Wind and solar diversity

24th August 2022

Intro

- We looked at how diversity, both in location and technology type, will affect incorporating wind and solar into the New Zealand electricity system over the next 15-30 years

- To do this, we looked at how generation output and residual demand changes with different amounts of diversity.

- We didn’t undertake a full system simulation exercise, but we considered how these curves interact with demand and inflows and the effect that has on the electricity system.

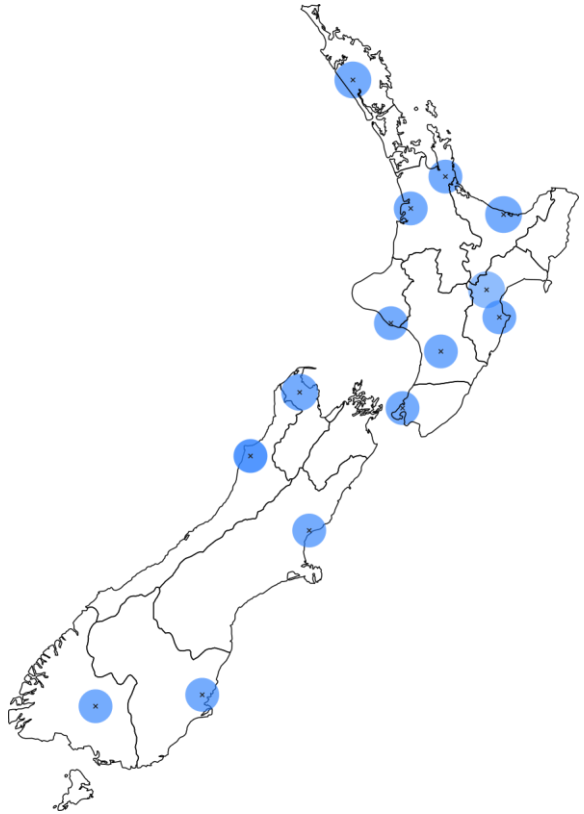
Approach

- We based our analysis on simulated wind and solar data across 40 years at 14 sites in New Zealand
  - We cross checked to historical generation where possible, and the match is reasonable
- Three steps:
  - Firstly, look at the correlation between generation from different locations and technology types,
  - Then combine those sites and generation types into various hypothetical build schedules, and look at the combined generation from these build schedules,
  - Finally consider how that generation interacts with electricity market demand and hydro inflows.

- Also, we take a brief look at current wind farms and the revenues they have received from the market to see what that tells us about our analysis.

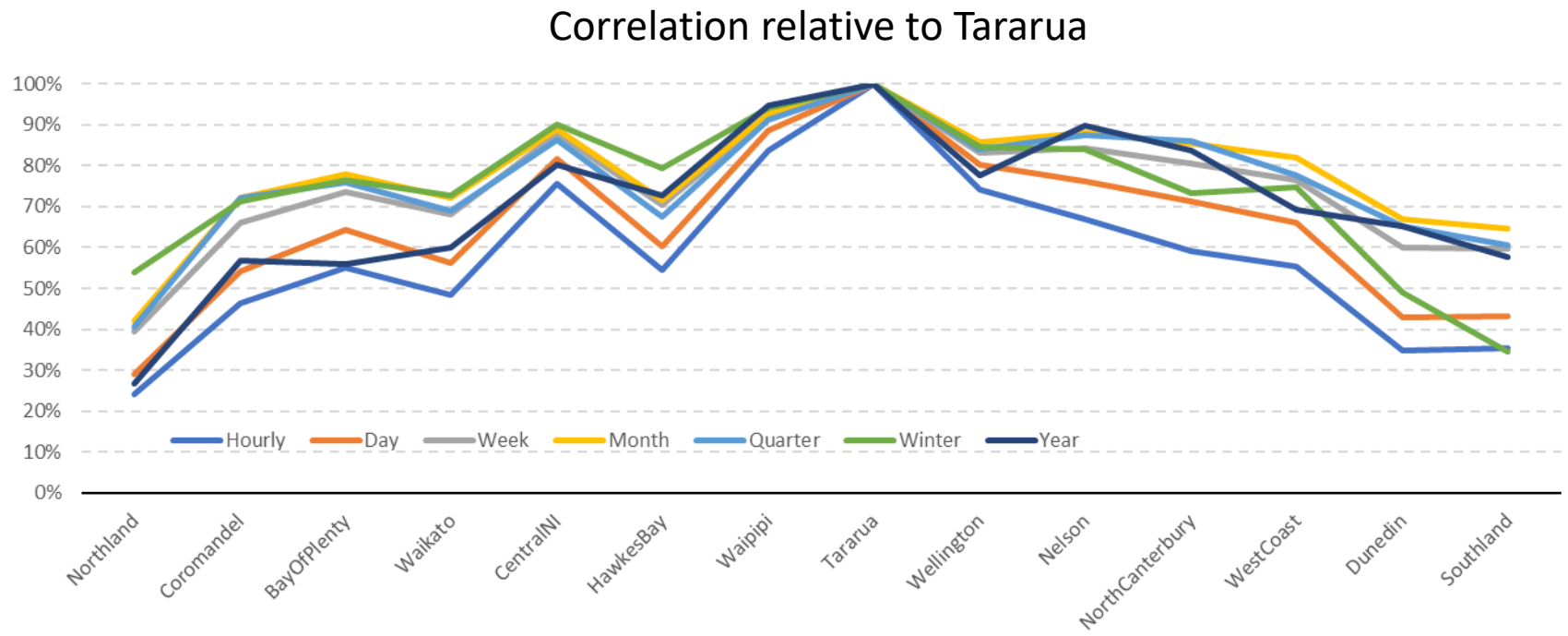
Step 1 – Look at correlations between sites and technologies

