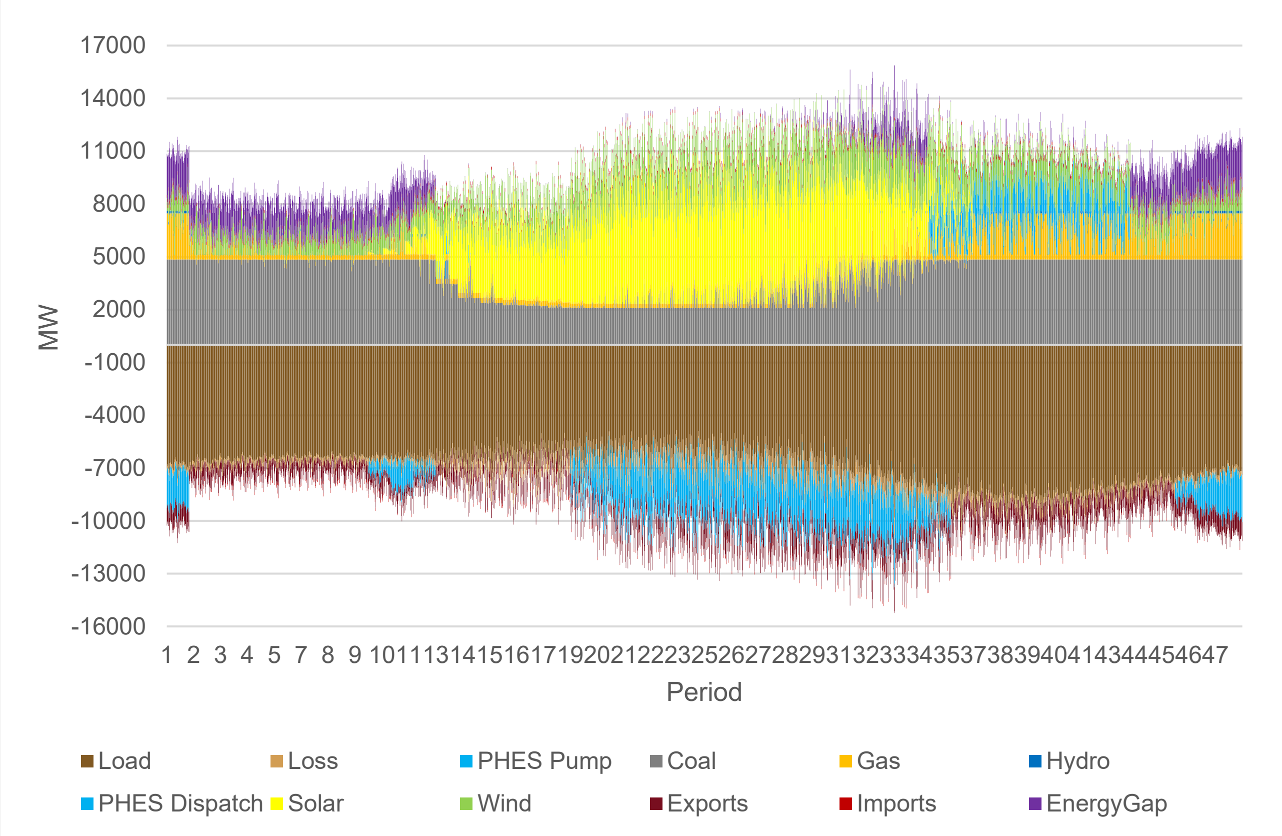


Figure 46: Queensland Summer Weekdays Energy Flows sB N

Finally, the Energy Balance as detailed in Tables 19 and 20 and the details in this sub-section suggest that even with large additions of wind and solar, a state-wide persistent Energy-Gap exists, although not as large as the Energy-Gaps under 2040C.

5. Energy transmission adequacy

Modelling of the different scenarios indicates the adequacy of the transmission network to facilitate the flow of energy from renewable energy generation locations to demand centres. Table 34 provides detail on the congestion predicted from the high renewable energy scenarios 2040C and sB.

Table 34: Transmission congestion hotspots: 2040C vs sB

Scenario	Line	Time	N-1 Congestion	N Congestion	N+1 Congestion
2040C	CWQ-GLAD	Summer WD Ave	80% 68%	35% 26%	8% 5%
	WB-NM	Summer WD Ave	40% 24%	0.3% -	- -
	SWQ-SM	Summer WD Ave	76% 59%	3% 1%	- -
	GC-DL	Summer WD Ave	59% 46%	26% 25%	25% 25%
sB	CWQ-GLAD	Summer WD Ave	54% 38%	4% 3%	0.5% 0.1%
	WB-NM	Summer WD Ave	53% 36%	25% 14%	0.4% 0.1%
	SWQ-SM	Summer WD Ave	57% 36%	0.2% -%	- -
	GC-DL	Summer WD Ave	53% 42%	48% 36%	49% 36%

In summary, 2040C with total closure of GPS, addition of 515MW of solar at GLAD and 500MW of solar at WB, predicts significant congestion on the CWQ-GLAD transmission line due to the large flows of energy required to serve Gladstone (and WB) demand. Even under an augmented transmission scenario, evidence remains of congestion on that line. With only a partial closure of GPS and greater wind and solar in GLAD and WB, sB predicts lower congestion on the CWQ-GLAD transmission line, but also predicts ongoing albeit small levels of congestion on the line under augmentation.

