# 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.

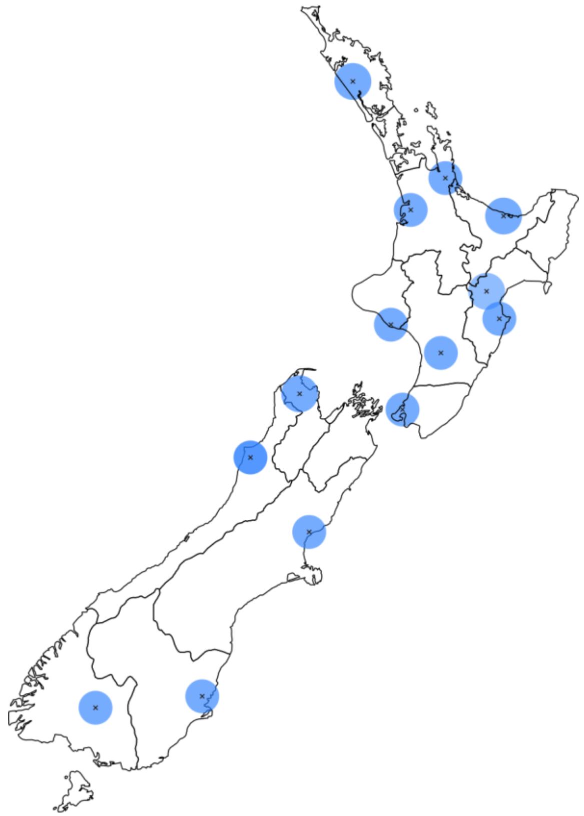
- We didn’t undertake a full system simulation exercise, but we considered how these curves interact with demand and inflows and the effect that has on the electricity system.

# 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.

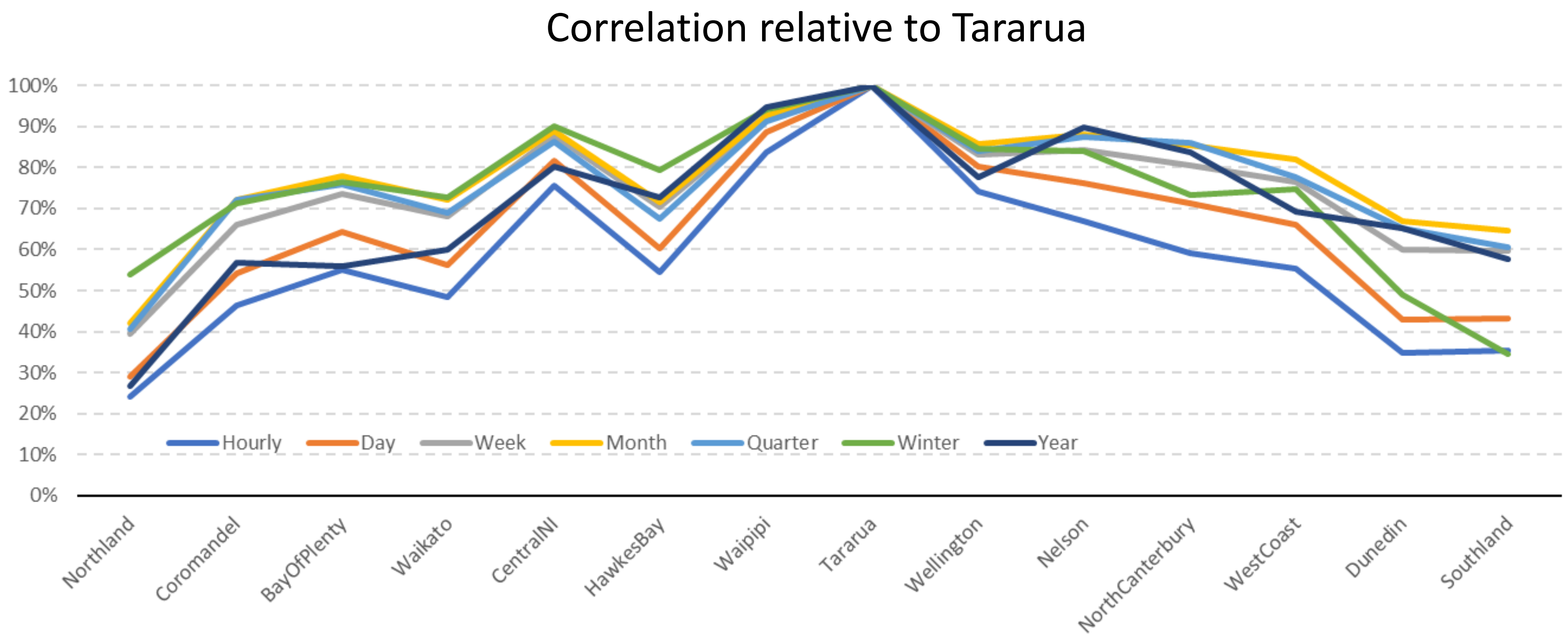
# Step 1 – Look at correlations between sites and technologies