- We used data for 14 sites around New Zealand ranging from Northland all the way to Southland
- The sites we chose either have existing wind generation, or have been proposed as possible sites for wind or solar development



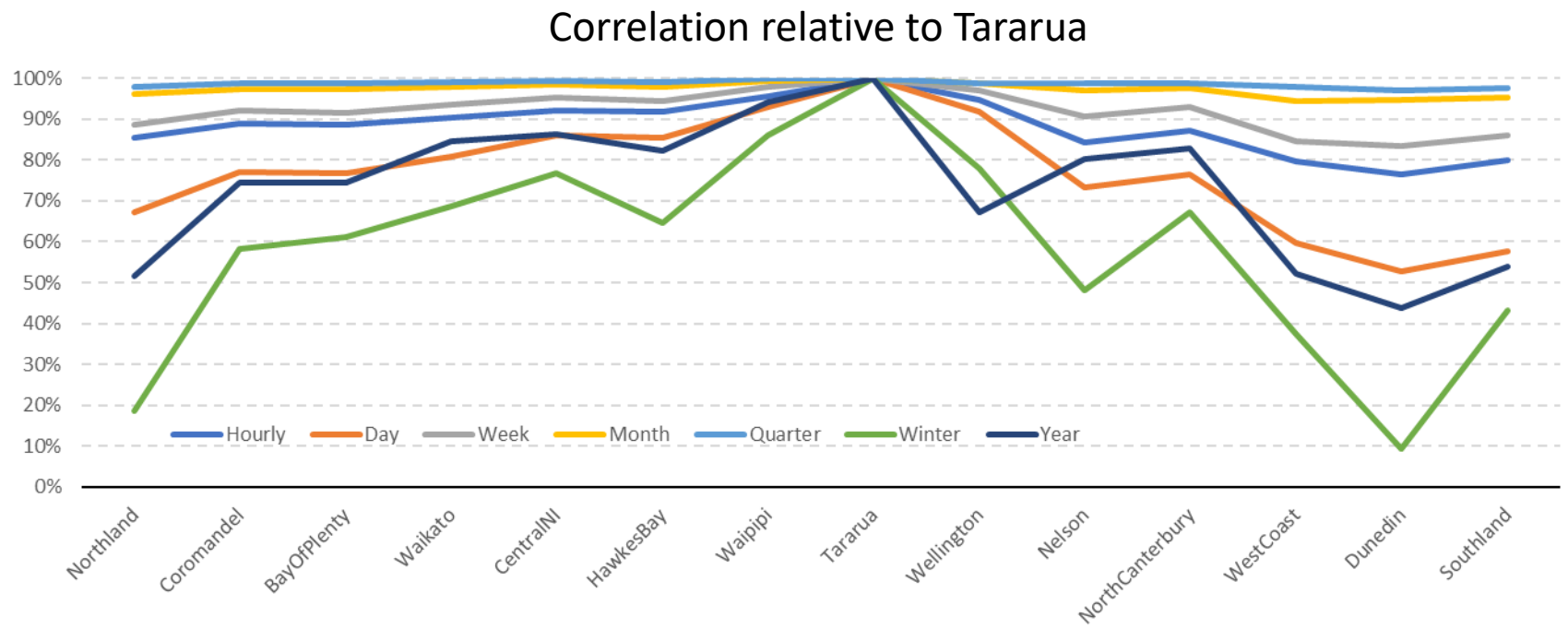
Wind Site Data – Geographic diversity

- Our first step is to look at simple correlation between wind sites for a range of time periods.
- We use Tararua as the reference point and the sites are shown in roughly North to South order
- We show correlations for different time frames from hourly to year-to-year
- Unsurprisingly, either end of the country has the most diverse wind resources relative to Tararua
- Hourly is most diverse, but weather systems moving across the country mean higher correlation on a weekly and monthly basis