2040C includes only 500MW of solar in WB but sB includes 808MW of solar and 1200MW of wind in the WB node, which highlights the network limitations from WB-NM. Even under augmented N+1 conditions, small levels of congestion are evident on this line.

Modelling indicates heavy congestion on SWQ-SM transmission lines under restricted N-1 conditions, and some congestion under N conditions. As SWQ becomes a significant REZ by AEMO, and the source of the majority of energy for SM, it is prudent to augment this line for high VRE assumptions.

Under all scenarios, the GC-DL line shows significant congestion. The congestion is a factor of restricted energy supply from SM node. Where energy deficits are evident from SM to GC, then GC becomes reliant on energy flows from NSW. As modelling predicts Energy-Gaps in SM when wind resource declines, it would be prudent to augment GC transmission capacity to NSW to ensure energy security for the Gold Coast.

6. Marginal loss factors

The ANEM model and outputs allow the derivation of marginal losses for each node in the model. The detail of modelling marginal losses is included in the Final Report on Electricity Market Modelling Project (Wild, 2020), a report that should be read in conjunction with this report. Marginal losses and marginal loss factors as determined through the modelling are derived by node and therefore not directly comparable to AEMO's reported marginal loss factors (MLF)(AEMO, 2020b). However, AEMO's MLFs, averaged across the nodes, provides a high-level comparison with the MLFs derived for this report.

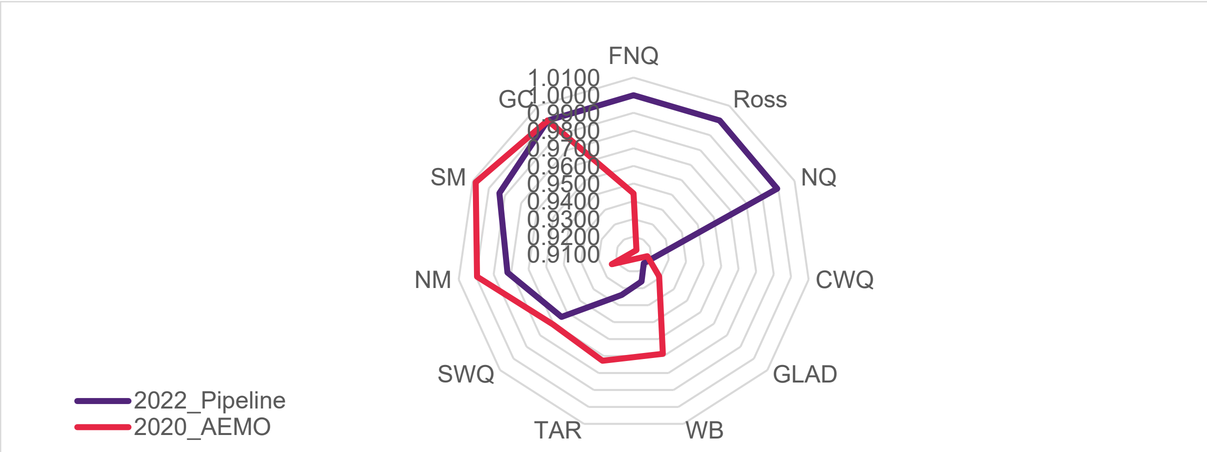


Figure 47: 2022 Pipeline N-1 versus AEMO 2020-21 MLFs

Figure 47 shows the MLFs as derived by the ANEM model for the year 2022 (effectively existing generation plus VRE projects which have financial closure) and the MLFS as reported by AEMO for 2020-21. The primary difference between the 2 estimations is in the northern nodes of FNQ, Ross and NQ. This is as a result of energy modelled as predominantly flowing northwards to FNQ, Ross and NQ and thus typically incurring lower marginal losses than if energy had flowed southwards. (The southern flows are more a feature of AEMO estimations and reflect the inconsistencies of estimating MLFs from zonal regional reference node models.

