Office of Energy and Climate Change

Lulls in variable renewable energy sources

Information paper

Acknowledgement of Country

The Office of Energy and Climate Change acknowledges that it stands on Aboriginal land. We acknowledge the Traditional Custodians of the land and we show our respect for Elders past, present and emerging through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places in which Aboriginal people are included socially, culturally and economically.

Published by Office of Energy and Climate Change

Lulls in variable renewable energy sources

First published: February 2023

ISBN: 978-1-923018-51-8

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Summary

Executive Summary

As the share of variable renewable energy (VRE) in the NSW electricity system increases, the impact of weather patterns will become increasingly important. Periods of extended low output of wind and solar generation – lulls – will have reliability implications for electricity supply, and will need to be considered in long term planning.

In recognition of this matter, the *Electricity Infrastructure Investment Act* 2020 (EII Act) regulations require that the Infrastructure Investment Objectives (IIO) report includes an assessment of the resilience of the NSW electricity system in relation to lulls in variable renewable energy sources, as it relates to the development pathway in the report including by reference to climate modelling [Regs 24 (2)(e)]. This work has investigated the characteristics of lulls in NSW in order to determine key areas of focus in future planning.

Further to this, AEMO is currently using 10 weather years, from 2011-2020 inclusive, for system reliability and planning forecasting in the Electricity Statement of Opportunities (ESOO) and the Integrated System Plan (ISP) respectively. There is a desire to understand whether this dataset is sufficient in length to fully understand the possible system risk arising from lulls. To address this matter, the Office of Energy and Climate Change (the Office) worked with Climate Change Research Centre at the University of New South Wales (UNSW) to investigate how lulls in the period 2011 – 2020 inclusive compare with lulls over the period from 1979 – 2020 inclusive.

This work found that there were measurable but not substantial differences in overall weather patterns – the average duration and frequency of lulls in both the long and short datasets were similar. However, there were some rare events that were not captured in the short dataset. In particular, the maximum lull duration found in some Renewable Energy Zones (REZs) was significantly higher in the long dataset, but these extended lulls were rarely concurrent with other REZs, highlighting the value of geographic diversity.

When examining broad patterns, it was clear both datasets demonstrated the same seasonal patterns, with both wind and solar lulls peaking in and around June. When investigating patterns over the long duration, there were no obvious changes in weather patterns over multiple decades.

The findings from this work have been incorporated into the IIO modelling as they address the legislative requirements regarding electricity system resilience. The field of climate change and electricity system resilience is still in its infancy and there are opportunities for additional work to further strengthen the IIO modelling. These would include expanding this work to cover all National Electricity Market (NEM) regions, studying periods of climate extremes such as the current triple La Niña, individual extreme events, and examining the predictability of lulls.

Contents

Shortened forms

Term	Meaning
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ASL	AEMO Services Limited
CT	Consumer Trustee
CWL-SL	Combined Wind Lull and Solar Lull
EII Act	*Electricity Infrastructure Investment Act 2020*
EnergyCo	Energy Corporation of NSW, appointed as the Infrastructure Planner under the EII Act
ESOO	Electricity Statement of Opportunities
IIO Report	Infrastructure Investment Objectives Report
ISP	Integrated System Plan
LDS	Long Duration Storage
LTESA	Long-term Energy Service Agreement
OECC	Office of Energy and Climate Change within NSW Treasury
REZ	Renewable Energy Zone
SL	Solar Lull
SSRD	Surface solar radiation downward
UNSW	University of New South Wales Climate Change Research Centre
VRE	Variable Renewable Energy
WL	Wind Lull
WS	Wind Speed

Background

Report Context

This work aims to investigate the characteristics of wind and solar lulls, given their potential impacts on the design and operation of the electricity system in NSW as the share of wind and solar generation increases. Characterising these lulls helps decision-makers to work out where potential vulnerabilities may exist, and plan to address them to ensure secure, reliable and affordable electricity supply for NSW consumers.

The Electricity Infrastructure Investment Act (EII Act) regulations require that the Infrastructure Investment Objectives (IIO) report includes an assessment of the resilience of the NSW electricity system in relation to lulls in variable renewable energy sources, as it relates to the development pathway in the report including by reference to climate modelling [Regs 24 (2)(e)].

Introduction

There is a global aim to deliver sustainable, secure, and reliable electricity at low cost to electricity consumers. Technological advancements and increasing fuel costs have meant that wind and solar generation capacity, firmed by storage capacity, is now the lowest cost electricity system solution[1]. Since wind and solar resources are variable, a key question to address is: what capacity and duration of storage is necessary to provide firming for variable renewable energy (VRE)? Further to this is the question of whether there will be enough generation at times of peak demand, such as our hottest summer days. This will be highly dependent on the frequency and duration of events when wind and solar resources are not delivering much power.

The Australian electricity system is undergoing the fastest transition from dispatchable coal power to VRE generation capacity in the world[2]. Further to this, the state of New South Wales (NSW), for which almost 70% of its electricity production came from coal-fired generation in 2021[3], is expecting four out of its five coal plants to close by 2033[4]. This increases the urgency in understanding the probability and duration of periods of exceptionally low wind and solar output, since this will have a significant impact on the infrastructure constructed to replace retiring coal generators.

The initial priority of this work is to characterise these lulls. The impact of these low output periods, or lulls, is dependent on their duration, and has significant implications for the design of policy, and

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[1] AEMO 2022 ISP report https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

[2] As above

[3] As calculated from https://www.energy.gov.au/publications/australian-energy-statistics-table-o-electricity-generation-fuel-type-2020-21-and-2021

[4] https://www.energy.nsw.gov.au/sites/default/files/2020-12/NSW%20Electricity%20Infrastructure%20Roadmap%20-%20Detailed%20Report.pdf

investment decisions, to mitigate their impacts. Short-lived lulls can be mitigated by geographically diversified generation and shallow storage. Lulls that are less than 24 hours in length can be mitigated through intra-day load shifting, though medium storage and demand management, among other strategies. However, when lulls extend beyond 24 hours, deep storage may be necessary. Given that deep storage options, such as pumped hydro, are capital intensive, have significant lead times, and face uncertain long-term revenues, it is prudent to minimise the capacity built to reduce total system costs passed onto electricity consumers. Gaining a good understanding of the probability and duration of combined wind and solar lulls will help to ensure that there is no expensive overbuild of deep storage, or an under build of deep storage that puts electricity supply at risk.

The second aim of this work is to establish if there is significant value in using an extended dataset to characterise lulls, given the possibility of changing weather patterns as a result of climate change. The Australian Energy Market Operator (AEMO) currently uses weather and renewable resource data from 2011 to 2020 as reference years in modelling to inform its planning and reporting[5]. While this multi-year dataset is preferable to the use of a single year, a period of 10 years could have limitations as a reliable analysis of the occurrence of lulls. Firstly, the climate variables determining renewable energy production are subject to large interdecadal variability that might not be captured by a dataset spanning 10 years. Secondly, lulls, defined by the far low tail of wind speed/solar radiation distributions, occur only a fraction of the time with their joint occurrence being even less frequent. As such, the sample size for their joint occurrence over a ten-year period may not be sufficient. Therefore, it is important to investigate whether the shorter period is representative of the longer-term occurrences of wind and solar lulls. In a changing climate, historical data may not capture the full extent of possible extremes, but nevertheless provides a solid basis to work from and helps indicate possible future areas of concern.

The Office of Energy and Climate Change (OECC) worked with AEMO Services Ltd (as the NSW Consumer Trustee) to commission UNSW to examine weather data covering the period 1979 - 2020 for the occurrence of wind, solar and combined wind and solar lulls. This report contains comparisons of the occurrence of wind lulls, solar lulls and combined wind and solar lulls in NSW Renewable Energy Zones (REZs) over the period 1979 – 2020 and the shorter period 2011 – 2020, with reference to data provided by UNSW Sydney’s Climate Change Research Centre.

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[5] https://aemo.com.au/-/media/files/major-publications/isp/2021/2021-inputs-assumptions-and-scenarios-report.pdf?la=en

Characteristics of Lulls

Definition of a Lull

The study of wind and solar weather data as applicable to renewable energy generation is continuing to develop. While the concept of an extended period of low wind or solar supply is not new, there is not yet a clear, broadly accepted method for threshold setting. The two dominant options are to use a fixed value threshold or to use a calculated threshold; both cases have their strengths and weaknesses.

In the case of a fixed threshold, the selected cut-off value can be challenging to justify. This can be set to levels where generation technology begins to deliver power to the grid, but this cut-off changes as generation technology, particularly wind generation, continues to advance. This may result in a pessimistic forecast of generation output in the long-term.

A calculated percentile threshold is more relevant to actual generation output as both wind and solar generation are typically proportional to wind speed and solar radiation. However, a formulaic threshold may vary where two different periods are used, impacting the comparability of lull events across the periods. By changing the threshold, the duration of and frequency of calculated lulls is affected.

Calculated lull threshold

A formulaic threshold is used for this work. The wind speed/solar radiation thresholds are determined by:

1. Calculating the 24-hour rolling mean of the wind speed/solar radiation data for each cell considered to be inside a NSW REZ
2. Calculating the average 24-hour rolling mean across NSW REZs for each timestamp
3. Taking the 5th percentile of this distribution as the threshold

Therefore, the threshold is defined as the '5th percentile of the average 24-hour rolling mean across NSW REZs'. This method yields a 3.58m/s wind speed threshold, and a 341.9kJ/m^2 solar radiation threshold for the period studied.

Averaging the 24-hour rolling mean across NSW REZs results in a geographical aggregation effect that limits the impact of extreme low and extreme high conditions that may occur locally. This may result in a threshold that does not necessarily reflect a true 5th percentile condition (one where lulls occur 5% of the time), but nonetheless results in a threshold that reflects very low wind generation and solar generation output over a 24-hour period. Therefore, it is considered appropriate for the purpose of analysing lulls.

A solar/wind lull is defined to begin when the 24-hour rolling mean value of the solar radiation/wind speed respectively falls below the threshold, and to end when the 24-hour rolling mean returns above the threshold.