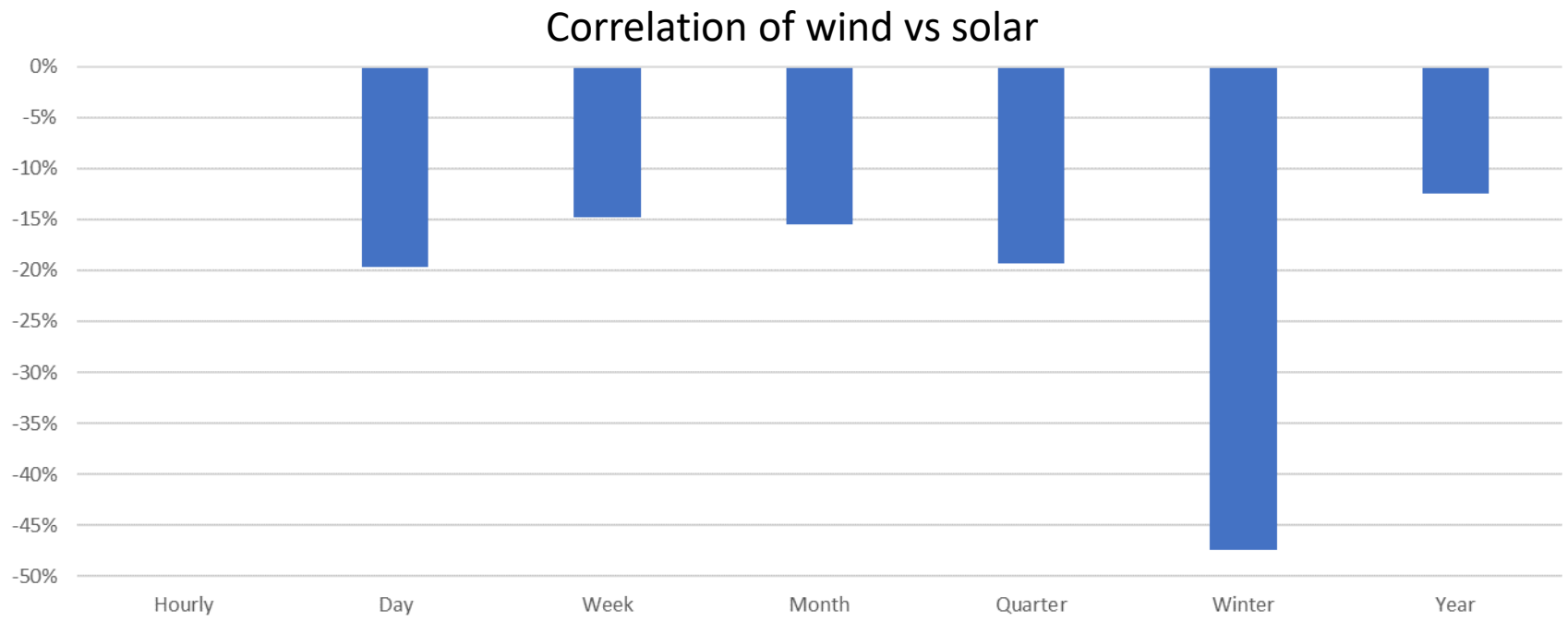
Solar Site Data – Geographic diversity

- Solar data look quite different, because seasonal effects lead to very high correlations across all sites for monthly and quarterly time frames (and to a lesser extent weekly)
- Hourly data is also highly correlated because of night/day.
- These two points tell us that locational diversity (at least on the New Zealand scale) doesn't address the intra-day and seasonal nature of solar. This is not surprising, but is important.
- For other time periods there is some diversity, but less so than for wind.
- Winter output is perhaps an exception, but the benefits of diversity don't outweigh the lower output in winter



Wind / Solar diversity

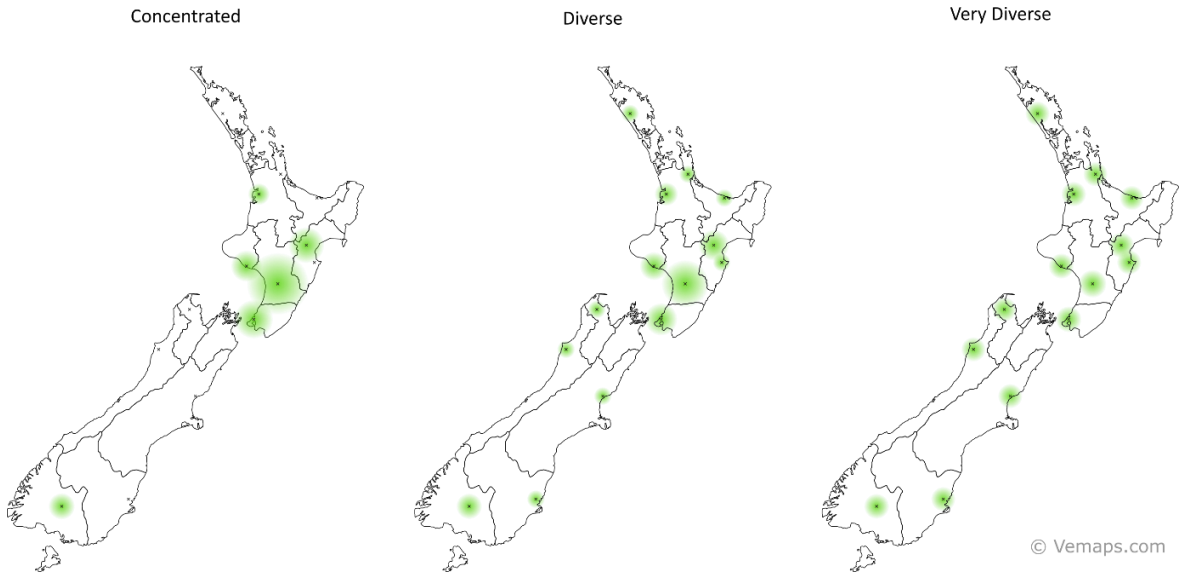
- We compared a national average solar profile to a national average wind profile
- Wind and solar are uncorrelated at the hourly level
- There is a slight negative correlations over other timeframes – perhaps “clouds” mean both more wind and less solar? This suggests that diversity between the two generation types could help.
- There is a larger inverse relationship for winter, but again the much lower output from solar in winter makes this less useful than it might initially appear.



Step 2 – Create hypothetical build schedules

- Our next step was to take our data for sites and construct some build schedules for the future
- We considered three dimensions:
  - Future year – we looked at both 2035 and 2050
  - Technology type – we considered solar only, wind only and a balanced mix
    - Our “Solar only” and “Wind only” options aren’t meant to be realistic, but to isolate the effect of either type of generation
  - Locational diversity – we considered a concentrated case and two more diverse scenarios