- 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



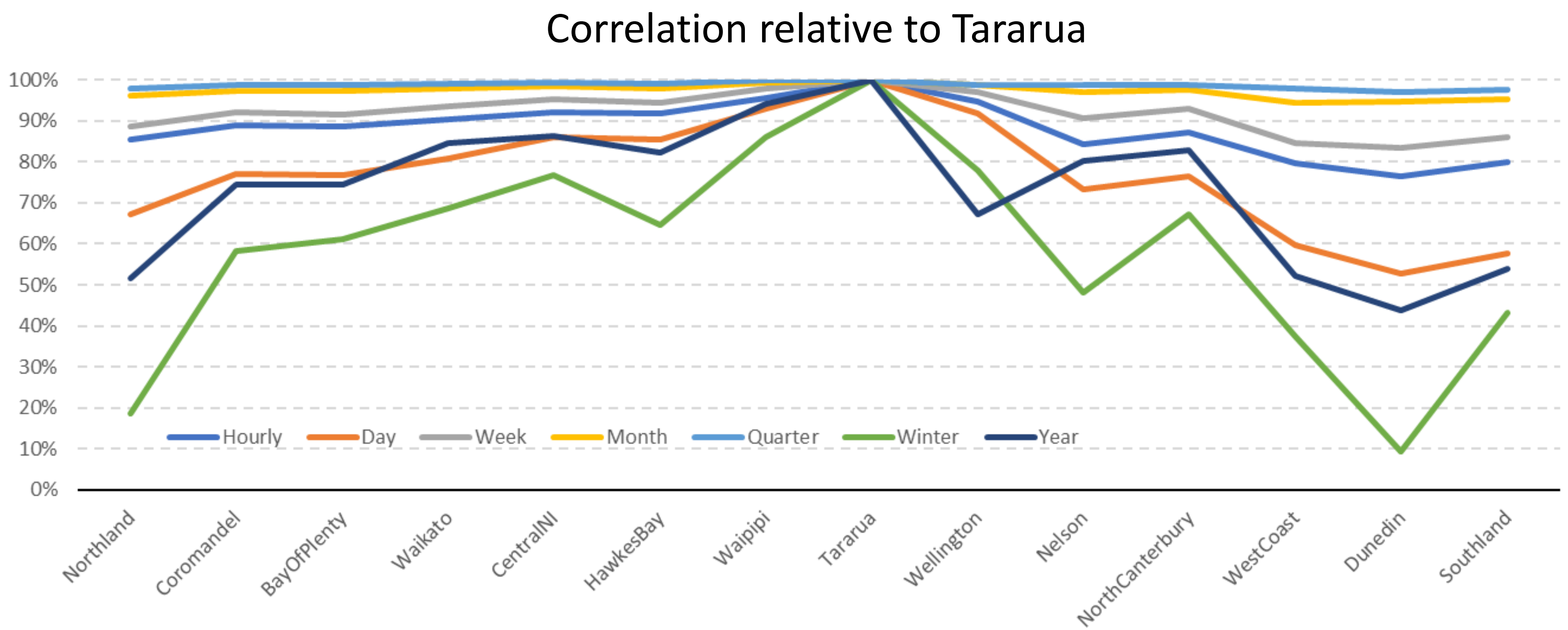
# Wind Site Data – Geographic diversity

- 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



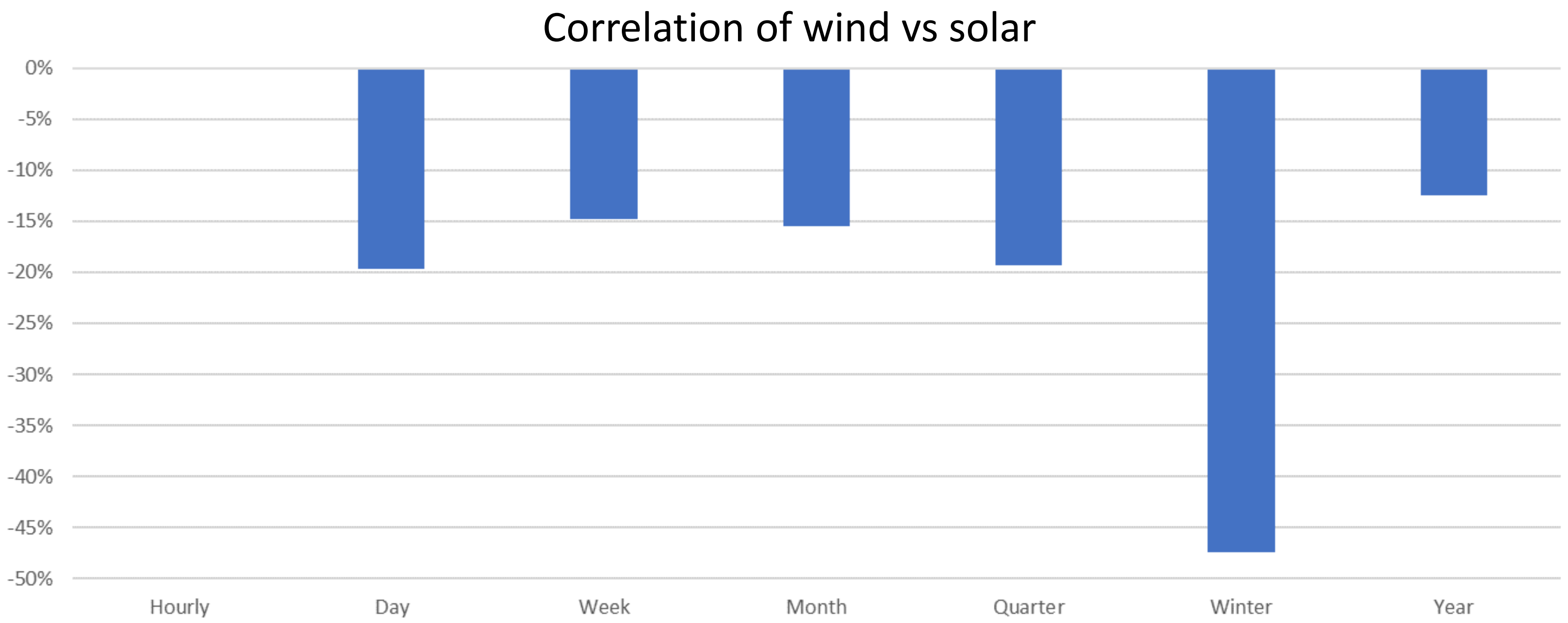
# Solar Site Data – Geographic diversity