A stylised example of a 30-day period of proxy wind speed data is provided below, showing how this method works in practice. Despite short periods of time where wind speeds falling below the defined threshold, a lull is only counted once the 24-hour rolling mean falls below the threshold. Conversely, a lull concludes only once this threshold is exceeded on a 24-hour rolling mean basis, despite momentary increases in output. This functions to remove momentary fluctuations as they can be readily managed by short-term storage, demand management, or alternative technologies.

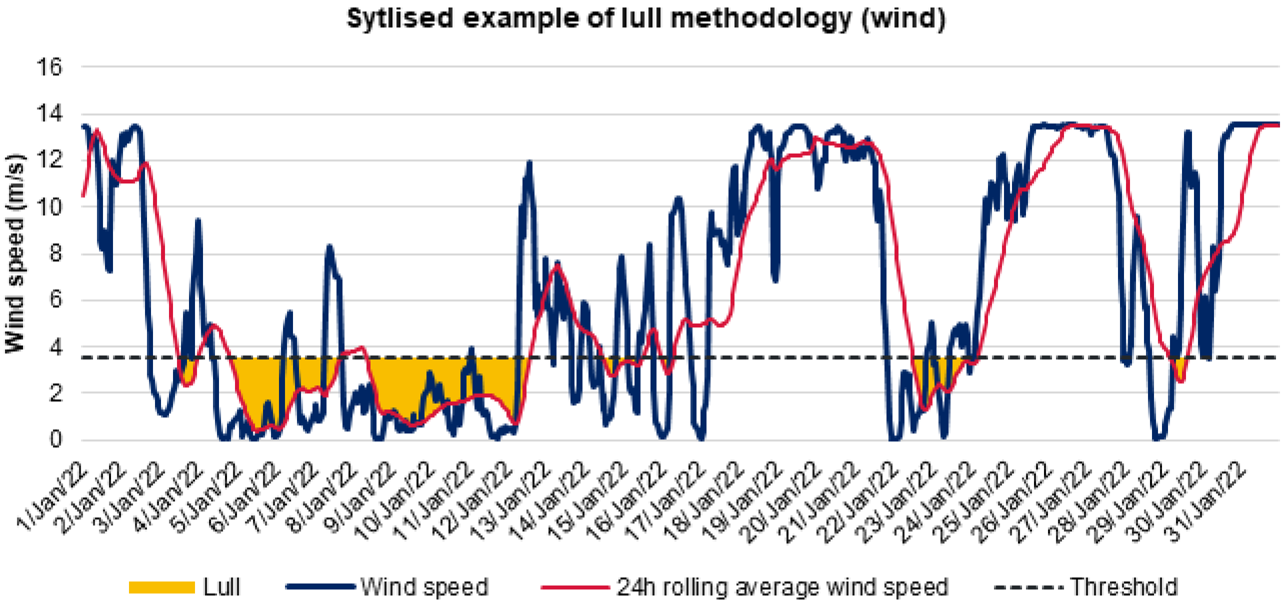

Figure 1: Stylised example of lull identification (30 days)

REZ-level lulls

The UNSW analysis calculated lulls at an individual 0.25° × 0.25° (~31km x 31km) cell level. UNSW provided OECC with an hourly dataset spanning the period 1979 – 2020[6] with binary results for each grid cell across NSW indicating whether the cell is experiencing a solar lull (SL), wind lull (WL), or a combined wind and solar lull (CWL-SL).

For the purpose of this report, OECC determined that it is more relevant to characterise lulls at a broader REZ-level. OECC defined a REZ to be in a lull if 50% or more of the individual cells in the REZ were simultaneously in a lull. This method was applied to all categories of lull such that a REZ-level combined wind and solar lull was defined as 50% or more of the individual cells being simultaneously in a combined wind and solar lull. A multiple REZ lull is then defined as the co-occurrence of a lull across the REZs of interest in the same time step.

Further details on the methodology are provided in the Appendix.

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[6] https://zenodo.org/record/6780614#.YvCUN3ZBxZd

Lull Analysis

This report includes some of the UNSW Climate Change Research Centre (UNSW) key results with additional OECC analysis using the output dataset supplied by UNSW.

Differences in REZ areas

The work performed by UNSW was completed before AEMO's 2022 Integrated System Plan (ISP) was released and before some of the new REZ draft declarations had been made. As a result, UNSW was working with approximate REZ locations, rather than known areas. Therefore, the exact locations and numbers of cells that were included in REZ level calculations in the UNSW analysis differ to those in the OECC analysis.

At the time of this work, the location and size of the Hunter-Central Coast REZ and Illawarra REZ was uncertain and was therefore excluded from analysis. Following the declaration of these locations, they can be included in any future work.

OECC sourced NSW REZ boundaries from the 2022 Final ISP. These boundaries were used to allocate relevant grid cells to REZs. A cell was defined as 'in REZ' if more than one third of its area fell inside the REZ boundary, resulting in the allocations shown in Figure 2. The number of cells considered 'in REZ' is shown in Table 1. As discussed in more detail in the next section, there is substantial variation in lull durations within each REZ. Given that it is impossible to know exactly where future generation projects will be sited, actual generation performance may be different to the values that are averaged over a larger number of cells.

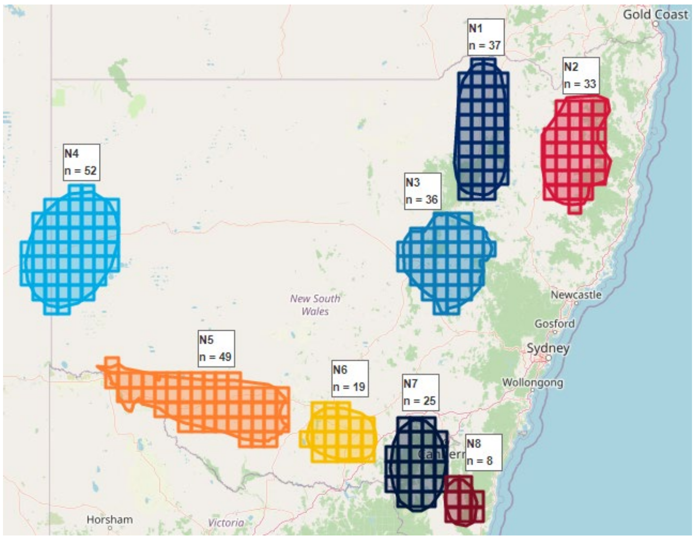


Figure 2: OECC assignment of grid cells to NSW REZs (n denotes the number of cells considered to be in REZ)

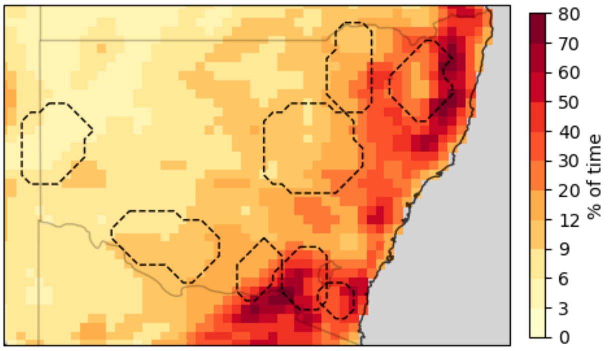
Table 1: List of NSW REZ IDs, names, and quantity of cells they cover

REZ ID	REZ Name	Number of Cells
N1	North West NSW	37
N2	New England	33
N3	Central-West Orana	36
N4	Broken Hill	52
N5	South West NSW	49
N6	Wagga Wagga	19
N7	Tumut	25
N8	Cooma-Monaro	8

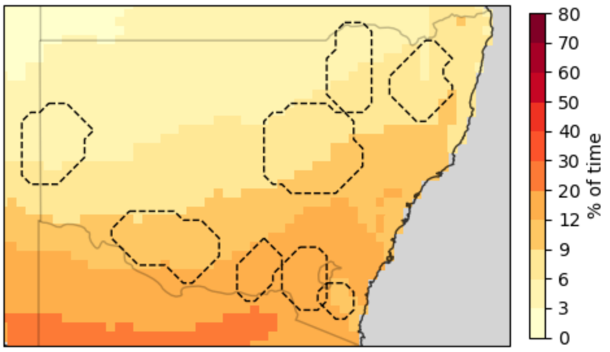
N2 (New England), N3 (Central West Orana) and N5 (South-West) REZs are of particular interest given they are the first REZs from the 2022 ISP likely to be developed in the NSW Electricity Infrastructure Roadmap. For this reason, the co-occurrence of lulls in these REZs is also analysed in this report.

Geographic variation of lulls

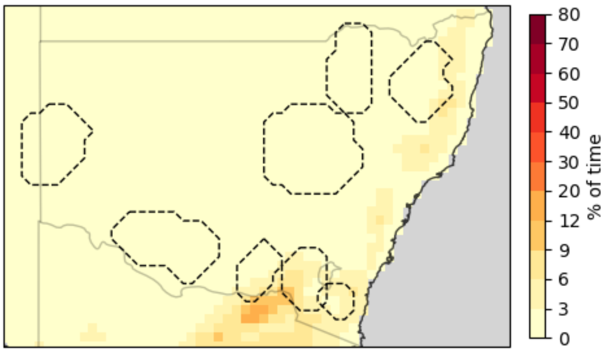
Figure 3 shows the geographic distribution of wind, solar and combined lulls, and their overall frequency as a proportion of time.



(a) Relative number of timesteps with WLs



(b) Relative number of timesteps with SLs



(c) Relative number of timesteps with CWL-SLs

Figure 3: Relative number of timesteps that experience (a) wind lulls (WLs), (b) solar lulls (SLs), and (c) joint failures of wind and solar energy production (CWL-SLs) over the study period 1979 – 2020. Black dashed contours are the different REZs in the Draft 2022 ISP[7] (Image source UNSW report)

Figure 3(a) shows a correlation between wind lulls and topographical variation; wind lulls are most evident in more mountainous areas, such as along the Great Dividing Range. In these areas, there are some cells that show wind output being below the lull threshold more than half of the time. N2 (New England) shows some of the greatest variation between cells within the region, highlighting the importance of siting for wind generation.