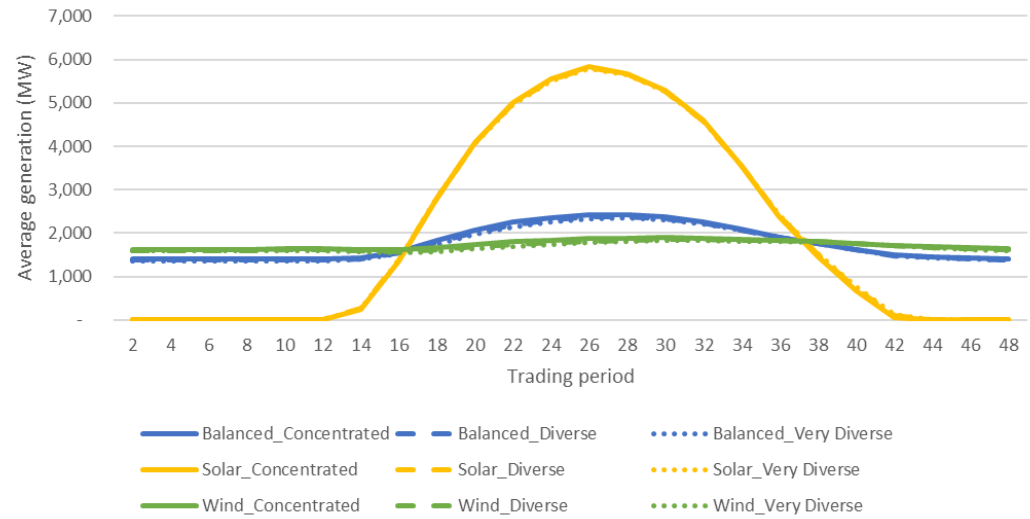
- In the interests of brevity, we concentrate on 2035 in this presentation, but both are shown in full in the report



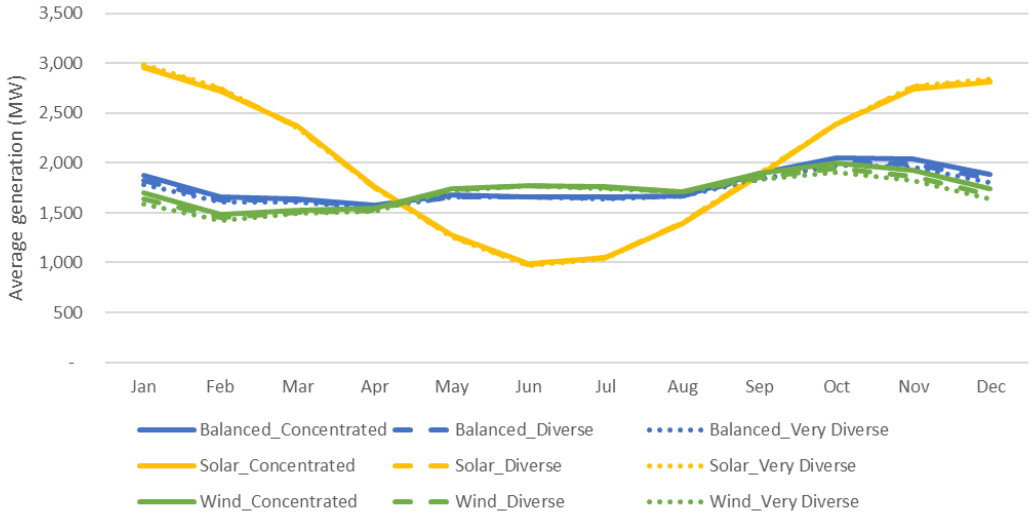
Build schedules output

- Solar output is as expected, both for within day and seasonally
- Wind is very flat compared to solar, but not completely:
  - It has slightly more generation in the afternoon
  - And slightly more generation in spring, less in late summer
- Balanced is somewhere between the two, but more similar to wind as we expect higher levels of wind than solar in 2035. This equalizes somewhat by 2050.

Average within-day profile



Average within-year profile

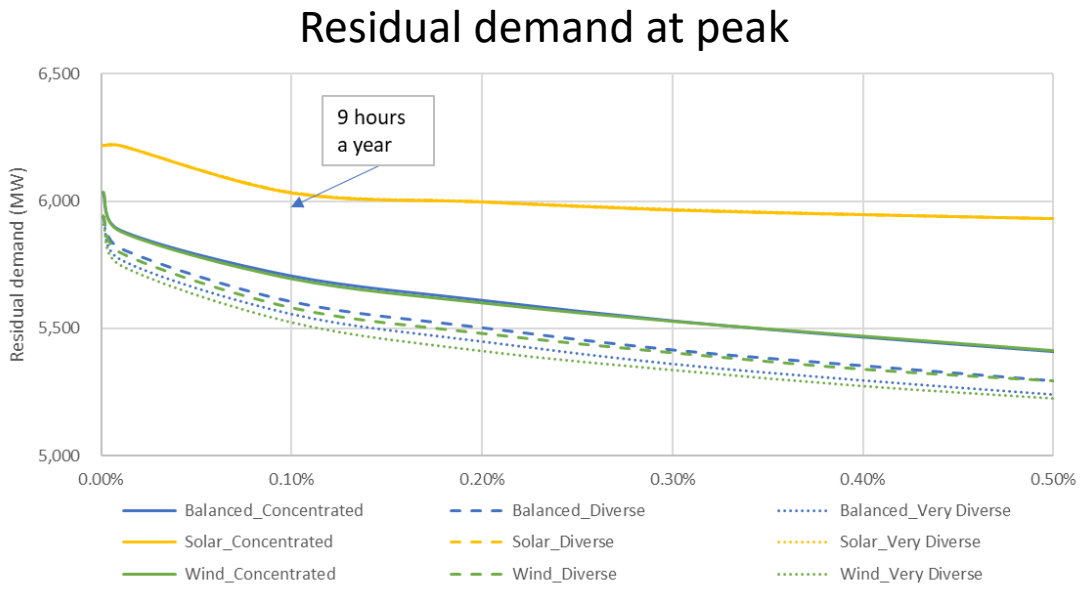


Step 3 – Consider how build schedules interact

- Our final step is to consider how the generation from our build schedules interacts with the wider electricity market.
- Running an electricity system is challenging because supply must meet demand at all times, so periods of low output could be particularly problematic if they coincide with high demand.
- We look at four timeframes:
  - System hourly peak
  - Week-to-week variation
  - Seasonal swing
  - “Dry years”

