

**ICCC MODELLING:  
WIND AND SOLAR  
PROFILES**

**FINAL REPORT  
APRIL 2019**

REPORT TO THE INTERIM CLIMATE CHANGE COMMITTEE

John Culy Consulting

APRIL 2019

# CONTENTS

<b>1</b>	<b>INTRODUCTION .....</b>	<b>4</b>
<b>2</b>	<b>DATA SOURCES .....</b>	<b>5</b>
2.1	HISTORICAL MARKET DATA .....	5
2.2	RENEWABLE NINJA .....	5
2.3	WIND CALIBRATION .....	6
<b>3</b>	<b>SYNTHETIC HOURLY DATA.....</b>	<b>11</b>
3.1	WIND DATA SUMMARY STATISTICS .....	11
3.1.1	SEASONAL AND DAILY PATTERN BY REGION .....	12
3.1.2	VARIATION .....	13
3.1.3	CROSS CORRELATION .....	14
3.2	SOLAR DATA .....	15
3.2.1	SUMMARY STATISTICS .....	16
3.2.2	SOLAR SEASONAL AND DAILY PATTERNS .....	16
3.2.3	SOLAR VARIATION DAILY, MONTHLY AND ANNUAL .....	18
3.2.4	SOLAR CORRELATIONS.....	18
3.2.5	ILLUSTRATIVE SOLAR PROFILES .....	19

## LIST OF TABLES

TABLE 1: ANNUAL SUMMARY STATISTICS .....	11
TABLE 2: MONTHLY SUMMARY STATISTICS .....	11
TABLE 3: DAILY SUMMARY STATISTICS .....	12
TABLE 4: CROSS CORRELATION MATRICIES FOR SYSTEMIC WIND DATA.....	15
TABLE 5: ANNUAL, MONTHLY AND DAILY SUMMARY STATISTICS.....	16

## LIST OF FIGURES

FIGURE 1: AN ILLUSTRATIVE POWER CURVE .....	6
FIGURE 2: COMPARISON OF MONTH RENEWABLE NINJA AND ACTUAL WIND.....	7
FIGURE 3: COMPARISON OF ACTUAL AND NINJA DATA - 1 .....	8
FIGURE 4: COMPARISON OF ACTUAL AND NINJA DATA - 2 .....	9
FIGURE 5: COMPARISON OF ACTUAL AND NINJA DATA - 3 .....	10
FIGURE 6: MONTHLY AND DAILY WIND PATTERNS.....	12
FIGURE 7: MONTHLY VARIATION BY WIND PROFILE.....	13
FIGURE 8: DAILY, MONTHLY AND ANNUAL VARIATION BY WIND PROFILE .....	13
FIGURE 9: CROSS CORRELATIONS BETWEEN WIND FARMS.....	14
FIGURE 10: SEASONAL AND DAILY PATTERN.....	17
FIGURE 11: SEASONAL AND DAILY PATTERN.....	17
FIGURE 12: VARIATION BY DAY, MONTH AND YEAR .....	18
FIGURE 13 CROSS CORRELATION BETWEEN SOLAR FARMS .....	19

# 1 INTRODUCTION

This report summarises the construction of synthetic hourly data sets for several wind and solar weather years from a range of locations in New Zealand.

The wind profiles use actual market data where this is available and extrapolate this back in time using data from the Renewable Ninja website.

Wind and solar profiles for new plant in other locations is derived directly from the data available on the Renewable Ninja website. This data is adjusted to reflect generic capacity factors in each region.

The wind and solar profiles used in the modelling do not reflect any particular site or turbine/panel choice, rather they are reflective of a generic new plant in the relevant region. The profiles attempt to capture the likely variation in supply and the correlation with other existing and new wind/solar projects.

The solar profiles are only applied to large scale solar.

## 2 DATA SOURCES

### 2.1 HISTORICAL MARKET DATA

Actual generation data is available from the Electricity Authority for several wind farms by half hour from their commissioning dates. These include Tararua, Te Apiti, West Wind, Te Uku, Te Rere Hau and White Hill. This data was downloaded and converted into hourly average capacity factors by dividing average MW by the wind farm capacity. Where necessary the wind farm capacity was adjusted to reflect significant step ups in capacity or for major maintenance periods. The initial construction period was excluded, since no information was available on the commissioning timetable for turbines. As a rule, the historical data includes random short run availability deratings, except for periods where it is clear there have been major sustained outages.

### 2.2 RENEWABLE NINJA

The renewable Ninja data<sup>1</sup> is available for the period 2000 to 2016<sup>2</sup> by hour. It is derived by taking weather data from global reanalysis models and satellite observations. The 2 main sources are the NASA MERRA reanalysis and the CM-SAF's SARA dataset. The data used was based on the NASA MERRA(2) global reanalysis.

Data available includes wind speed, solar irradiance data and simulated power output based a virtual wind farm (with a specified turbine type, hub height, etc) and a typical solar farm.