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[7] The areas covered by some of the REZs changed in the interval between the Draft 2022 ISP and the Final 2022 ISP – OECC has determined that this does not have a significant impact on the overall outcomes.

Solar lulls show a north-south gradient, with occurrences most likely in the south of the state and less likely in the north of the state. This is well aligned with the known solar irradiation distribution in Australia, with declining solar resources at lower latitudes. However, the variation in lull probability within individual REZs is far smaller, with most REZs having very similar probabilities of lulls across their full area. This indicates that the siting of solar farms is less sensitive than that of wind farm locations.

Lulls across other NEM regions

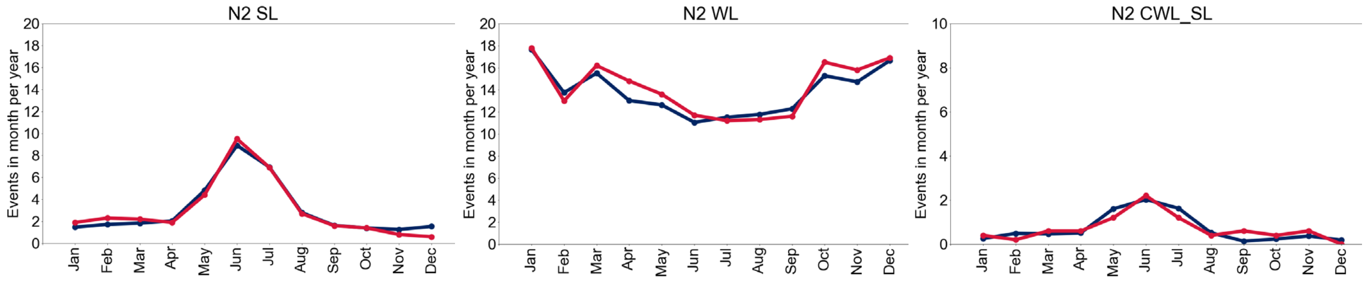
This work was initially performed to examine the frequency and distribution of lulls in NSW REZs across several decades. Investigating lulls in other NEM regions was beyond the scope of this initial analysis. Geographic diversification of wind and solar farms across NEM regions may offer an opportunity to further reduce (but not eliminate) the impact of lulls. This additional analysis would further assist in planning decision-making.

Seasonality

Figure 4 compares the solar lulls, wind lulls and combined wind and solar lulls of N2, N3 and N5 – in all cases, the solar lulls (left) show a clear seasonal effect because of reduced daylight hours. However, the wind lulls (right) for each REZ shows very different seasonal patterns. Wind lull frequency is at its lowest in New England (N2) in summer and at its lowest for the South-West NSW REZ (N5) in winter. This seasonal variation in the wind lulls highlights the value of geographic diversification of generation locations to minimise lulls.

The seasonality of combined wind and solar lull occurrences is similar across the two datasets, with a peak in late autumn and throughout austral winter (May, June, July). Reduced solar outputs are clearly the driving force behind combined wind and solar lulls. The 2011 – 2020 dataset appears to peak more strongly in June than the 1979 – 2020 dataset in most REZs, but it is possible that the longer dataset does provide some smoothing. A deeper exploration of the differences between the two datasets later in this report does indicate that while the mean and median values are similar, there are some instances of longer lulls in the 1979-2020 dataset that are not captured in the 2011-2020 dataset.

The wind lull, solar lull and combined wind and solar lull seasonality figures for all REZs are provided in the Appendix for brevity.



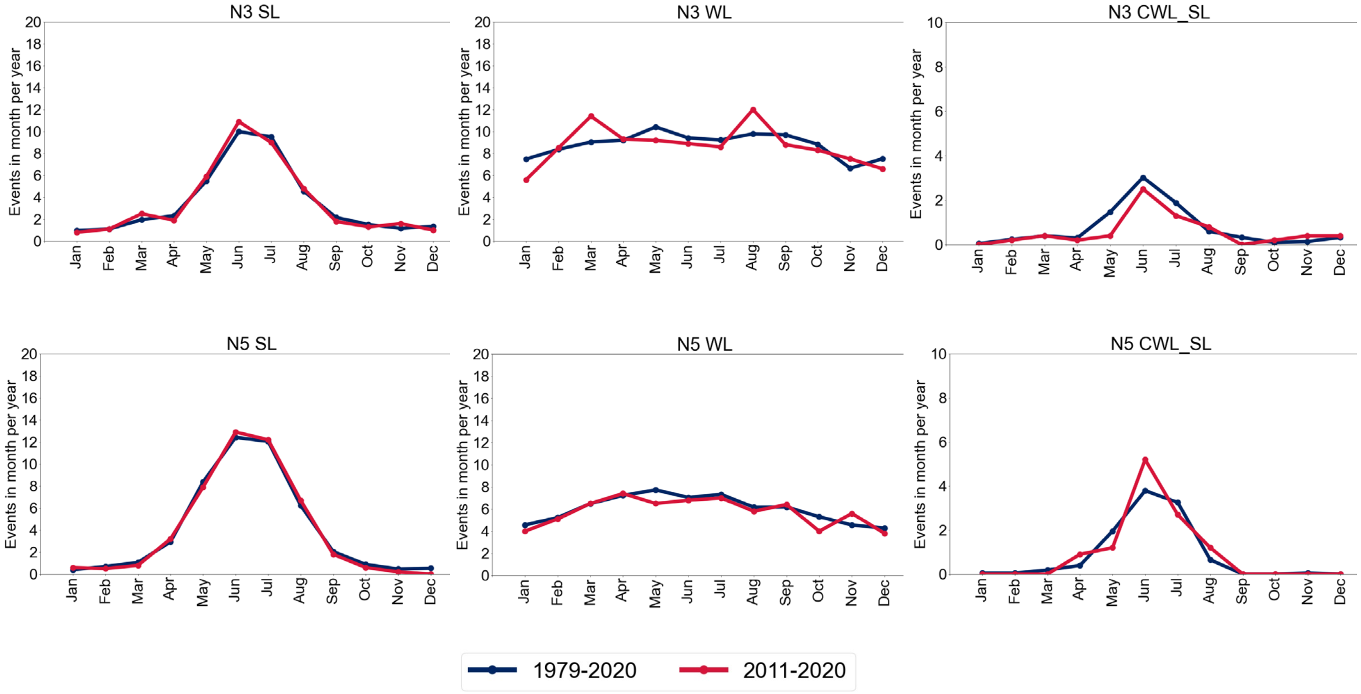


Figure 4: Solar (SL) and wind lull (WL) seasonal profiles for New England (N2), Central West Orana (N3) and South West (N5) REZs

Trends over decades

This work aimed to investigate whether there was any evidence of observable trends as a possible result of climate change that could be used to inform future planning. There is a large degree of variation in weather between individual years, which reduces the ability to detect trends. However, when lull information is aggregated to decades, broad trends are visible as changes in the distribution between decades.

Figure 6 shows that the distribution of wind lulls and solar lulls in N2 have been relatively consistent over the decades between 1979 – 2020. Whereas, compared to wind lulls or solar lulls, combined wind and solar lulls have shown much more variability with the 1991 – 2000 decade experiencing 3 combined wind and solar lulls over 50 hours in duration. It is plausible to suggest that there has been a small decline in the occurrence of mid-length lull events (75 hours to 150 hours), but further analysis would be required to establish if this is valid. Figure 5 shows very long wind and solar lulls occur in all decades, highlighting the need to consider these events. Decadal distributions for Central West Orana (N3) and South West REZ (N5) can be found in the Appendix.

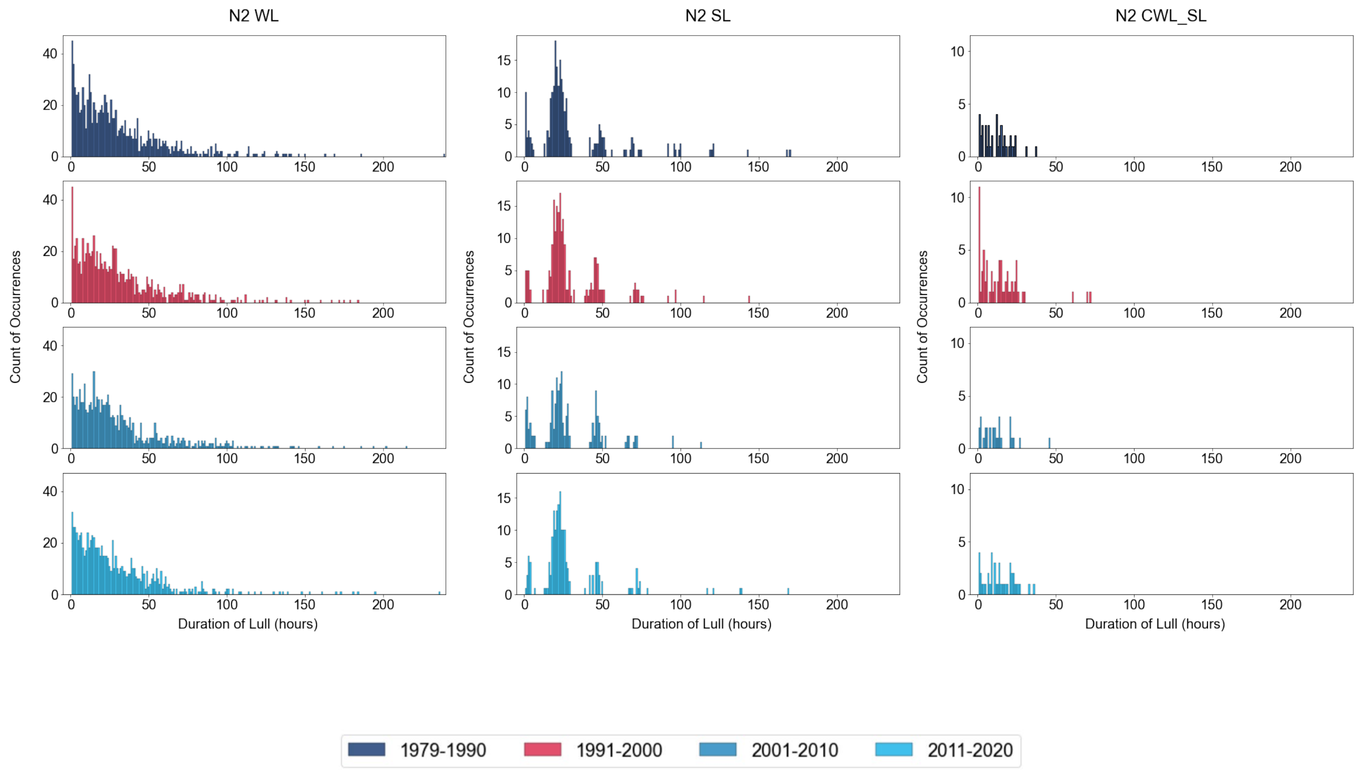


Figure 5: Decadal distribution of lulls in New England REZ (N2)