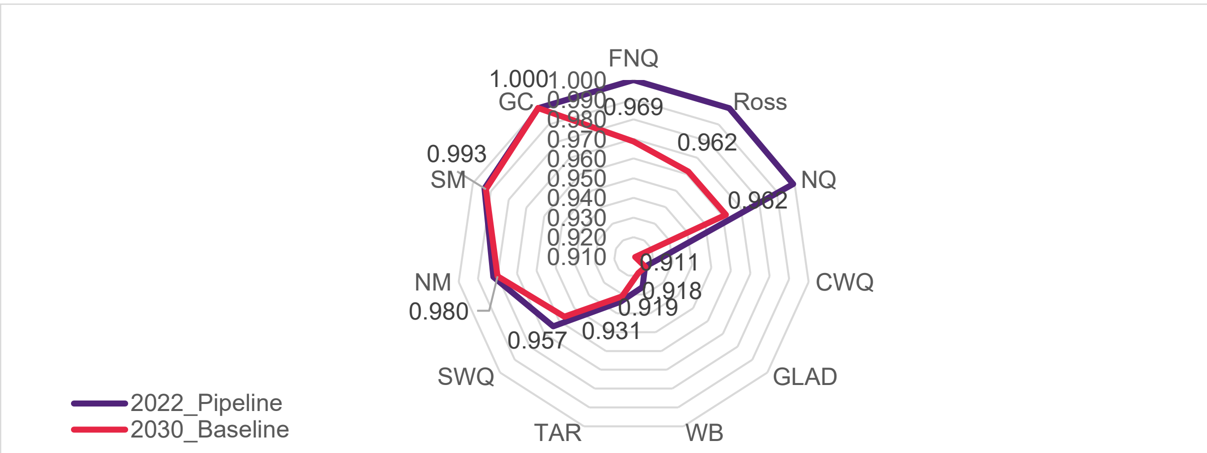


Figure 48: 2022 Pipeline N-1 versus 2030 Pipeline N-1

Figure 48 shows the MLFs as derived by the ANEM model for the year 2030 with the Pipeline of investments in solar and wind power. Energy flows indicate that MLFs will adjust in the northern nodes to reflect energy flowing southwards. However, further analysis should be conducted on these energy flows as they will be dependent on PHES pump load in the NQ node, which may vary significantly depending on PHES load modelling assumptions.

Further analysis is provided in Figure 49 which details the MLFs projected for sB, the scenario that achieves the highest dispatch of renewable energy, compared to the MLFs projected for the Pipeline Baseline scenario. Higher dispatch of renewable energy under sB indicates increasing southward energy flows and thus higher marginal losses in the northern nodes.

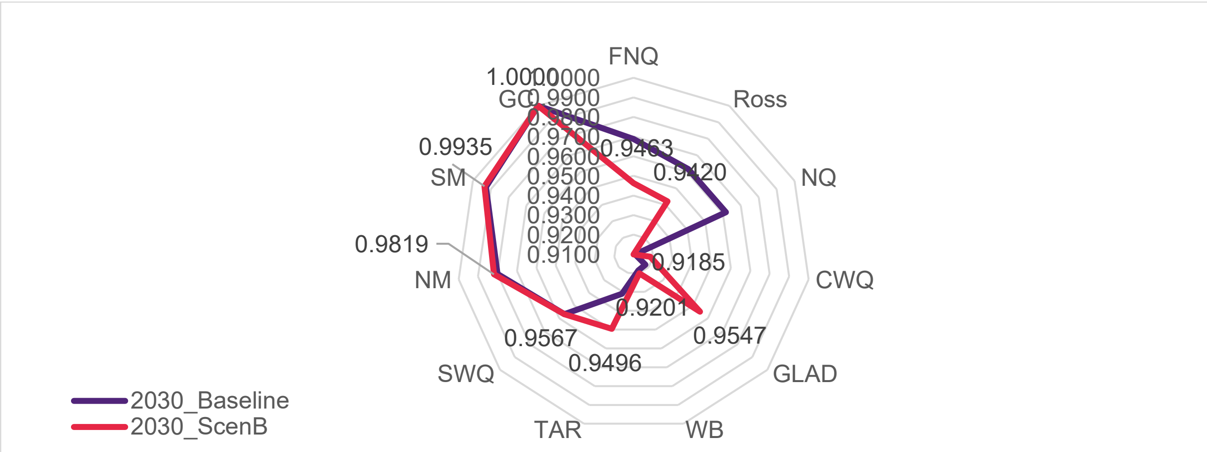


Figure 49: 2030 Pipeline N-1 versus scenario B N-1

Transition plans to high levels of renewable energy therefore need to predict potential changes to MLFs, so that investment decisions are informed by the best available assumptions underpinning plans.