Typically, the wind speed data was used from the renewable Ninja site, then adjusted it to reflect known or expected wind speeds. It was then converted to power output using an empirical or modelled power curve reflecting the actual wind farm (where known) or a typical turbine type for possible future wind farms in other locations.

The Renewable Ninja data is used to extrapolate data from the date of commissioning back to 2000 for existing wind farms, and to estimate expected output from future wind farms for the historical weather years 2000 to 2016.

For existing wind farms the power curve is tuned to calibrate the power curve shape and wind speed scaling to get a good match to the level, volatility and correlation for the actual and simulated synthetic data. An example of the power curve used to convert from wind speed to

---

<sup>1</sup> <https://www.renewables.ninja/>.

<sup>2</sup> Data from 2016 to 2018 is now available as at 9 April 2019, but was not when the data sets were constructed.

generation is given below. This shows capacity factor achieved as a function of wind speed.

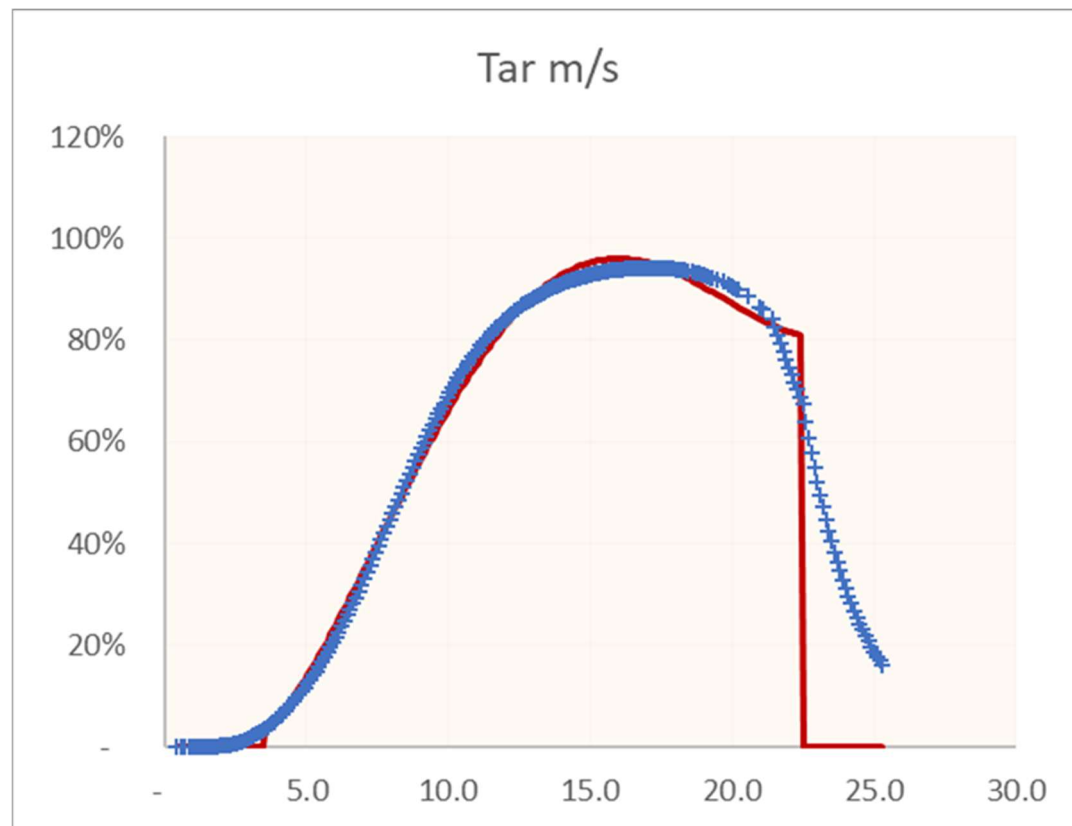


FIGURE 1: AN ILLUSTRATIVE POWER CURVE

## 2.3 WIND CALIBRATION

The charts below show examples of the calibration of Ninja based synthetic data with actual market generation data on a monthly basis back to 2000.

The second set of charts show the comparison for a sample historical year and month.

As can be seen the Renewable Ninja data is not exactly the same as the actual, but follows it reasonably well and has similar levels of correlation and variation. It's a reasonable proxy to backfill the hourly wind data back to 2000 for existing wind farms. The actual wind generation is slightly more volatile on an hourly time step. This is not considered to be a major limitation since most of the Energy Link modelling uses a 3-hour time step.