Distribution of lulls and climate change

Past climate data will assist with understanding the correlation between broader macro trends and wind and solar lulls. As an example, the decade of 1991-2000 includes the last triple La Niña and demonstrates the longest combined lulls of any decade for the New England REZ (N2). Verifying if these lulls correspond with large rainfall events and testing against data from the current year when available would be useful, and is proposed as additional an additional stream of work to better determine the factors affecting lulls.

The events which are most likely to have an impact on planning are the tail risk events; occurring less than 0.1% of the time based on previous climate data. However, recent years have shown new extremes of weather – reaching record maximum temperatures in 2020 and record rainfall in 2022. As of September 2022, the Australian Bureau of Meteorology confirmed that for the first time in 20 years, there would be a triple La Niña event leading to a cool, wet summer.

Given the record-breaking nature of recent weather years, there may be limits on the insights that can be gained from historical data. This may require the development of synthetic weather years or testing known extremes with an additional margin for security. The development of synthetic weather years is a complex matter and would require additional research prior to development. It is suggested that IIO modelling test the impact of lulls that are longer than those discovered in this analysis.

Predictability of lulls

One element of lulls that was beyond the scope of this work was determining the predictability of wind and solar lulls, and if there are specific weather conditions that will contribute to their occurrence or duration.

The characteristics that drive lulls have several aspects that could be further explored. These have a variety of temporal and geographic ranges. At the broadest time scale is the question of whether La Niña or El Niño events have different lull patterns – for example, is there more sunshine in an El Niño year, or more wind in a La Niña year? This report does not explore this, but it is worth future investigation.

This work does indicate that there is a clear seasonal trend in lulls, but there is room to explore this further and perhaps investigate the likelihood of extended lulls in a manner similar to the expected severity of a cyclone season. This may be quite complex, but would be quite useful in seasonal planning and operation of the NEM. Finally, there is opportunity to examine the effects of specific weather events or disasters, such as the 'rain bomb' that hit northern NSW in early 2022. In these instances, gaining an appreciation for how localised and extended any associated lulls are would assist in planning for similar future events.

Temperature correlation with lulls

Temperature and demand

AEMO has noted that there is a strong correlation between temperature and electricity demand[8] particularly due to the use of heating and cooling appliances to maintain thermal comfort. In past years, the most extreme demand peaks have corresponded with very high cooling loads due to air-conditioning. However, electrification of heating may drive higher demand in cooler temperatures.

As indicated in Figure 6, when the daily maximum temperature in Sydney is below 17°C or above 32°C, total NSW electricity demand is likely to be very high. AEMO notes that when temperatures pass 32°C, demand is at its most sensitive to temperature due to cooling loads[9] and that 17°C is the threshold temperature for electrical heating in NSW[10]. This emphasises the need to ensure temperature and weather information is factored into demand forecasts. These demand forecasts are used to help determine the minimum amount of generation capacity needed to deliver reliable supply and meet peak demand.

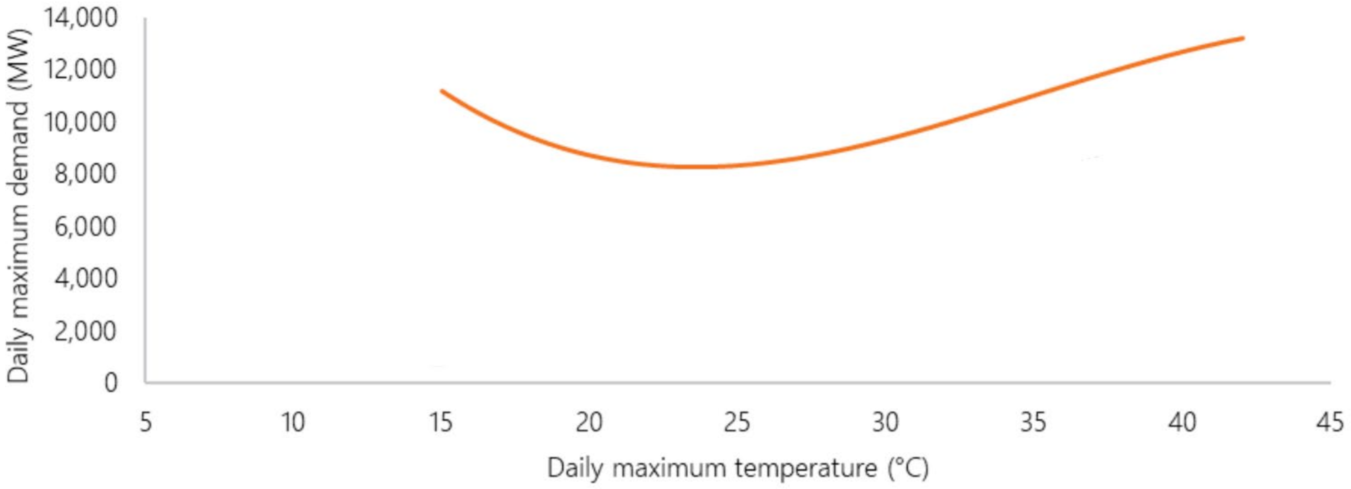


Figure 6: Energy demand as a function of daily maximum temperatures in the Sydney region (Source: AEMO)

Correlation between lulls and temperature

Given the impact of temperature on demand, it is critical to understand whether there is a strong correlation between temperature and combined wind and solar lulls and hence how they might correspond with demand. Figure 7 shows that it is highly unlikely that there will be a combined wind and solar lull in any REZ during hot weather in major load centres. The dashed grey line shows the maximum temperature distribution in Sydney – showing that there are an appreciable number of days where temperatures exceed 32°C, correlating with days of high electricity demand. However, the solid blue line shows that there are very few occurrences of combined lulls in any REZ when the

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[8] https://www.aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptions-methodologies/2020/2020-electricity-demand-forecasting-methodology-information-paper.pdf

[9] https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/load-forecasting/temperature-forecast-analysis-for-summer-2020-21.pdf?la=en

[10] https://www.aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/electricity-demand-forecasting-methodology-information-paper.pdf?la=en

temperature is above 32°C. Given that high temperature events in NSW are usually correlated with extended periods of clear, sunny weather, this is not surprising.

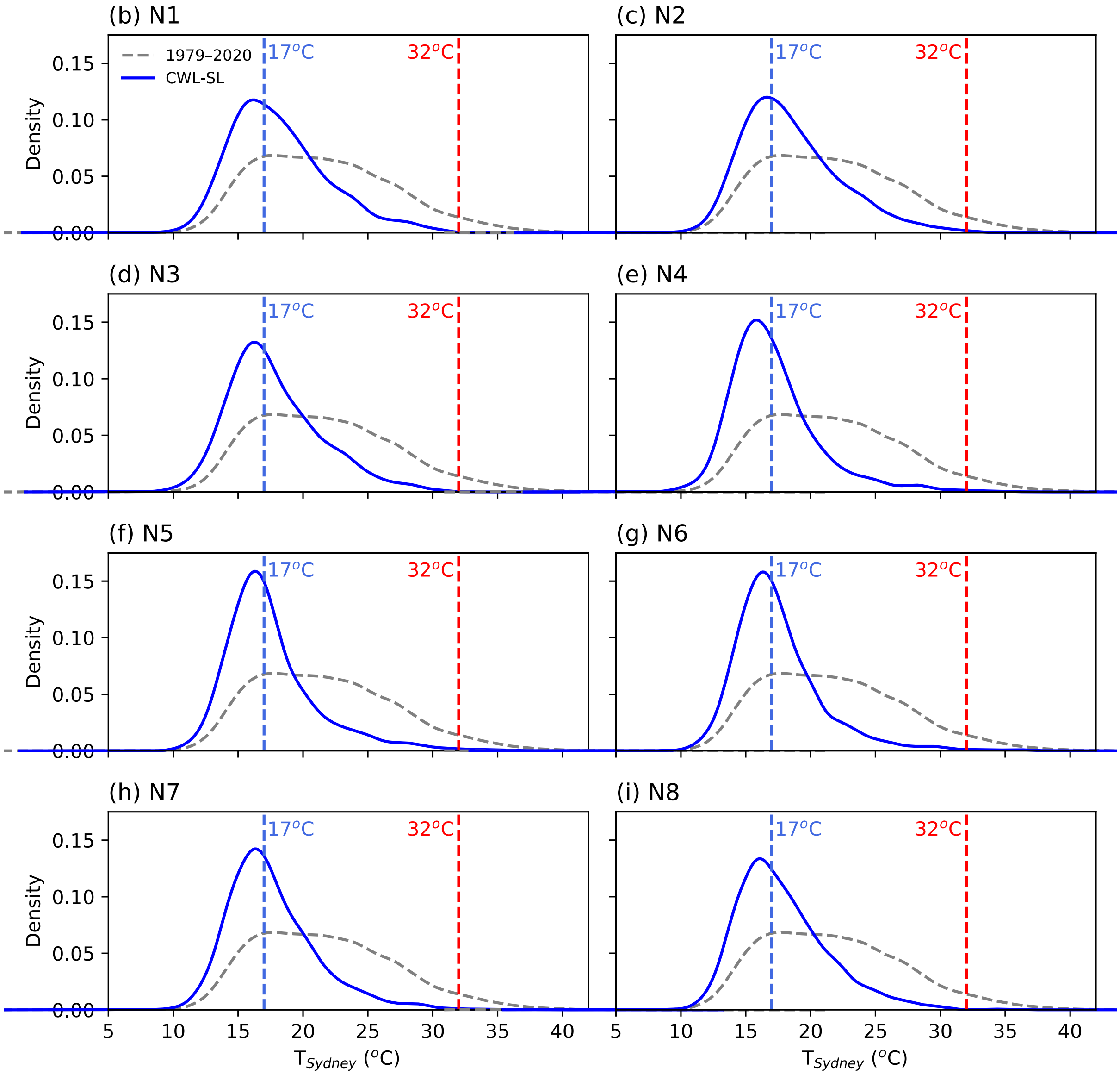


Figure 7: Probability density for the daily maximum temperature (dashed grey line) in the Sydney region during CWL-SL events (blue line) occurring in the different regions of interest. The blue and red dashed vertical lines show the cut-off temperatures (Image source: UNSW report)