7. Policy framework to facilitate contingency plan

Energy policy in Australia has fragmented over the last decade. Any policy framework to succeed in deploying high levels of VRE needs to clarify for investors the plans that government and the NEM governing bodies have for facilitating investment and achievement of targets. The scaffolding of the framework therefore needs to be composed of clear communication of plans and strategies.

a. Plan for and communicate coal generator closure

The first message on Queensland electricity supply needs to be that in order to meet QRET, there will have to be a reduction in generation from coal generators. The closure of coal-plant creates challenges for the large demand centres, for workers and for communities where coal generators are located. The second message needs to reference good research that supports closure plans, informed by modelling of different combinations of coal unit closures for supply stability. Findings from this report, that indicate greater stability in supply if closures are applied across several nodes, can be a starting point for discussion.

A policy of staggered unit closure at power stations will also facilitate a managed transition for employees and communities.

Announcement of staggered unit closure at power stations will facilitate the planning for VRE and storage investors, to take up supply from retiring coal units.

b. Plan for and communicate transmission requirements to facilitate roll-out of VRE

Queensland investors in VRE and storage need to be secure in the knowledge that the transmission infrastructure will facilitate the dispatch of a high proportion of VRE. A clear plan of augmentations planned to meet QRET should be available to the public. Findings from this roadmap report could inform initial plans. Augmentation of the transmission network between CWQ-GLAD will be crucial for secure supply of VRE to GLAD. Augmentation of the transmission network between WB-NM will be instrumental in successful supply of VRE from the WB area. Augmentation of the transmission network between SWQ-SM will underpin the creation of a large VRE REZ in SWQ. Providing transmission roadmaps to meet QRET will facilitate investment in VRE and storage.

Fast tracking augmentation to transmission infrastructure to increase dispatch of VRE and reduce the Energy-Gap, can be achieved through recommendations proposed by Garnaut (2019), including but not limited to encouraging private investment in transmission infrastructure.

c. Gather good data on wind resource across the state

Without good quality information on the quality of wind and solar resources around the state, it is time consuming for investors to gather adequate data to support proposals. If investors do gather data at their cost, this information will not be publicly available to other investors nor policy makers for determining requirements for a managed transition to high levels of VRE. Inasmuch as Queensland conducted geological surveys into coal and other mineral resources in the 1960s and 1970s to attract investors from Japan and elsewhere, it is similarly good practice to conduct surveys and gather data on the wind and solar resource across the state, to attract local and international investors.

d. Preference solar generation for PHES storage

Solar resource in Queensland is more predictable than wind resource, which modelling here suggests makes for more stable supply of energy for PHES daytime pumping. As found by modelling sB, higher levels of solar generation than that included in 2040C, provided greater stability for supply to large demand loads. Wind is important too, but there is benefit from a reasonable expectation of when generation will be available for storage charging. However, there is a need to investigate more fully wind and solar resource yields especially from the perspective of providing energy for PHES pumping during day and night-time (from solar and wind) as well as energy during morning and especially evening peak.

e. Plan in detail for PHES requirements

The Energy-Gaps that become evident from the modelling for this report indicate that higher levels of additional storage than the 2.3GW modelled are required. Potential PHES locations need to be examined, with consideration of co-location with solar resources, but also located within strong network corridors to the large demand nodes of NM, SM and GLAD.

f. With high levels of wind generation, plan for reserve capacity

Although wind generation is forecast to experience higher capacity factors than solar generation it is less predictable than solar generation. The wind resources in Queensland appear to be unreliable at important periods like the start of Evening Peak in SEQ and between midnight and dawn in CWQ. Short periods of low wind resource are associated with very high Energy-Gaps, which creates challenges for encouraging investment because of potentially low and infrequent revenue returns. Serious consideration needs to be given to reserve capacity where large wind farms are located and required for supply to large demand nodes.

g. Where large sporadic Energy-Gaps are probable, plan for investment or ownership models

Ownership structures for both PHES and reserve capacity need to be investigated, as the infrequency associated with dispatch makes for challenging investment models. Perhaps control of PHES and reserve capacity could be awarded to one of the state owned generation or network entities, tasked with securing supply. In Germany, where large proportions of VRE already supply to the German and European market, Transmission System Operators shoulder much of the responsibility for energy security.

h. Build a bridge with essential entities

Achieving QRET will require coordinated effort from the Queensland Government, the Queensland generators, Powerlink, AEMO, AEMC and investors. The Queensland Government can direct its state owned electricity supply entities to follow a prescribed plan in an attempt to achieve QRET or higher targets, but divergent actions by the NEM governing bodies can scupper the best of plans. AEMO’s actions affect investment through unpredictable changes to MLFs, and Integrated System Plans that do not reflect the complexities and uncertainties of commissioning and being able to connect and dispatch to the grid. The AEMC’s rule changes are too slow to accommodate a fast transition to QRET. There is a need for a joint collaborative body tasked with developing a roadmap to achieve QRET, comprised of investor groups, AEMO, AEMC, Powerlink, Queensland generators and the Queensland Government. Roadmaps developed by this collaborative body would give greater security to investors, and the Queensland public, of the achievement of high levels of VRE in Queensland electricity supply.

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