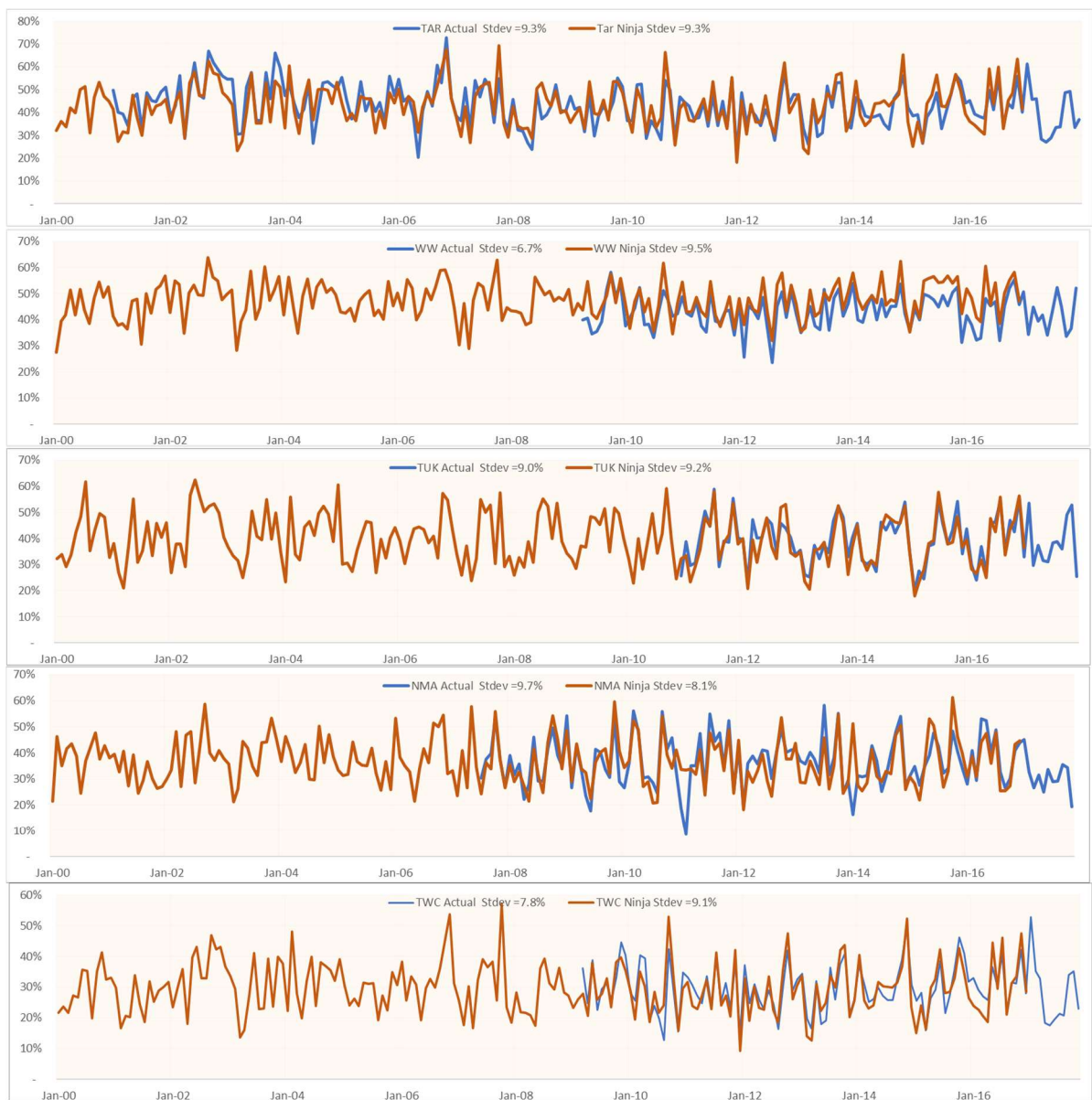


FIGURE 2: COMPARISON OF MONTH