When examining colder weather, the inverse is true. Combined wind and solar lulls are at their most likely when the daily maximum Sydney temperature is slightly below 17°C as this is when the solid blue line is highest. Short, cold, still days are likely to be one of the biggest challenges for NSW and the NEM as variable renewable energy penetration increases, and electrification drives increased winter electricity demand.

Dataset comparisons

Maximum, Mean and Median Lull Durations

One aim of this work is to compare the long-term weather conditions in the 1979 – 2020 dataset to the 2011 – 2020 dataset. The analysis by OECC explores the full UNSW dataset and compares the lull durations for the long (1979-2020) dataset and the short (2011-2020) dataset based on the calculated threshold for the long dataset. N2 (New England), N3 (Central West Orana) and N5 (South-West NSW) REZs are of particular interest given they are likely to be the first REZs from the 2022 ISP to be developed in the NSW Electricity Infrastructure Roadmap. For this reason, the co-occurrence of lulls in these REZs is also analysed in this report and included in the following tables. As previously noted, the location and size of the Hunter-Central Coast REZ and Illawarra REZ was not fixed at the time of this work and was therefore excluded from analysis.

Table 2, Table 3 and Table 4 present the maximum, mean and median lull durations, respectively. For the 2011-2020 table of maximum durations, values are underlined and **bold** if the duration of the lulls are shorter than the 1979-2020 dataset by more than 20%, indicating noticeable divergence between the two datasets. In the tables representing mean and median lull duration, where the values of the 2011-2020 dataset exceed 1979-2020 dataset by 20%, they are underlined and *italicised*. For the REZ combinations, WL refers to the co-occurrence of a wind lull in the REZs, and likewise for solar lulls and combined wind and solar lulls.

Table 2: Maximum lull durations

Dataset	1979-2020			2011-2020		
Lull type	WL	SL	CWL_SL	WL	SL	CWL_SL
REZ	Max (hrs)	Max (hrs)	Max (hrs)	Max (hrs)	Max (hrs)	Max (hrs)
North West NSW (N1)	146	169	71	146	169	60
New England (N2)	239	170	72	236	169	**33**
Central West Orana (N3)	196	232	86	196	215	**50**
Broken Hill (N4)	97	144	47	89	140	45
South West (N5)	160	311	108	**126**	**173**	108
Wagga Wagga (N6)	171	482	80	150	482	**51**
Tumut (N7)	495	410	86	476	**316**	80
Cooma-Monaro (N8)	500	291	119	**368**	**174**	98
N2 + N3	139	144	26	139	144	**19**

N2 + N5	122	120	24	103	101	23
N3 + N5	90	209	35	55	124	23
N2 + N3 + N5	85	101	16	55	101	16

Table 3: Mean lull durations

Dataset	1979-2020			2011-2020		
Lull type	**WL**	**SL**	**CWL_SL**	**WL**	**SL**	**CWL_SL**
REZ	**Mean (hrs)**	**Mean (hrs)**	**Mean (hrs)**	**Mean (hrs)**	**Mean (hrs)**	**Mean (hrs)**
North West NSW (N1)	21	31	12	22	29	11
New England (N2)	30	30	13	29	29	14
Central West Orana (N3)	21	35	13	21	33	15
Broken Hill (N4)	17	29	15	16	27	*18*
South West (N5)	20	37	17	21	38	18
Wagga Wagga (N6)	23	41	17	23	41	17
Tumut (N7)	49	45	17	49	44	16
Cooma-Monaro (N8)	48	37	20	44	33	17
N2 + N3	19	26	9	19	26	9
N2 + N5	15	22	10	16	21	*12*
N3 + N5	13	27	11	14	26	13
N2 + N3 + N5	12	20	7	14	20	8

Table 4: Median lull durations

Dataset	1979-2020			2011-2020		
Lull type	**WL**	**SL**	**CWL_SL**	**WL**	**SL**	**CWL_SL**
REZ	**Median (hrs)**	**Median (hrs)**	**Median (hrs)**	**Median (hrs)**	**Median (hrs)**	**Median hrs)**
North West NSW (N1)	16	23	9	17	22	8
New England (N2)	22	23	12	21	23	13
Central West Orana (N3)	17	24	11	17	24	12
Broken Hill (N4)	13	23	12	12	22	*16*

South West (N5)	16	24	14	17	25	16
Wagga Wagga (N6)	18	25	13	18	25	15
Tumut (N7)	34	25	12	33	24	12
Cooma-Monaro (N8)	35	24	17	35	23	15
N2 + N3	15	22	8	14	21	9
N2 + N5	11	21	10	12	21	10
N3 + N5	9	22	11	*12*	22	*15*
N2 + N3 + N5	9	20	6	*12*	19	6

These results show that the mean and median lull durations are relatively similar between the two datasets, however, there is general trend of lull durations recorded in the 2011 – 2020 dataset being slightly below those of the 1979 – 2020 dataset. This suggests that, on average, the 2011 – 2020 period may have experienced slightly more consistent wind/sun conditions than on average over the 1979 – 2020 period.

However, the 2011 – 2020 maximum lull durations differ from the 1979 – 2020 maximum lull durations in several cases. Worthy of note is the combined wind and solar lulls in the New England (N2) and Central West Orana (N3) REZs, for which the 1979 – 2020 maximum lull durations are 39 hours and 36 hours longer than the 2011 – 2020 maximum lull durations.

Likelihood of events

Relative share of hours with lulls

Table 5 shows the relative number of hours (% of all timesteps) experiencing a wind lull, solar lull or combined wind and solar lull. It is worth noting that the threshold for a lull has been set based on a state-wide average and as a consequence, regions that have typical wind or solar resources below that threshold will show high amounts of lull periods, such as New England (N2). Further to this, the average lull values for REZs that cover an area with a high variation in lull frequency, such as Tumut REZ (N7) and Cooma-Monaro (N8), may be distorted by a few cells with low outputs.

Table 5: Relative number of timesteps with lulls

Dataset	1979-2020			2011-2020		
Lull type	WL	SL	CWL_SL	WL	SL	CWL_SL
REZ	% of periods	% of periods	% of periods	% of periods	% of periods	% of periods
N1	13.9%	5.7%	0.6%	13.6%	5.2%	0.6%
N2	29.1%	6.4%	0.7%	27.6%	5.6%	0.6%
N3	13.2%	8.7%	0.7%	12.4%	7.7%	0.5%
N4	4.1%	5.1%	0.3%	4.1%	4.3%	0.4%

N5	8.5%	10.3%	1.1%	8.0%	9.7%	1.1%
N6	15.1%	13.1%	1.7%	14.3%	12.6%	1.6%
N7	48.9%	14.3%	3.0%	49.5%	14.1%	2.8%
N8	47.6%	12.0%	4.3%	45.7%	10.9%	3.6%
N2+N3	10.0%	3.3%	0.1%	9.1%	3.0%	0.1%
N2+N5	4.3%	1.9%	0.1%	4.0%	1.9%	0.1%
N3+N5	2.6%	4.0%	0.1%	2.4%	3.5%	0.2%
N2+N3+N5	2.0%	1.5%	0.0%	2.0%	1.5%	0.0%

The results in Table 5 show that there is a general trend of the likelihood of lulls in the 2011 – 2020 dataset being slightly below those of the 1979 – 2020 dataset. This supports the earlier commentary that suggested that the 2011 – 2020 period may have experienced slightly sunnier and windier conditions than the 1979 – 2020 dataset.

The value of geographical diversity is also observable, with the likelihood of lulls across multiple REZs being significantly lower than the individual REZs themselves. This is particularly evident in the N2 + N3 + N5 combination. The N2 + N3 combination has the highest likelihood of experiencing combined lulls across both REZs, which aligns with their geographical proximity to each other.

Limitations of this work

This work focused on characterising the nature and duration of lulls in renewable energy supply in NSW using data from 1979 – 2020. The methodology has several limitations that may be worth addressing in future work.

One key limitation of this work is that research into the interaction between climate change and wind and solar lulls is in its infancy, and this will not be quickly resolved. However, work such as this analysis can begin to provide some insights into the development of appropriate streams of research that can be used to inform future work.

Another limitation of this work is that this scope of this work did not include investigating lulls in other NEM regions. Since the NEM regions are interconnected, it would be valuable to extend this analysis to cover other NEM regions and their REZs, prioritising REZs that are likely to be built out earliest according to the ISP.

This work also does not include weather data from the last 18 months, from 2021 to 2022. This period includes multiple extreme rainfall events that would be likely to correlate with extended solar lulls that may not currently be captured in the long dataset. At the time of writing, it was announced that Australia will have a triple La Nina weather event – including higher than average rainfall and probability of extreme rainfall events – which only occurs in one other period in the extended dataset. Capturing the impacts of these extremes will add value to future analysis.