- 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



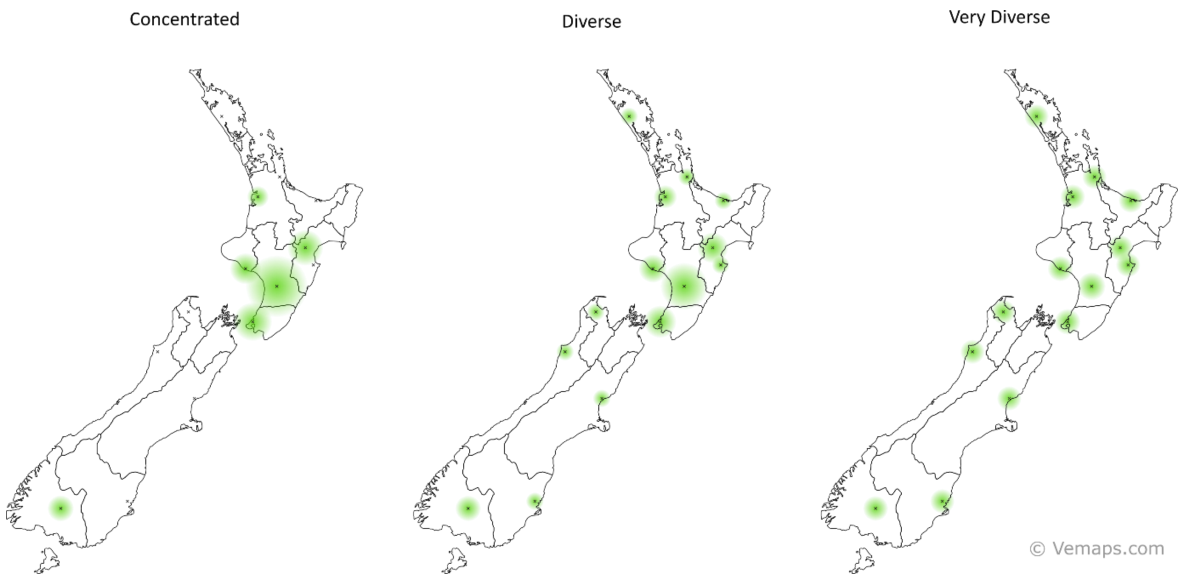
# Wind / Solar diversity

- 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

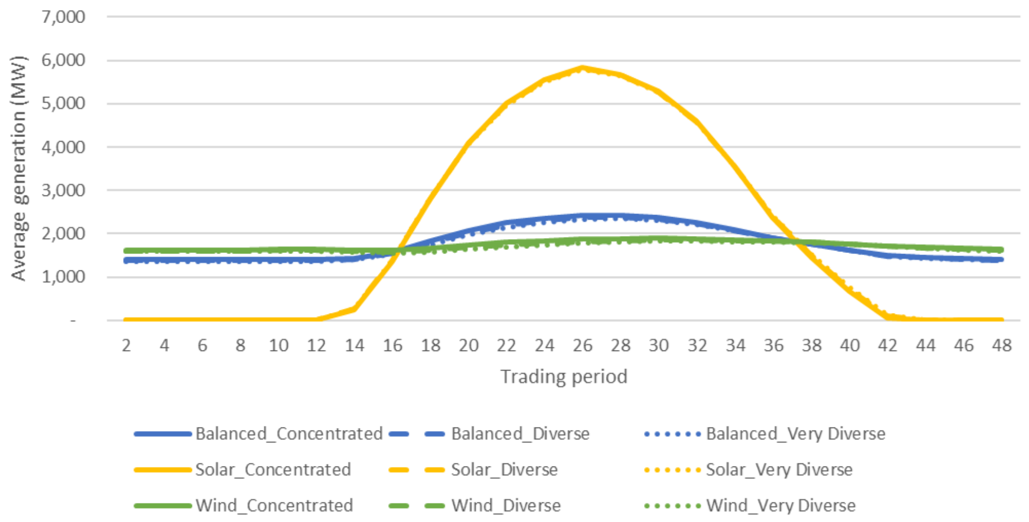



- In the interests of brevity, we concentrate on 2035 in this presentation, but both are shown in full in the report