RENEWABLE NINJA AND ACTUAL WIND

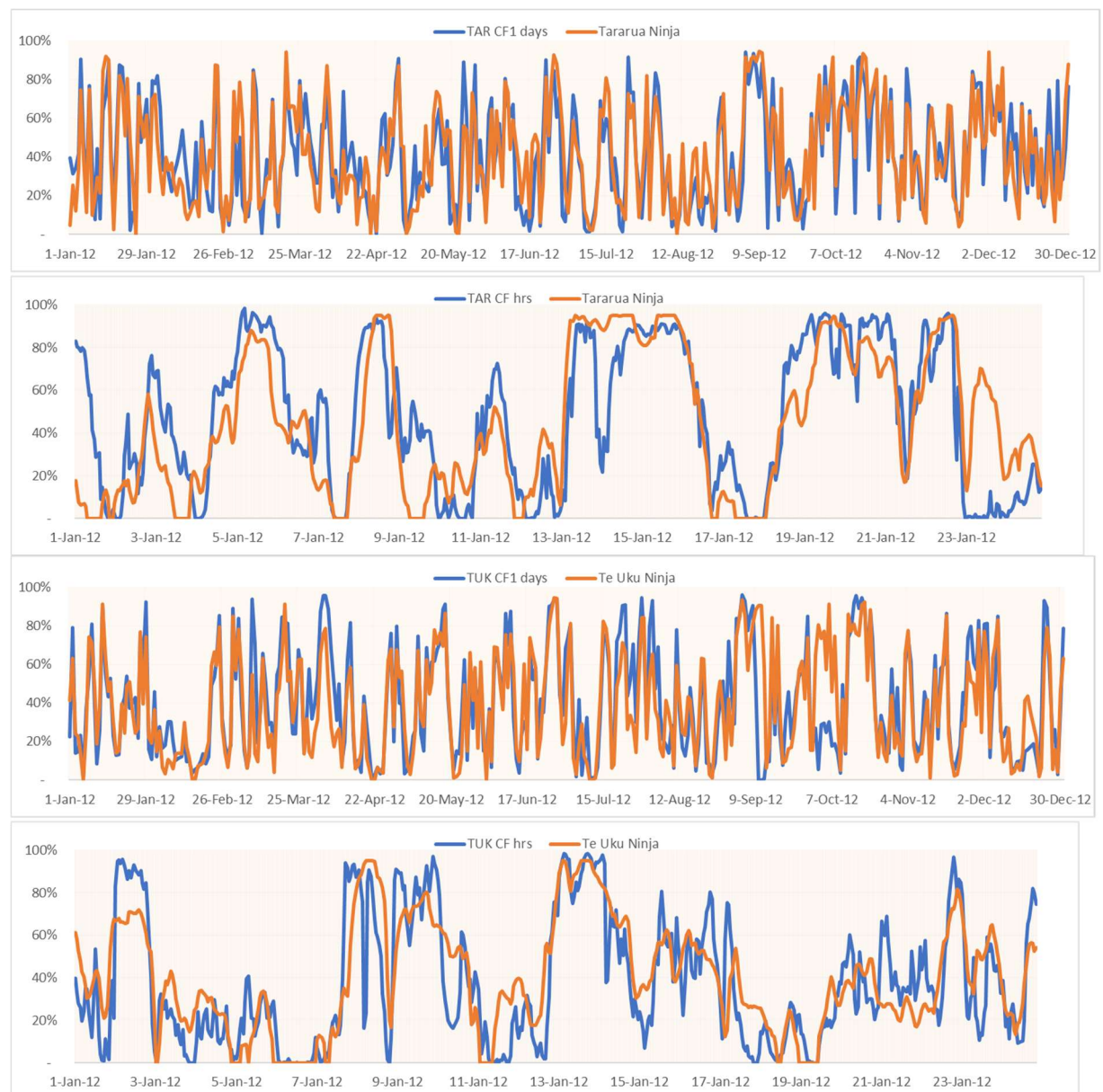