Future actions

Following the work outlined in this report, there are several areas where additional work would add value. Of these, the most immediate and valuable would be to expand the work in this analysis to cover other NEM regions as it may contribute to the value case for additional interconnection transmission projects.

In addition, examining the potential correlation of extreme weather events and lulls in recent history may assist in informing actions to support system resilience in coming years. This can take the form of examining specific events such as East Coast Lows, or also examining macro systemic effects, such as the prevalence of lulls under La Niña or El Niño events and determining if there is a noticeable difference. There may also be value in investigating if there are seasonal climate drivers that also affect the likelihood and duration of lulls allowing weeks to months of advance notice to prepare for lulls to occur.

It is also worth recognising that the field of climate change and electricity system resilience is still in its infancy and some work areas may require extensive research to deliver. As an example, while increases in temperature are well established, it is not well known if there is a trend in lull duration as a result of climate change. Historical data can provide some indication, but future extrapolation of climate trends may take some time to integrate into energy research.

Conclusions

AEMO's existing practice, including for modelling to inform the NSW Consumer Trustee's IIO reports, uses a one-decade period of historical weather data as part of its work to project future market requirements, amongst a range of other inputs. OECC's analysis, using the 1979 – 2020 dataset provided by UNSW, reveals that the 2011 – 2020 period captures the typical occurrence of long-duration wind lulls, solar lulls, and combined wind and solar lulls relatively well. The mean duration, median duration, relative likelihood, and seasonality of lulls is similar in the 1979 – 2020 and 2011 – 2020 datasets.

However, the 2011 – 2020 period does not capture all the extreme duration lulls that are present in the larger 1979 – 2020 dataset. This may have an impact on the infrastructure required to replace retiring coal generators. As the electricity system moves towards higher penetrations of variable renewable energy, deep storage or additional firming capacity may be required to provide resilience during these extreme duration lulls. The analysis in this report will assist AEMO Services Ltd, in their role as NSW Consumer Trustee, to ensure the development pathway is resilient to VRE lulls.

The most recent two years have included multiple record-breaking weather events that have not been captured in the datasets studied. The extensive nature of these events may well be affected by climate change. It is recommended that as the data becomes available, that lulls associated with these events be calculated and incorporated into future modelling. Further work on the impacts of climate-change driven events may also be beneficial.

Appendix

UNSW Method Details

Data Source

Wind speed and solar irradiation data was sourced from the ERA5 reanalysis dataset generated by the European Centre for Medium-Range Weather Forecasts (ECMWF). The ERA5 dataset provides hourly estimates of historic climate variables, combining historical observations into global estimates using advanced modelling and data assimilation systems. The data covers the Earth on a $0.25° \times 0.25°$ (~31km x 31km) grid.

ERA5 provides wind speed (ws) data in m/s at two model layers, 10m and 100m above model surface. The 100m wind speed was used for the purpose of this analysis because it is better aligned to typical wind turbines heights (~130m). Solar irradiation data in ERA5 is provided as surface solar radiation downwards flux (ssrd) measured in units of J/m^2.

Lull Definitions

A wind lull/solar lull is considered to occur if the 24-hour moving mean of the ws/ssrd falls below the 5th percentile of the distribution of the average ws/ssrd across all REZs. The 5th percentile global threshold values were calculated to be 3.58 m/s for ws and 341.91 kJ/m^2 for ssrd. Combined wind and solar lulls are then defined as the co-occurrence of a wind lull and solar lull at the same time step in the same grid cell.

Analysis

UNSW calculated the 24-hour moving mean of ERA5 ws/ssrd data over the period 1979 - 2020 for each grid cell covering the NSW region. When the ws/ssrd falls below the thresholds above in any individual cell, a value of 1 is set in that time step to indicate that a lull has begun. This value of 1 is maintained until the 24-hour moving mean exceeds the threshold.. A combined wind and solar lull is then considered to be occurring in an individual cell if it simultaneously in both a wind lull and a solar lull.