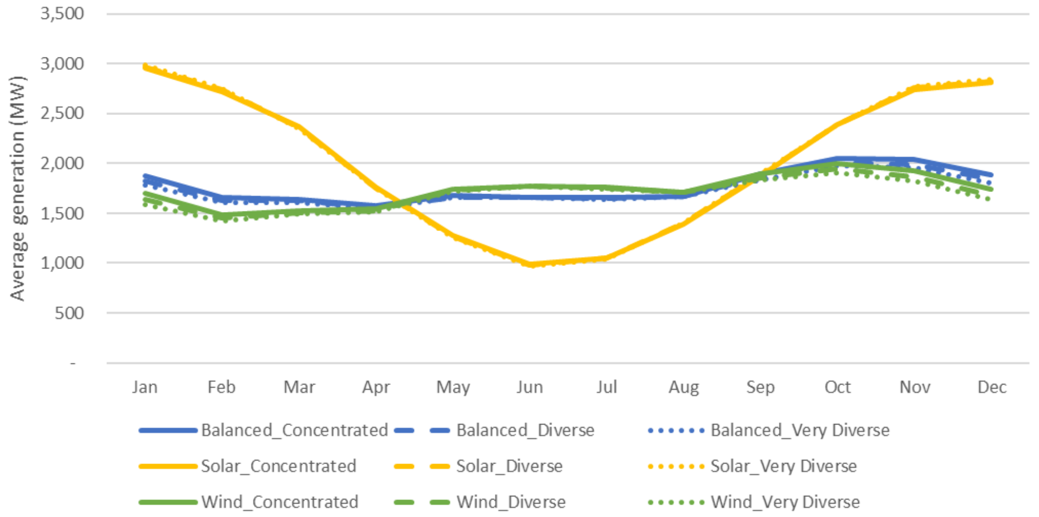
# Build schedules output

- 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

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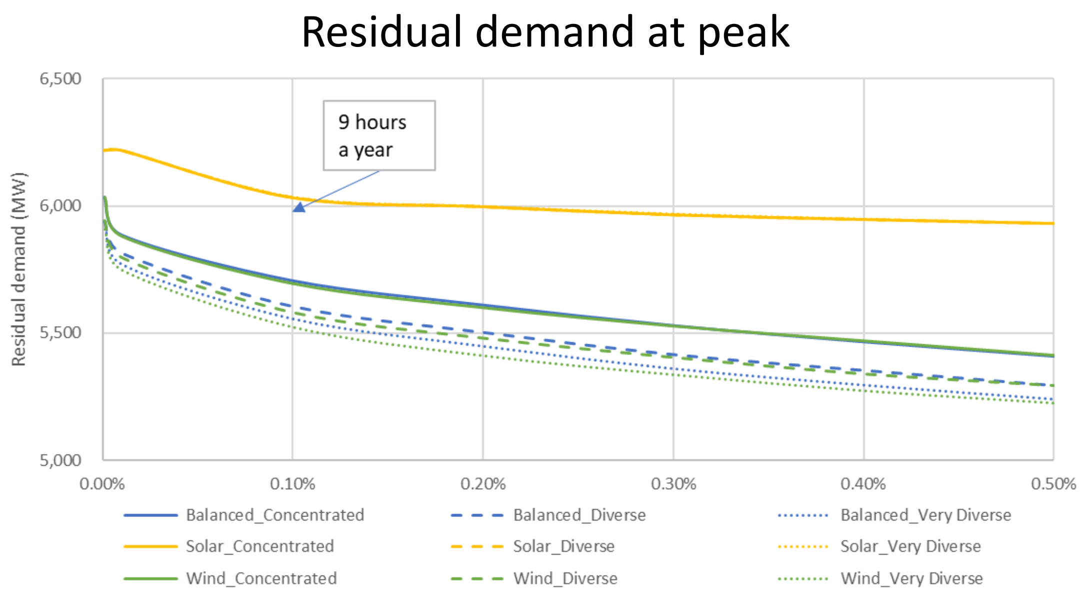
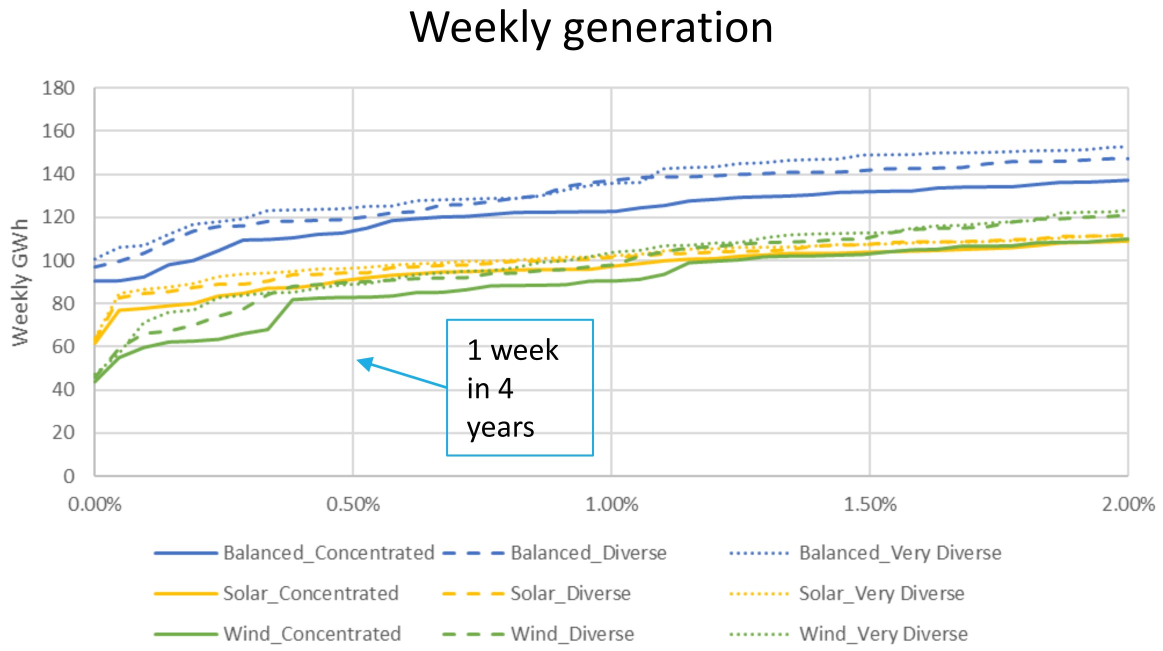
- We matched historical demand with the historical generation data to produce residual demand at an hourly level
- This is significantly higher for the solar-only series since there is negligible generation during system peak
- As before, the difference between dashes, dots and solid lines shows the 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