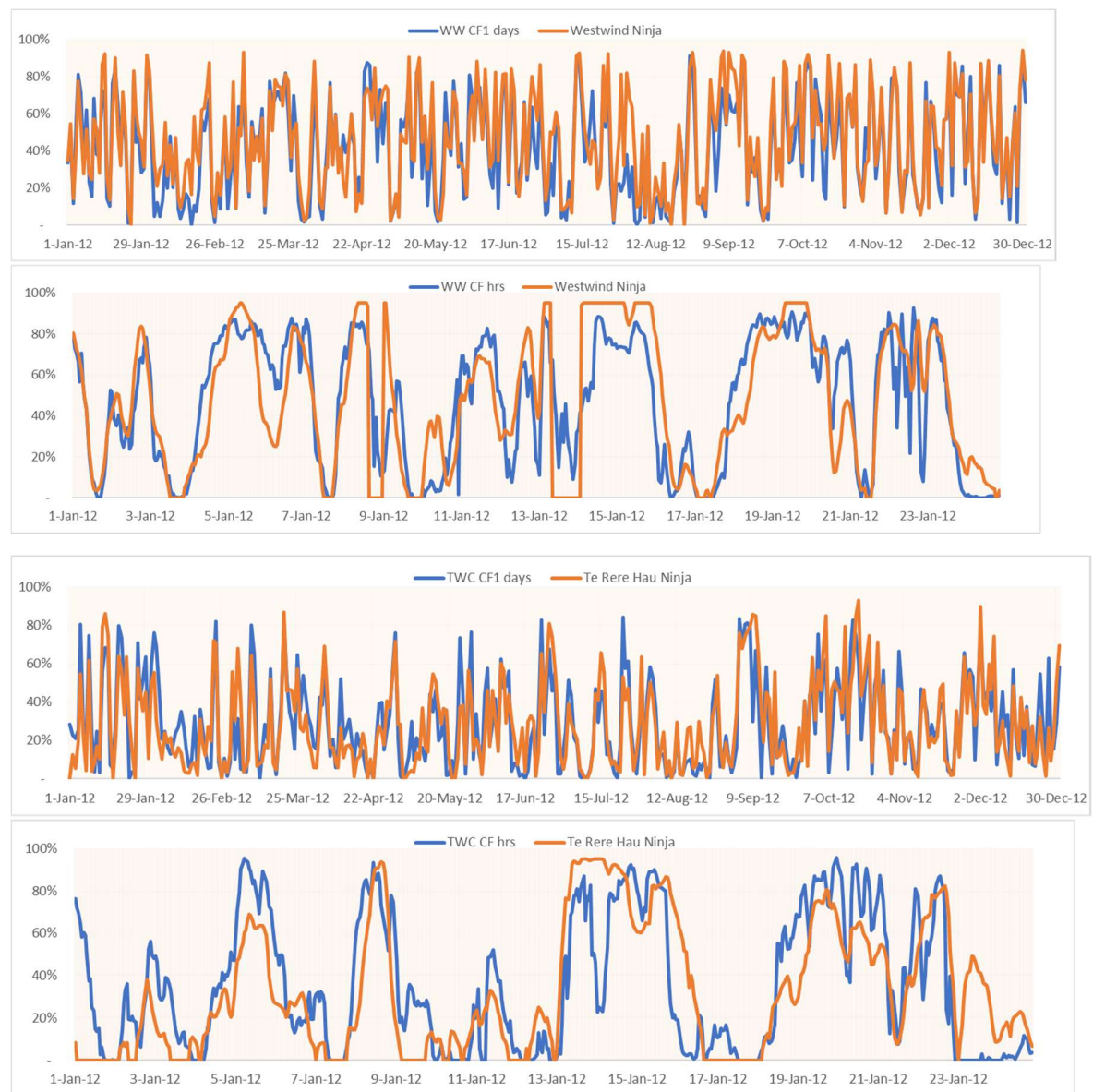
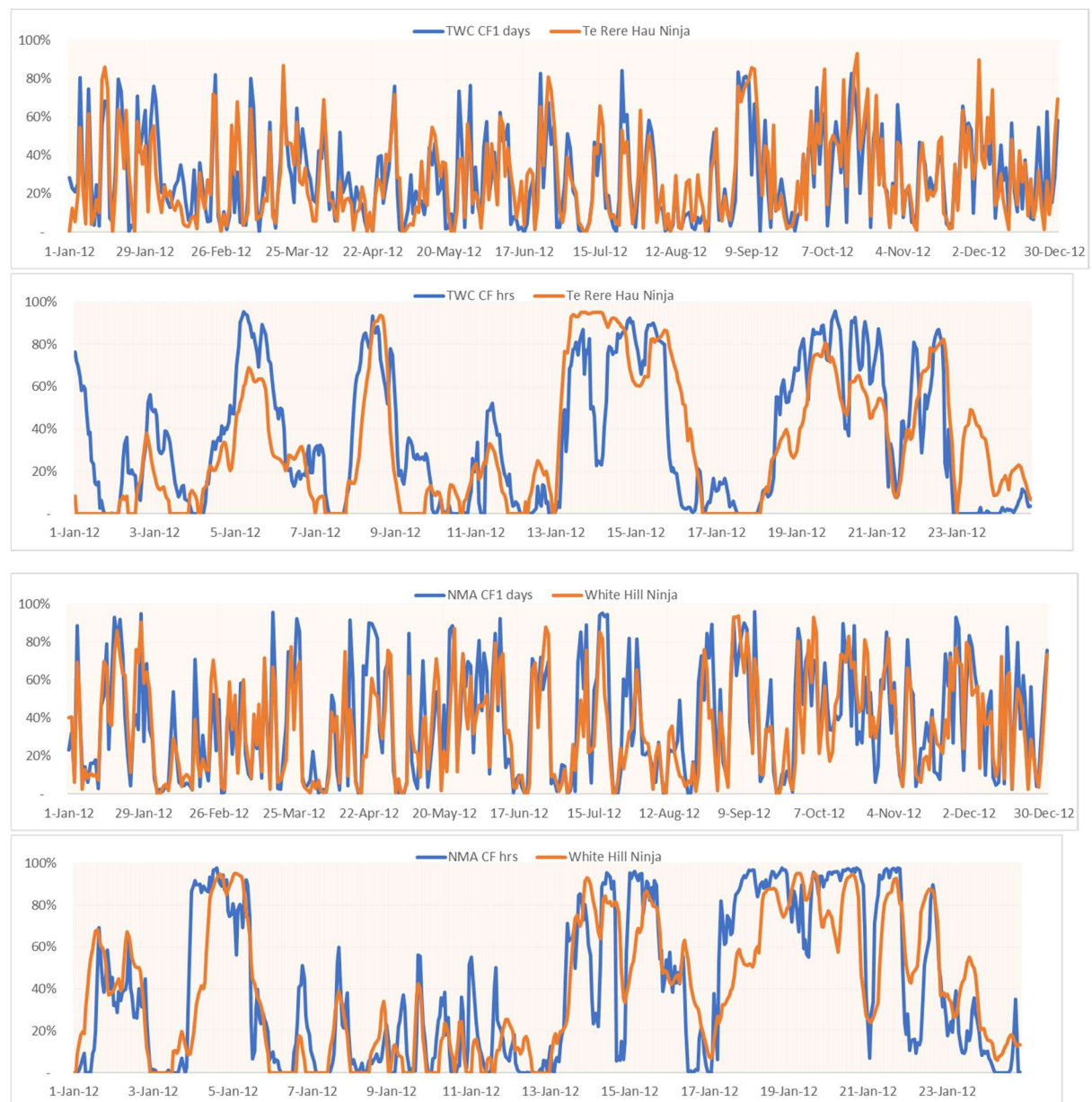