Additional modelling analysis outputs

Decadal Distributions

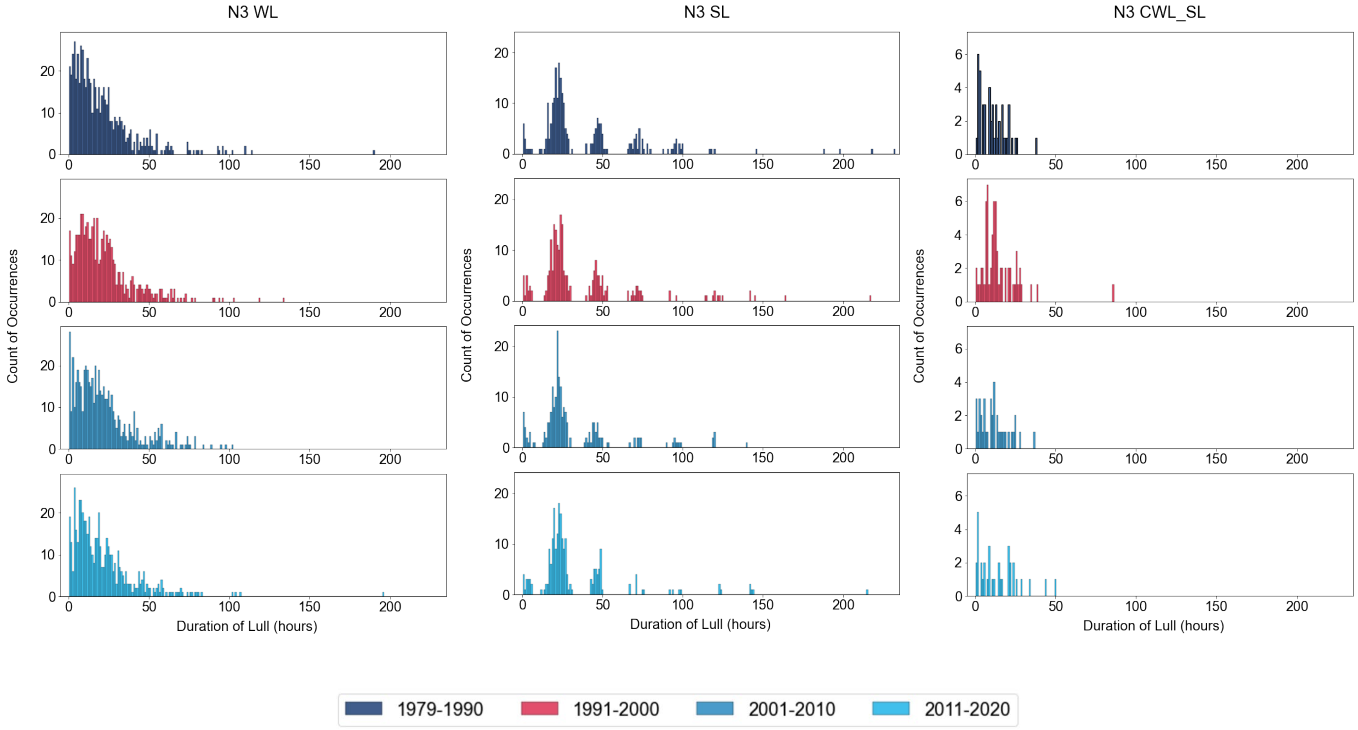


Figure 8: Decadal distribution of lulls in N3

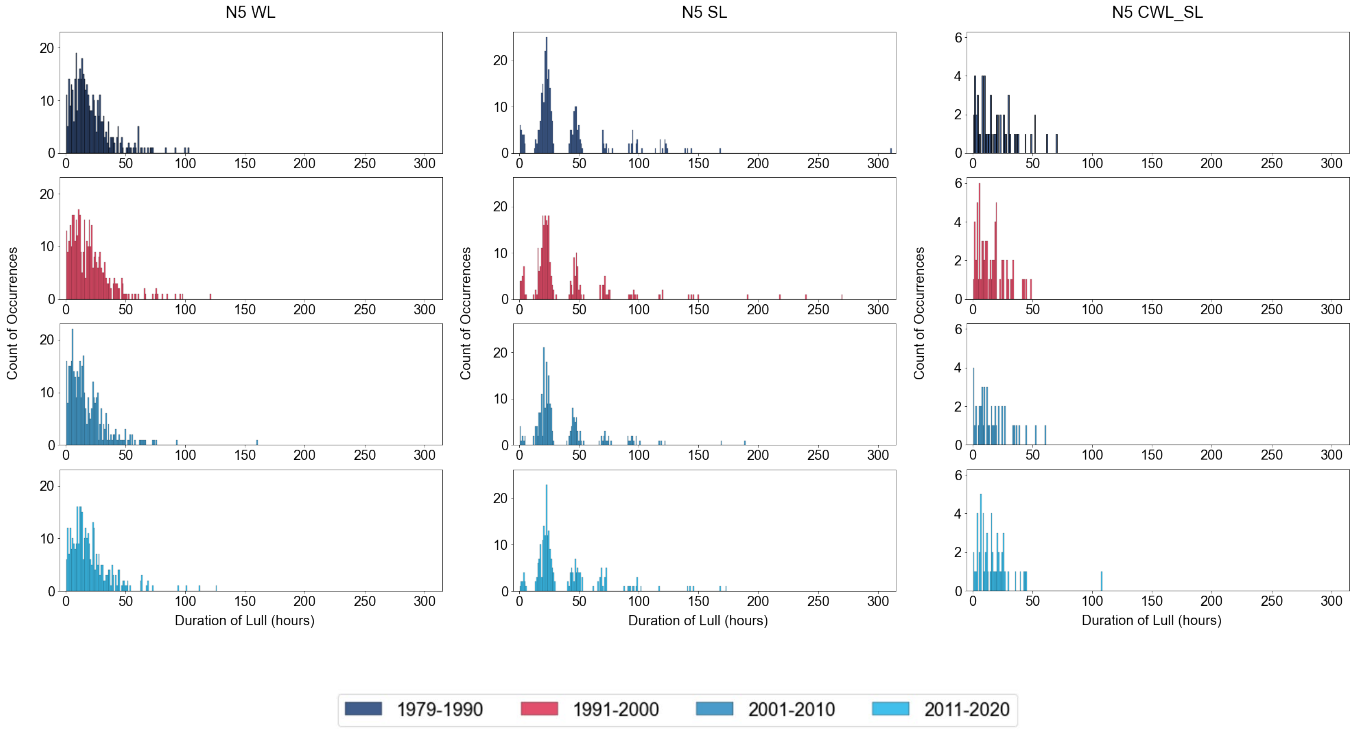
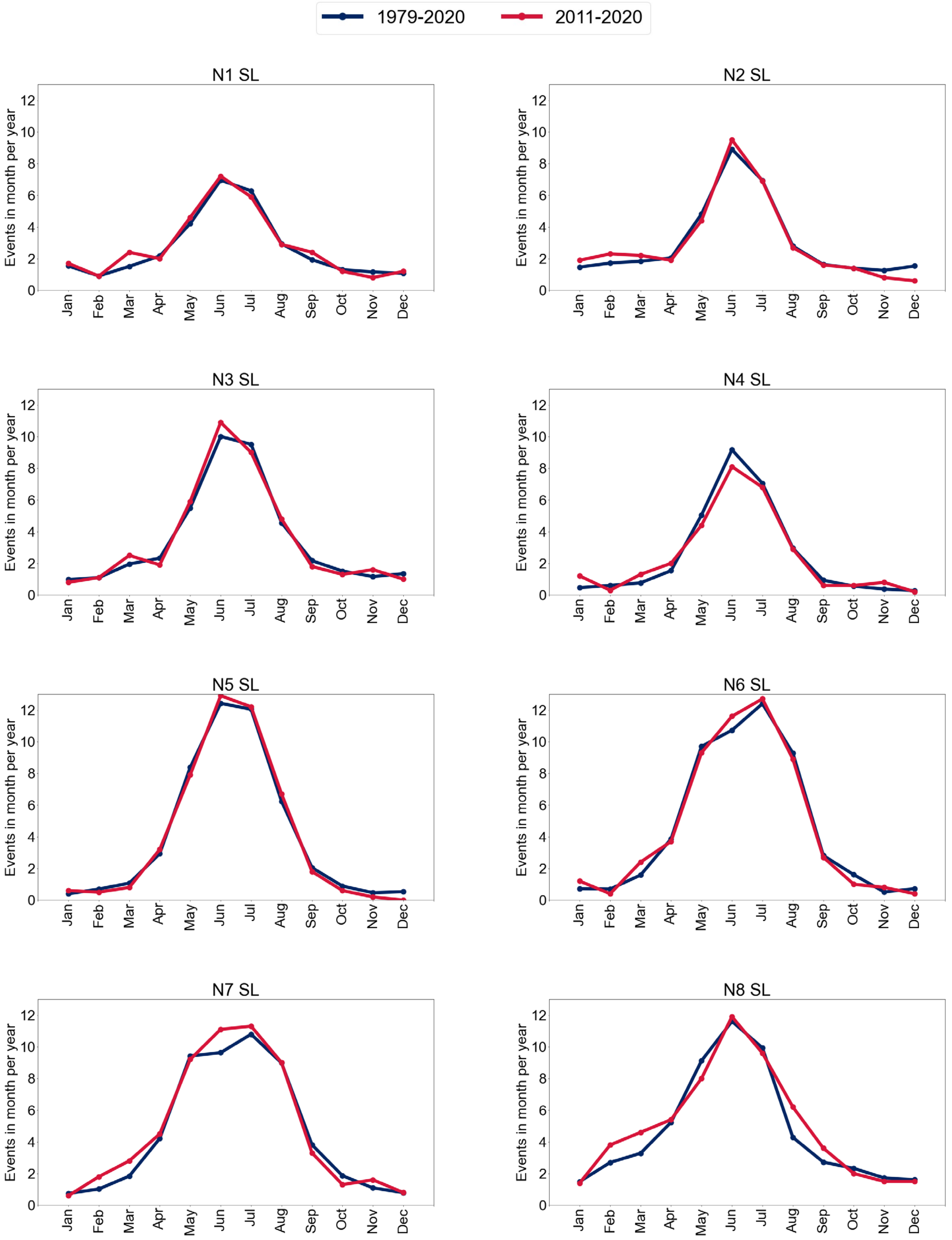


Figure 9: Decadal distribution of lulls in N5

Monthly solar lull comparison



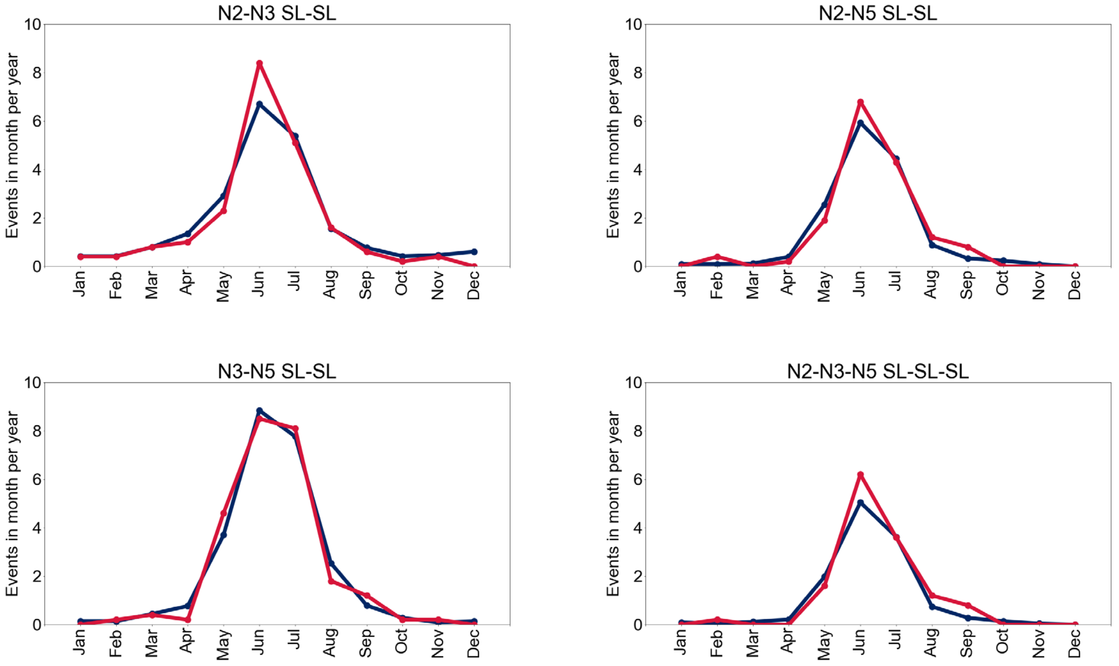
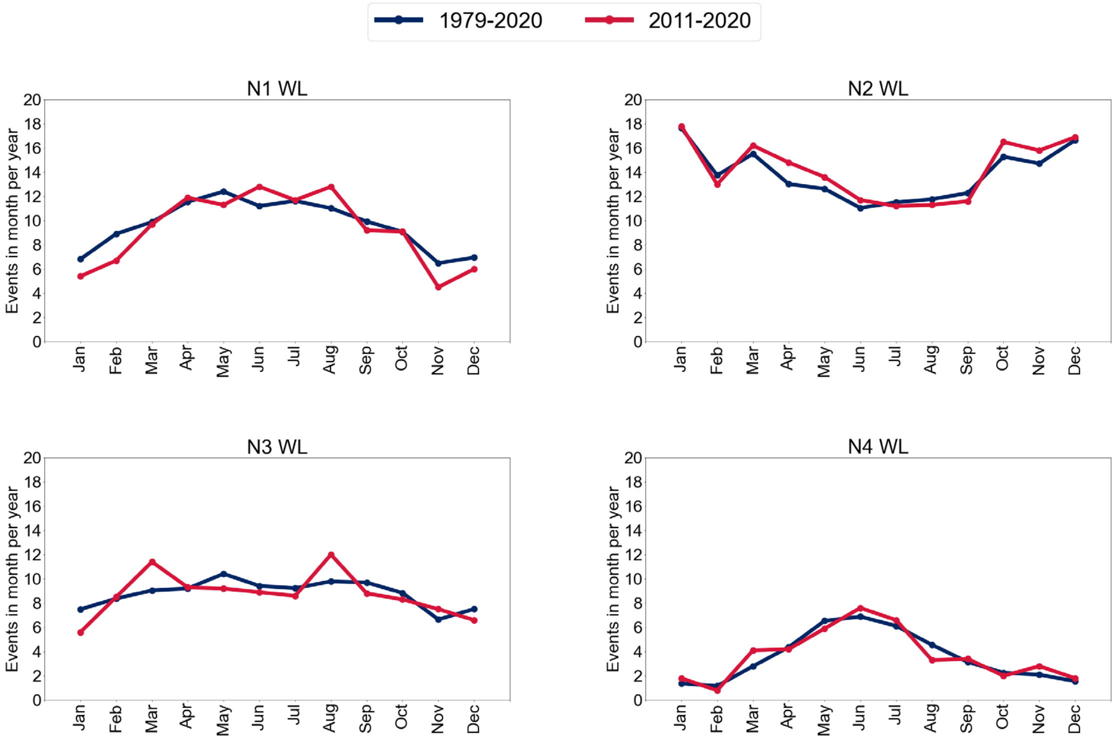


Figure 10: Seasonality of SL occurrences in each REZ and REZ combination of interest