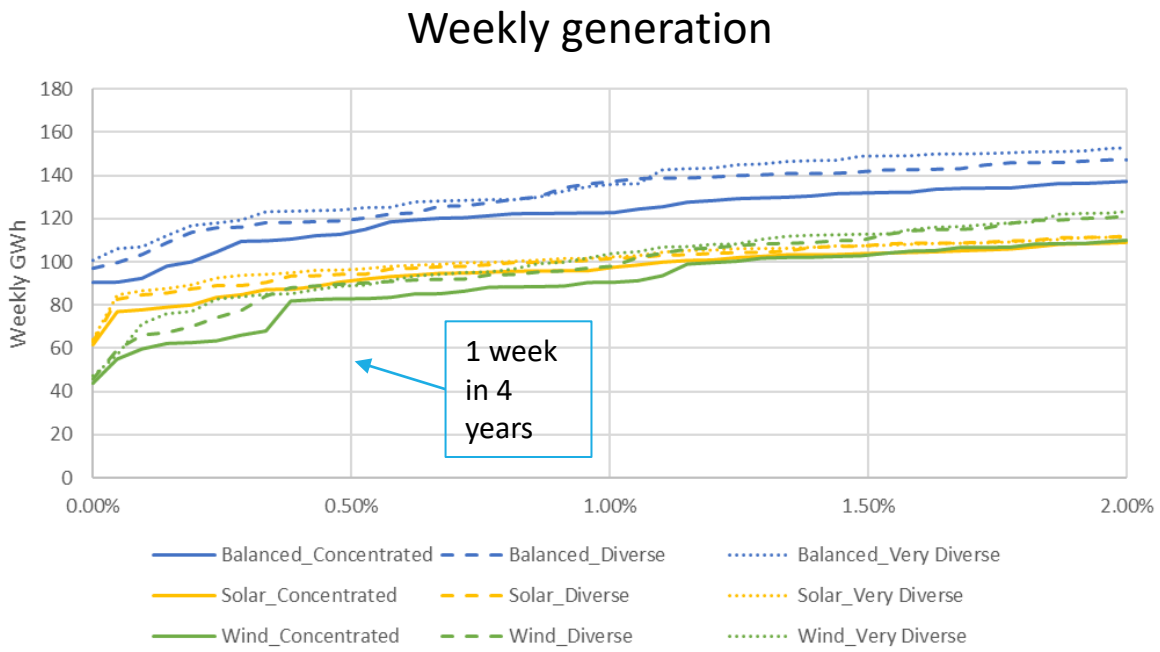
System hourly peak

- We matched historical demand with the historical generation data to produce residual demand at an hourly level
- This is significantly higher for the solar-only series since there is negligible generation during system peak
- As before, the difference between dashes, dots and solid lines shows the effect of geographical diversity
  - For the balanced scenario, moving from the concentrated to diverse scenario reduces residual demand at the “9 hours a year” line by about 70 MW.
  - Moving to the very diverse scenario reduces it by an additional 50 MW.
  - For 2050, these values are 125 MW and 50 MW.
- But note that this timeframe can be well served by batteries, so peak supply may be less important in the future



Week-to-week variations

- However, batteries are less well suited to shift energy from one week to the next so this may become a more important time period
- Our analysis indicates that “wind-only” has the lowest output for this timeframe, followed by “solar-only”
- Interestingly, the balanced scenarios have significantly higher minimum output than either technology type alone
- Locational diversity helps a little bit too