FIGURE 3: COMPARISON OF ACTUAL AND NINJA DATA - 1





**FIGURE 4: COMPARISON OF ACTUAL AND NINJA DATA - 2**



**FIGURE 5: COMPARISON OF ACTUAL AND NINJA DATA – 3**

As can be seen, it is not possible to get a perfect match, but in general the errors appear to be reasonably small, and the synthetic data retains the expected levels of volatility and correlation as the actual.

### 3 SYNTHETIC HOURLY DATA

This section provides summary statistics for the full synthetic data set. These statistics are provided separately for monthly, daily and hourly time steps.

#### 3.1 WIND DATA SUMMARY STATISTICS

The summary statistics for the synthetic wind data is summarised in the following tables. These show the mean (unconstrained) capacity factors and the observed % variation on an annual, monthly and daily basis.

TABLE 1: ANNUAL SUMMARY STATISTICS

	Annual Max	Annual P10	Annual P90	Monthly Min	Mean Capacity Factor	Annual Volatility	Annual Cross Correl Taranua
Te Apati	51%	46%	37%	34%	41%	10%	89%
Taranua	51%	48%	40%	38%	43%	8%	100%
West Wind	51%	49%	42%	42%	45%	6%	78%
Te Uku	46%	43%	37%	36%	40%	6%	54%
Te Rere Hau	35%	33%	27%	26%	30%	8%	64%
White Hill	40%	39%	34%	32%	37%	7%	47%
Northland	48%	45%	39%	38%	42%	6%	47%
Kaimai	49%	46%	40%	39%	43%	6%	56%
Hawkes Bay	49%	47%	41%	39%	43%	7%	68%
Wairarapa	48%	46%	39%	38%	42%	7%	65%
Waverley	49%	46%	40%	39%	43%	6%	56%
Taranaki	49%	47%	41%	39%	43%	6%	68%
Wellington	45%	45%	40%	39%	42%	5%	50%
Canterbury	47%	46%	40%	38%	42%	6%	51%
Southland	48%	46%	41%	40%	43%	5%	62%

TABLE 2: MONTHLY SUMMARY STATISTICS

	Monthly Max	Monthly P10	Monthly P90	Monthly Min	Mean Capacity Factor	Monthly Stdev	Monthly Volatility	Monthly Cross Correl Taranua	Monthly Serial Correl
Te Apati	67%	54%	30%	20%	41%	9%	23%	93%	18%
Taranua	73%	55%	32%	20%	43%	9%	22%	100%	18%
West Wind	64%	54%	36%	23%	45%	7%	16%	66%	20%
Te Uku	63%	54%	27%	20%	40%	10%	24%	50%	25%
Te Rere Hau	57%	40%	19%	13%	30%	8%	27%	86%	11%
White Hill	59%	49%	26%	9%	37%	9%	25%	58%	7%
Northland	67%	56%	29%	17%	42%	10%	24%	30%	37%
Kaimai	70%	56%	31%	22%	43%	9%	22%	53%	23%
Hawkes Bay	69%	56%	31%	20%	43%	10%	22%	76%	15%
Wairarapa	67%	54%	31%	21%	42%	9%	21%	78%	11%
Waverley	68%	54%	32%	23%	43%	9%	21%	71%	14%
Taranaki	69%	55%	31%	19%	43%	9%	22%	82%	10%
Wellington	58%	51%	34%	24%	42%	7%	16%	68%	8%
Canterbury	64%	53%	32%	22%	42%	8%	19%	66%	8%
Southland	71%	55%	33%	23%	43%	9%	21%	61%	8%

TABLE 3: DAILY SUMMARY STATISTICS

	Daily P5	Daily P10	Daily P25	Daily P75	Daily P90	Daily P95	Average	Daily Stdev	Daily Cross Correl Tararua	Daily Serial Correl
Te Apiti	87%	80%	64%	17%	6%	3%	41%	27%	96%	45%
Tararua	88%	82%	66%	20%	8%	4%	43%	27%	100%	44%
West Wind	86%	82%	67%	23%	10%	5%	45%	26%	53%	33%
Te Uku	86%	79%	62%	16%	6%	3%	40%	27%	35%	53%
Te Rere Hau	74%	66%	47%	10%	3%	1%	30%	23%	87%	48%
White Hill	86%	79%	60%	11%	3%	1%	37%	28%	32%	50%
Northland	88%	81%	65%	19%	6%	2%	42%	27%	16%	56%
Kaimai	86%	80%	64%	21%	10%	5%	43%	26%	35%	55%
Hawkes Bay	89%	82%	65%	21%	10%	6%	43%	26%	68%	50%
Wairarapa	87%	80%	62%	21%	10%	6%	42%	25%	66%	47%
Waverley	86%	79%	63%	21%	9%	5%	43%	25%	62%	48%
Taranaki	89%	82%	64%	21%	10%	6%	43%	26%	73%	50%
Wellington	81%	76%	62%	22%	11%	6%	42%	24%	48%	35%
Canterbury	86%	80%	63%	21%	10%	6%	42%	25%	46%	46%
Southland	88%	82%	65%	21%	10%	6%	44%	26%	41%	58%