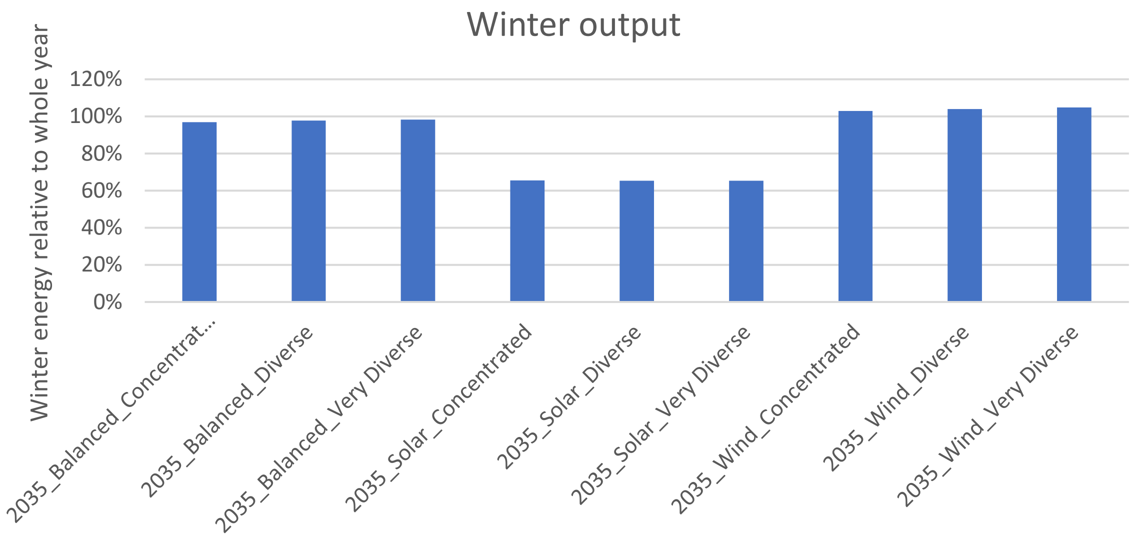


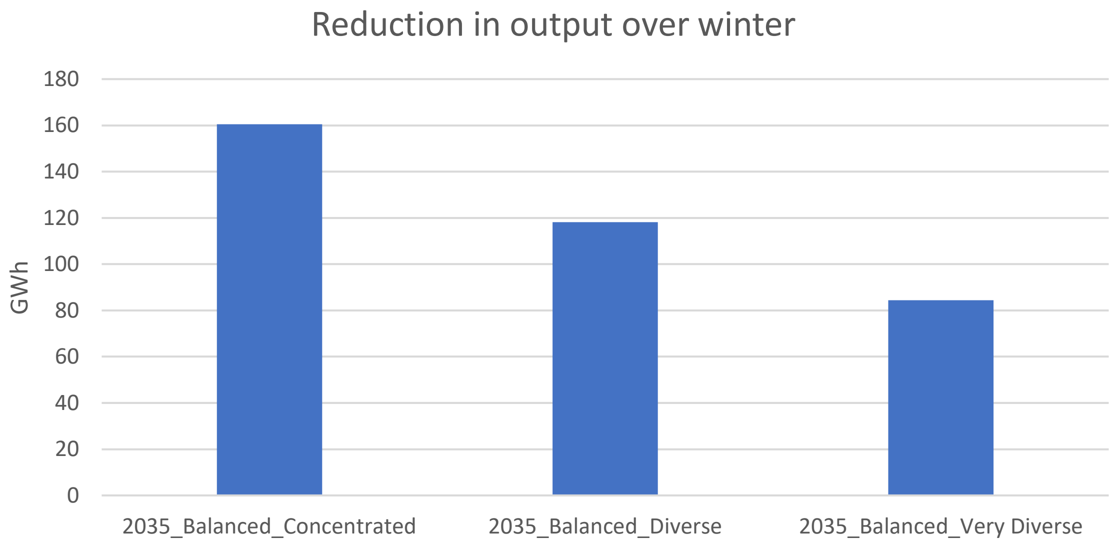
# Seasonal output (i.e. winter)

- 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)