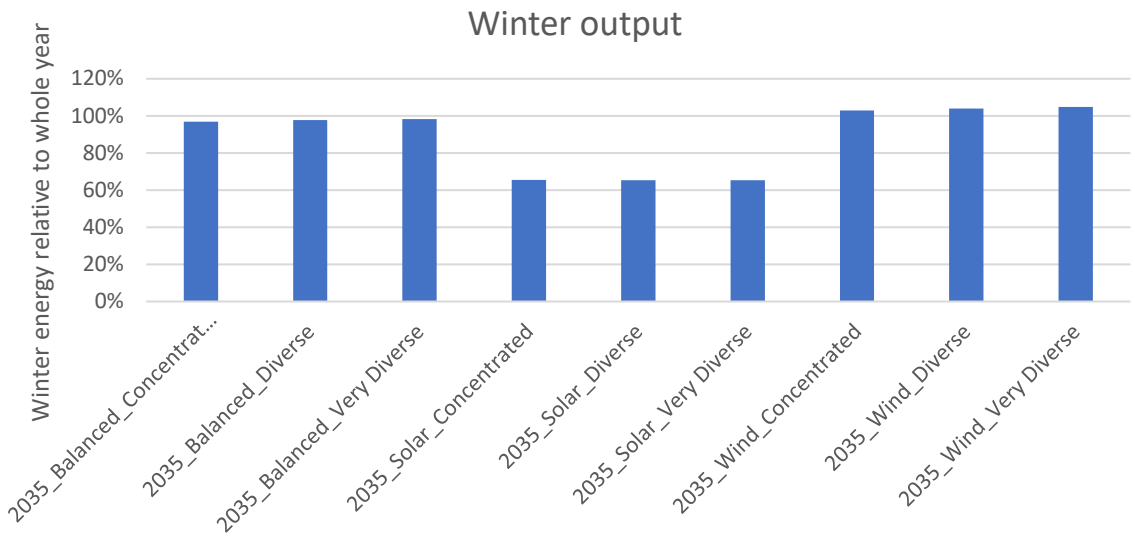


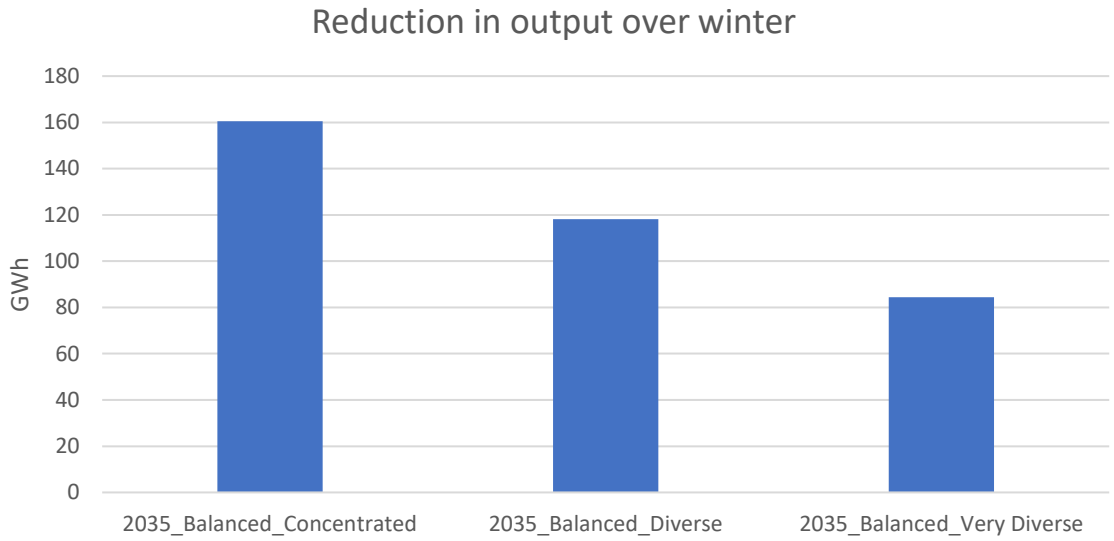
Seasonal output (i.e. winter)

- Meeting increased demand during winter is one of the main challenges faced by the electricity sector, and we expect this will continue to be the case in the future.

- You can see:
  - Solar only schedules have much less output in winter
  - Wind is slightly higher than 100%
  - Balanced scenarios are less than 100% (solar brings output down more than wind increases it)

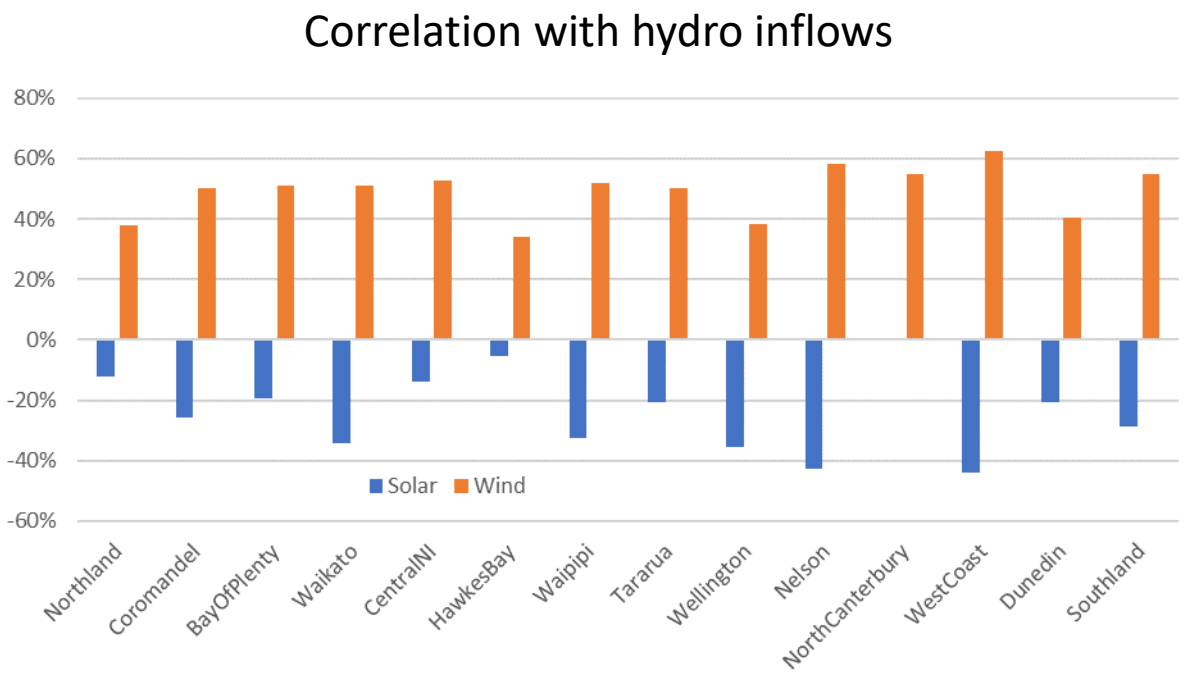
- We can quantify the reduction in energy during winter:
  - 160 GWh on average for concentrated case
  - Locational diversity reduces this slightly
    - Primarily because output from sites other than Tararua is higher in winter