### 3.1.1 SEASONAL AND DAILY PATTERN BY REGION

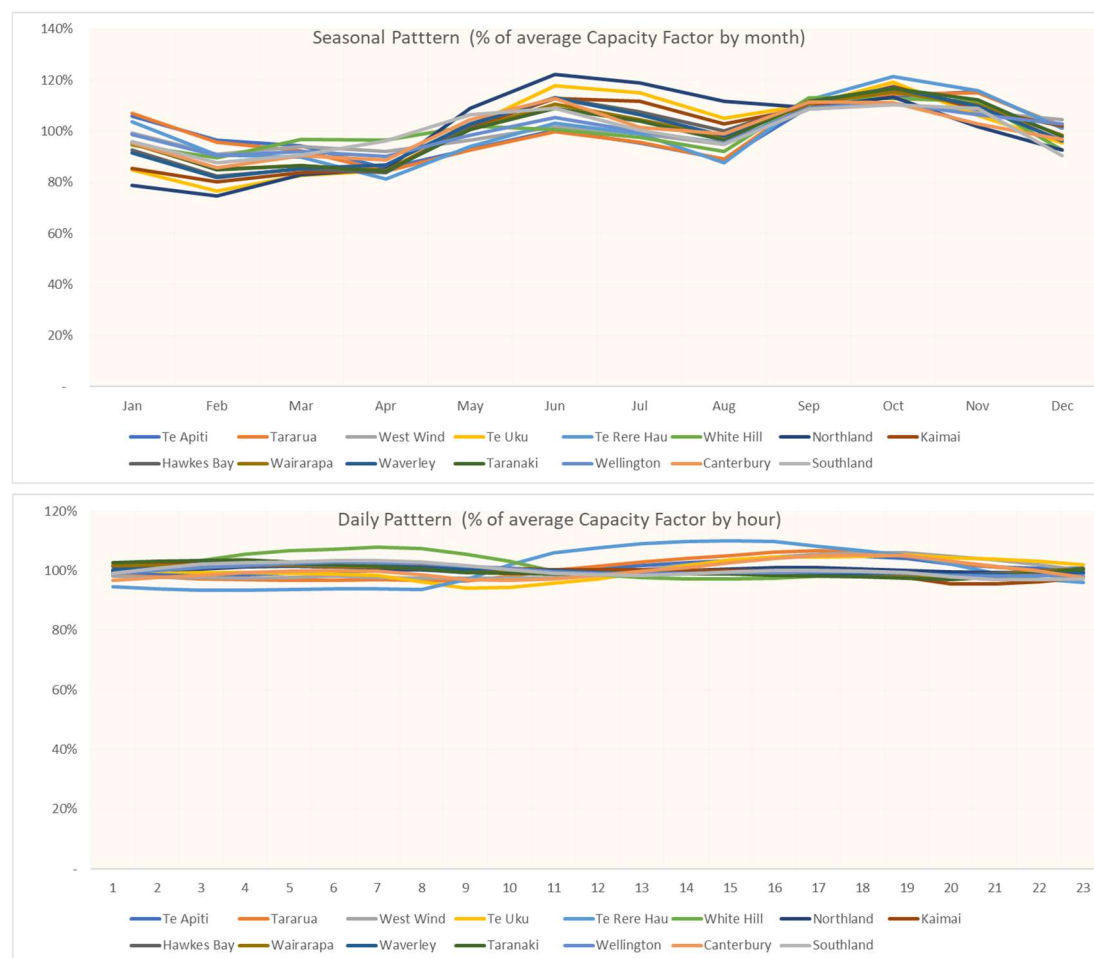


FIGURE 6: MONTHLY AND DAILY WIND PATTERNS

As can be seen there is only a small seasonal variation, with a dip in March to April, and again in July and August. The peak wind is in

October and November. The daily pattern of wind is reasonably uniform.

### 3.1.2 VARIATION

The following charts show the variation in wind capacity factor on different time frames for each regional wind profile.