Monthly wind lull comparison



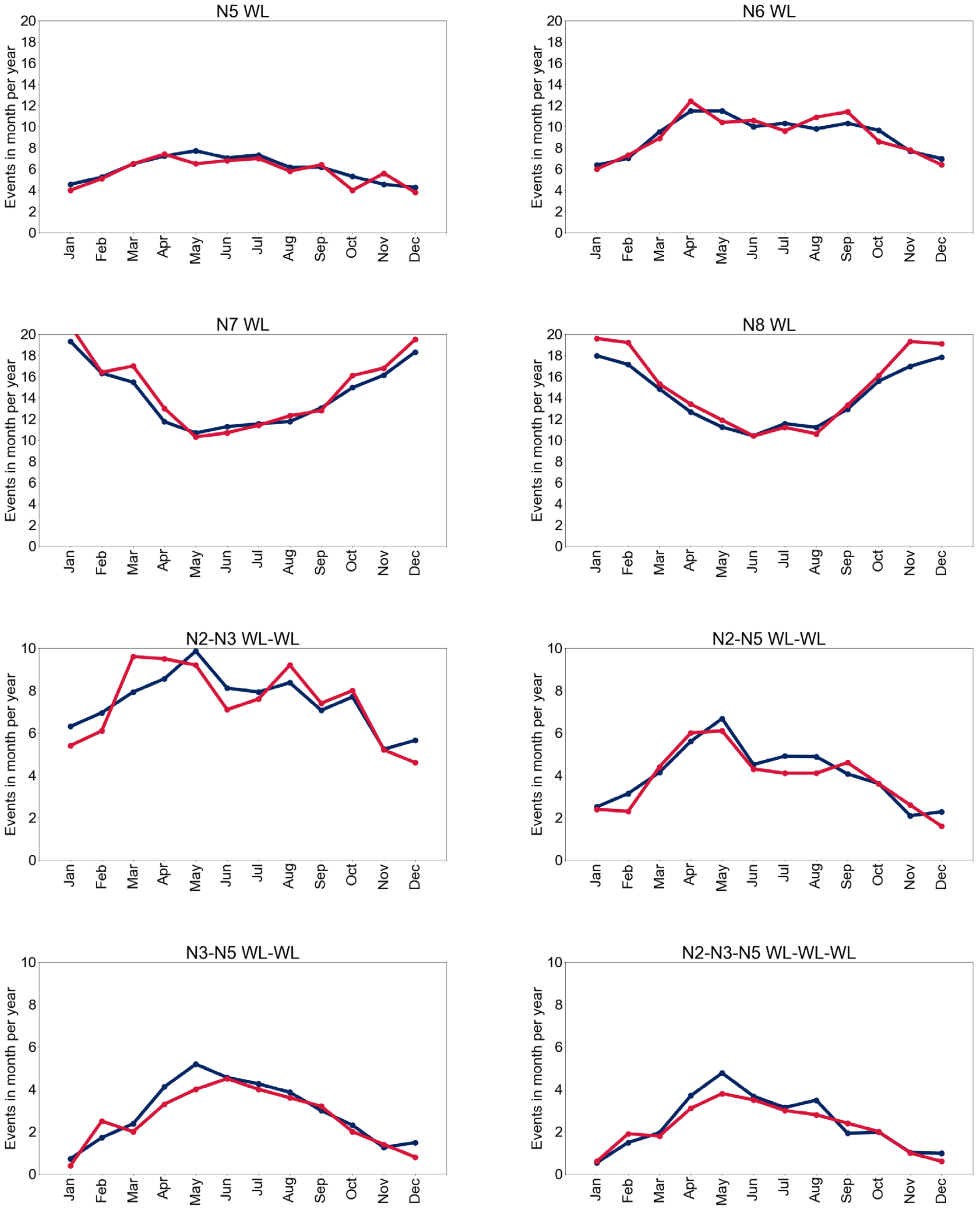
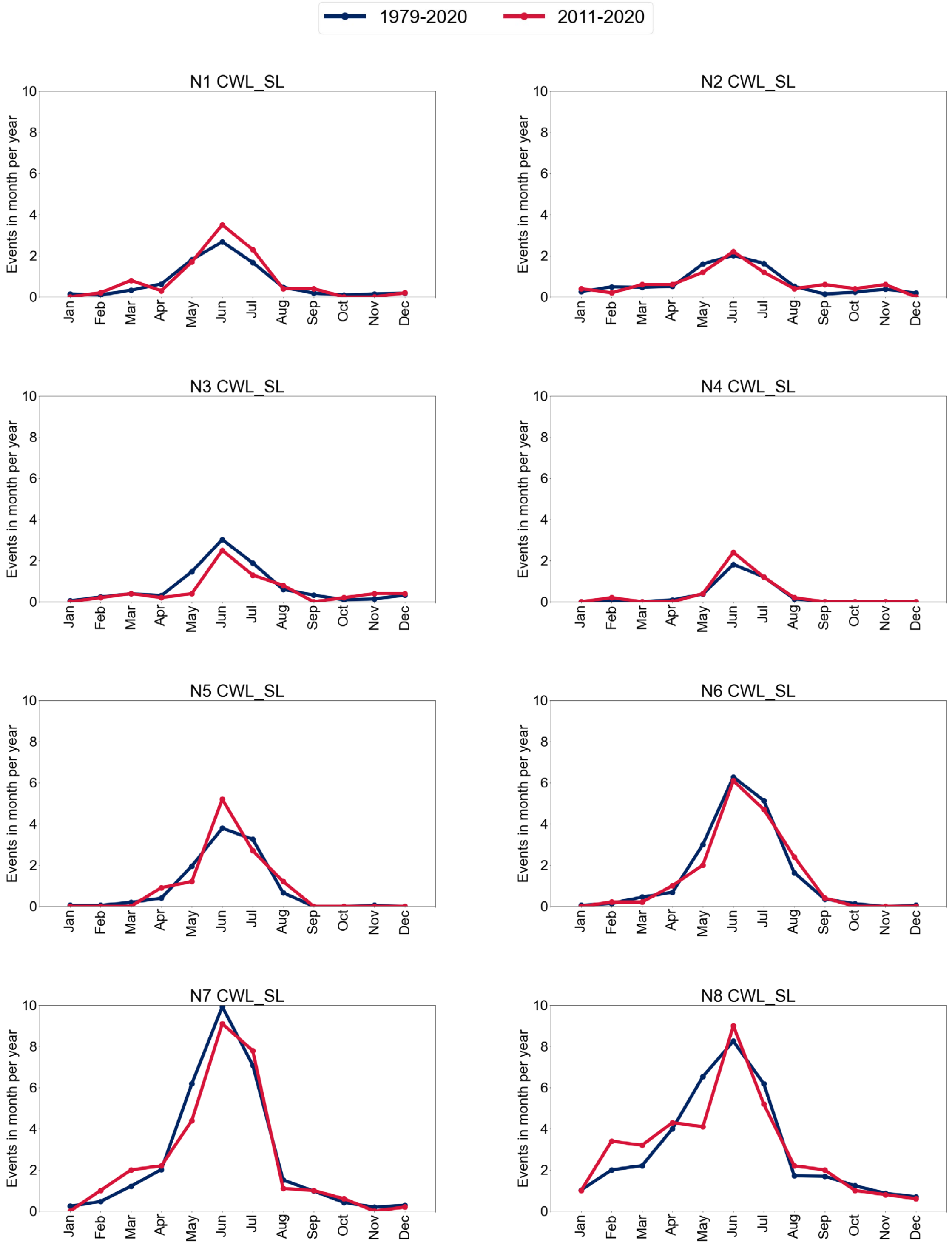
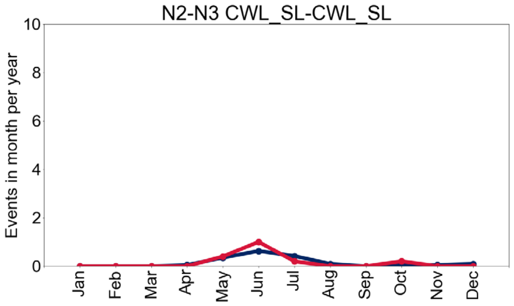
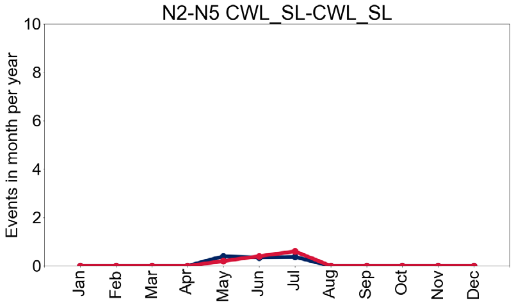


Figure 11: Seasonality of WL occurrences in each REZ and REZ combination of interest

Monthly combined wind and solar lull comparison




N2-N3 CWL_SL-CWL_SL
Events in month per year
0
2
4
6
8
10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


N2-N5 CWL_SL-CWL_SL
Events in month per year
0
2
4
6
8
10
Jan
Feb
Mar
Apr
May
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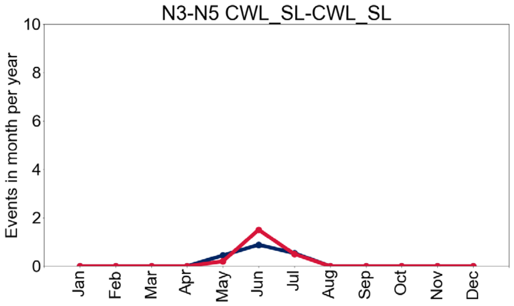
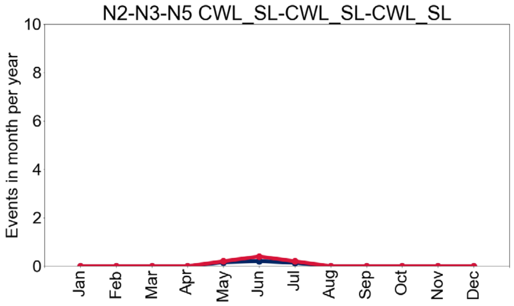
Jul
Aug
Sep
Oct
Nov
Dec


N3-N5 CWL_SL-CWL_SL
Events in month per year
0
2
4
6
8
10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


N2-N3-N5 CWL_SL-CWL_SL-CWL_SL
Events in month per year
0
2
4
6
8
10
Jan
Feb
Mar
Apr
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