“Dry winter”

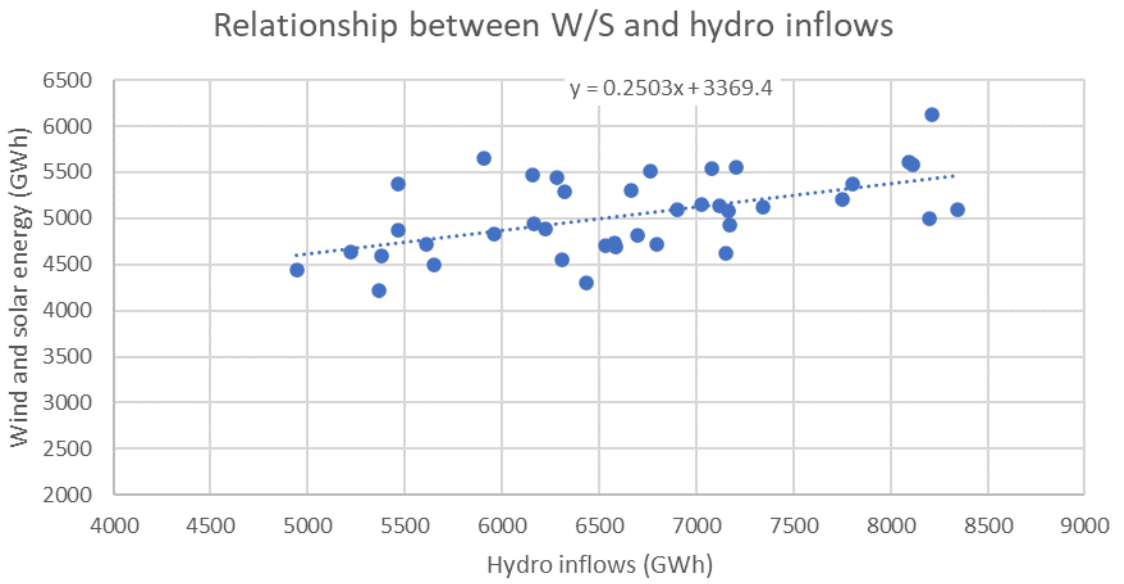
- The previous slide showed *average* output during winter – some years will be higher and some lower
- Hydro inflows are also variable, and if low wind and solar generation coincides with low inflows this will cause extra stress on the electricity system
- As above, we first show correlation between hydro inflows at a site and technology level
- Most wind sites are (very loosely) positively correlated with hydro inflows
  - i.e. they will tend to exacerbate dry winters
- Solar sites have the opposite relationship, but to an even lesser extent



Relationship

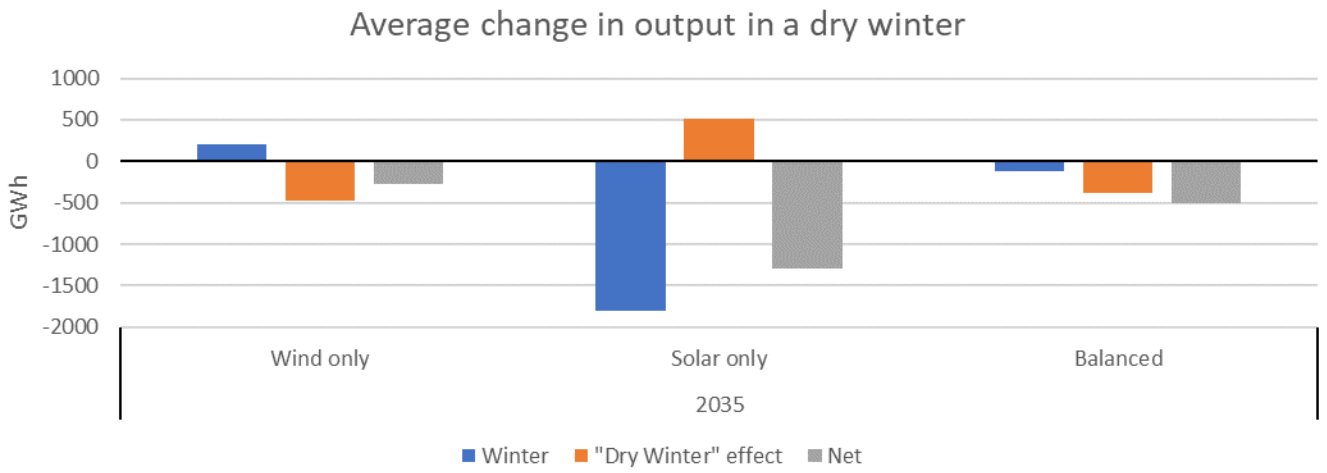
- Correlation alone provides little (no) information about the scale of the relationship between the two. The two series could be very highly correlated, but only move by a few GWh
- The graph below shows hydro inflows and wind + solar generation across the 40 winters considered.
- There is a clear positive relationship between the two, albeit with a large amount of noise
- The slope of this line suggests that in a dry winter, output from wind and solar will be about 400 GWh lower than normal *on average*
- A typical dry winter has about 1500-2000 GWh less inflows than normal, so dry winters will be made ~25% worse by increased wind and solar generation
  - Locational diversity has minimal effect on this

2035-concentrated-balanced scenario



Dry winter + winter

- The behaviour of wind and solar in a typical winter and its behaviour during dry winters are two closely linked effects
- Focusing on 2035:
  - Our wind only scenario increases generation on average over winter – but it drops during dry winters. The net effect is a reduction of about 300 GWh in a dry winter on average
  - Our solar only scenario reduces generation dramatically (-1800 GWh) over winter, so although it has slightly higher output in dry winters this is outweighed by the seasonal effect
  - Our balanced scenario has slightly lower output in winter on average, and even lower output in dry winters. The net effect is a reduction of about 500 GWh in our balanced scenario