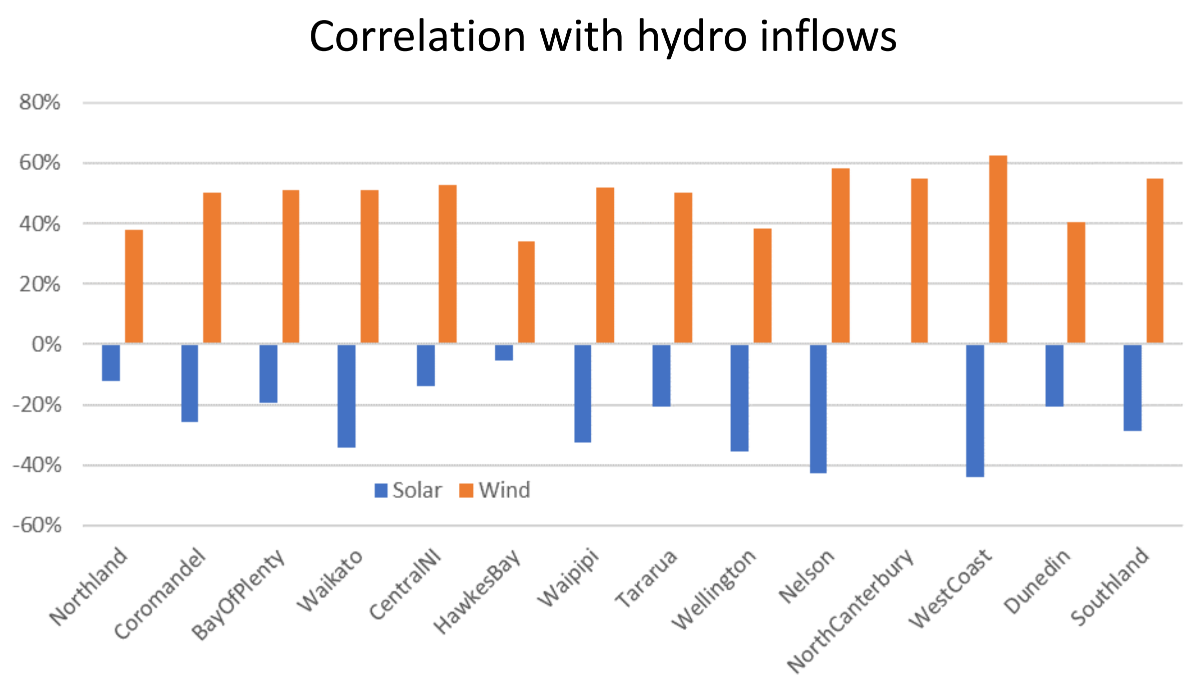
- We can quantify the reduction in energy during winter:
  - 160 GWh on average for concentrated case
  - Locational diversity reduces this slightly
    - Primarily because output from sites other than Tararua is higher in winter



# “Dry winter”

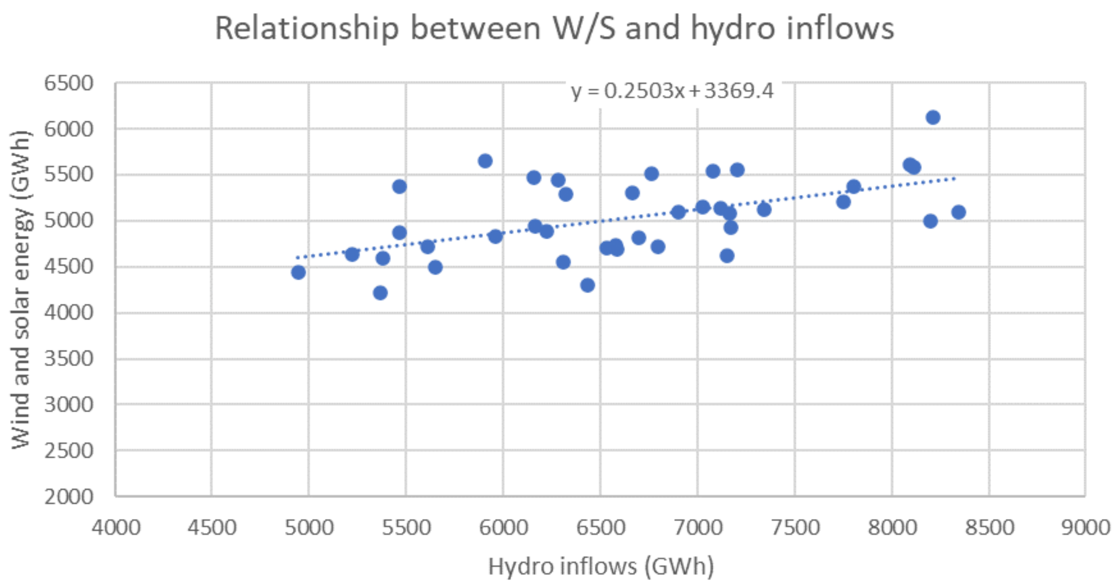
- The previous slide showed *average* output during winter – some years will be higher and some lower
- Hydro inflows are also variable, and if low wind and solar generation coincides with low inflows this will cause extra stress on the electricity system
- As above, we first show correlation between 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

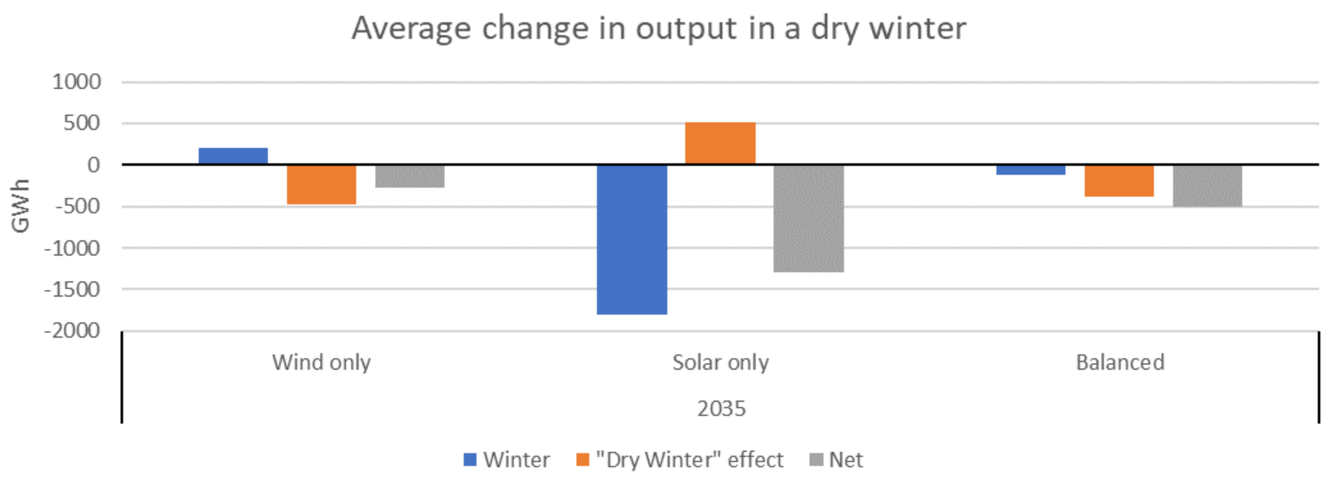
- Correlation alone provides little (no) information about the scale of the relationship between the two. The two series could be very highly correlated, but only move by a few GWh
- The graph below shows hydro inflows and wind + solar generation across the 40 winters considered.
- There is a clear positive 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

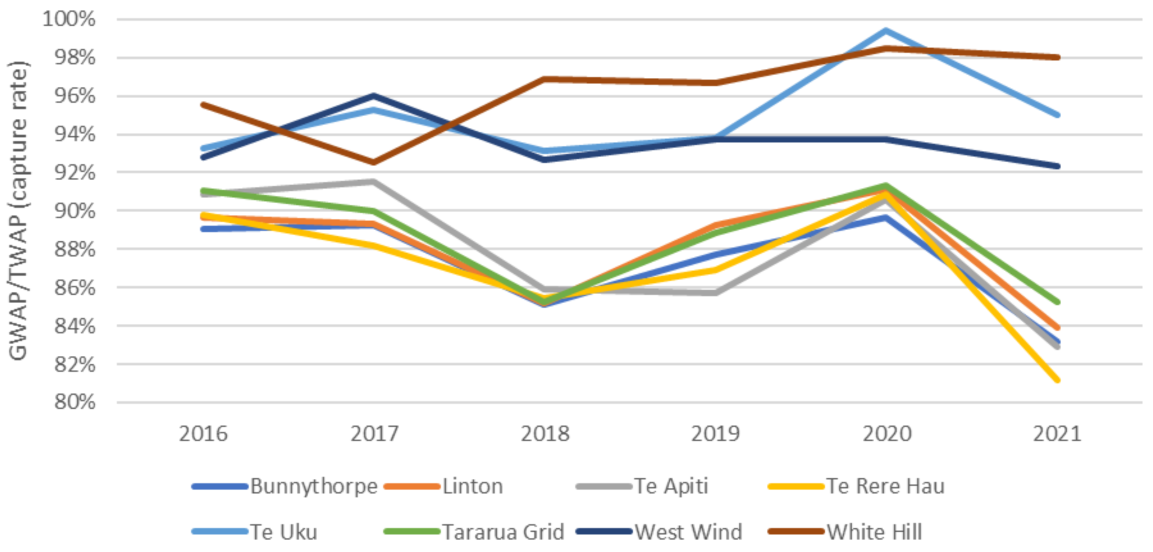


# Offshore wind?

- 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

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