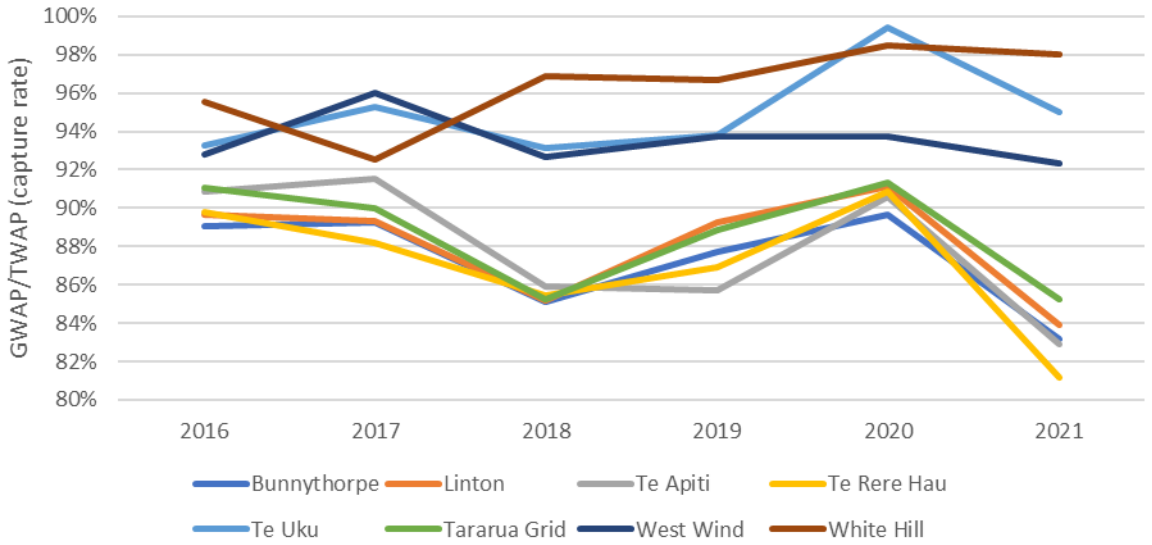


Offshore wind?

- As an addendum to the initial report we briefly looked at offshore wind at three possible sites:
  - South Taranaki
  - West Auckland
  - Waikato
- Offshore wind doesn't increase *diversity*
  - Offshore wind projects will probably be "mega"-projects, so are inherently concentrated. This is a particular challenge for a smaller market like New Zealand.
  - South Taranaki is highly correlated with existing wind at Tararua
- Lower diversity means worse outcomes for hourly peak and week-to-week variation.
- However, West Auckland and Waikato sites have very high (>120%) winter vs rest of year generation ratios, and
- Offshore wind is still positively corelated with dry winters, but less so than onshore sites.

Current wind farms

- Our analysis suggests that the “diversity benefit” for wind generation is not as large as might be expected.
- However, there are clear differences in revenues for current wind farms depending on location.
- Those in the Tararua region have significantly lower GWAP/TWAP ratios (capture rates) than those in other locations.



Why might that be?

- It’s not clear exactly what causes this difference, but we suspect that it is a combination of:
  - Steep supply curves
    - Very steep supply curves mean that small differences in generation during times of system stress can have a disproportionately large outcomes on prices and revenues
  - Transmission constraints
    - The prices experienced by White Hill may be significantly different from North Island locations
  - Less correlation in practice than our modelled generation data
    - The generation data used for our analysis comes from a modelling process. Our analysis (Appendix A in the report) indicates that this slightly underestimates the differences between different sites.

Conclusions

- Our timeframes of concern:
- Hourly
  - Solar alone will not contribute to meeting peak demand, while wind will help slightly
  - Batteries may mean this timeframe is less important in the future
- Weekly
  - Solar alone and wind alone are worse than a combination of both.
  - Technological diversity helps
- Winter
  - Solar generates significantly less in winter
  - Wind generates slightly more in winter, but slightly less in dry winters
  - The net effect of this is a reduction in output during dry winters

- Having a mix of solar and wind can help some aspects
- Increasing locational diversity can help most aspects

About Concept Consulting Group Ltd (www.concept.co.nz)

Concept is one of New Zealand's applied economics consultancies. We have been providing high-quality advice and analysis for more than 20 years across the energy sector, and in environmental and resource economics. We have also translated our skills to assignments in telecommunications and water infrastructure.

Our strength is from combining economic & regulatory expertise with deep sector knowledge and leading quantitative analysis.

Our directors have all held senior executive roles in the energy sector, and our team has a breadth of policy, regulatory, economic analysis, strategy, modelling, forecasting, and reporting expertise. Our clients include large users, suppliers, regulators, and governments – both in New Zealand and the wider Asia-Pacific region.

Disclaimer

Except as expressly provided for in our engagement terms, Concept and its staff shall not, and do not, accept any liability for errors or omissions in this report or for any consequences of reliance on its content, conclusions or any material, correspondence of any form or discussions, arising out of or associated with its preparation.

The analysis and opinions set out in this report reflect Concept's best professional judgement at the time of writing. Concept shall not be liable for, and expressly excludes in advance any liability to update the analysis or information contained in this report after the date of the report, whether or not it has an effect on the findings and conclusions contained in the report.

This report remains subject to any other qualifications or limitations set out in the engagement terms.

No part of this report may be published without prior written approval of Concept.