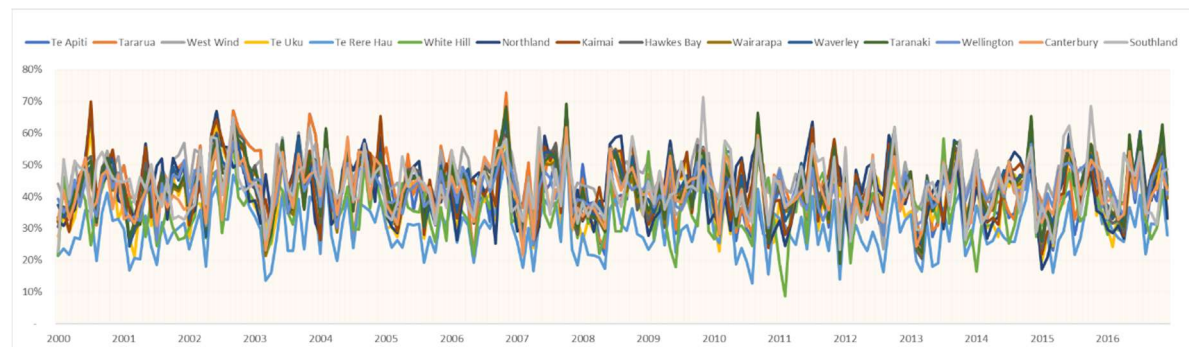


FIGURE 7: MONTHLY VARIATION BY WIND PROFILE

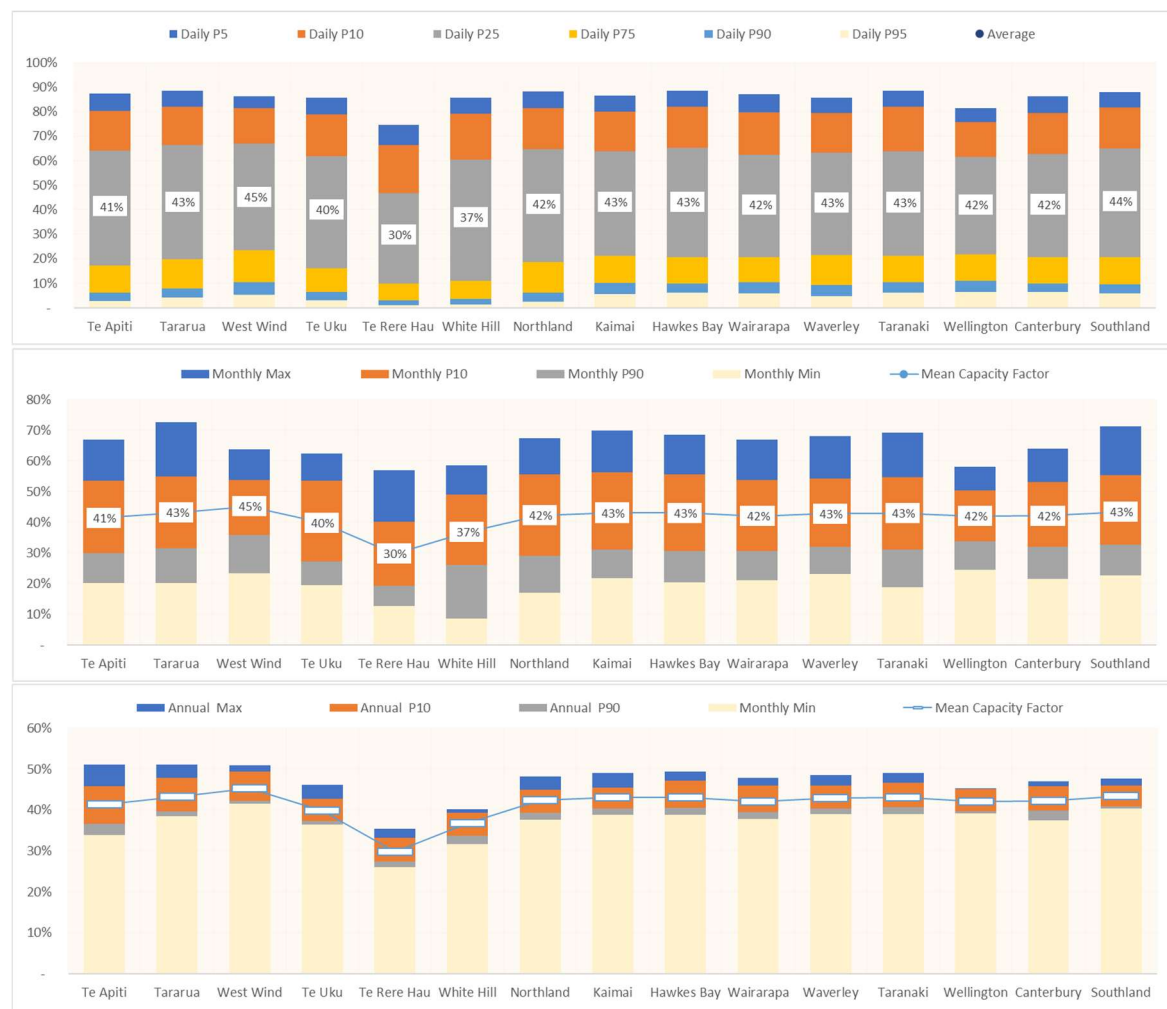
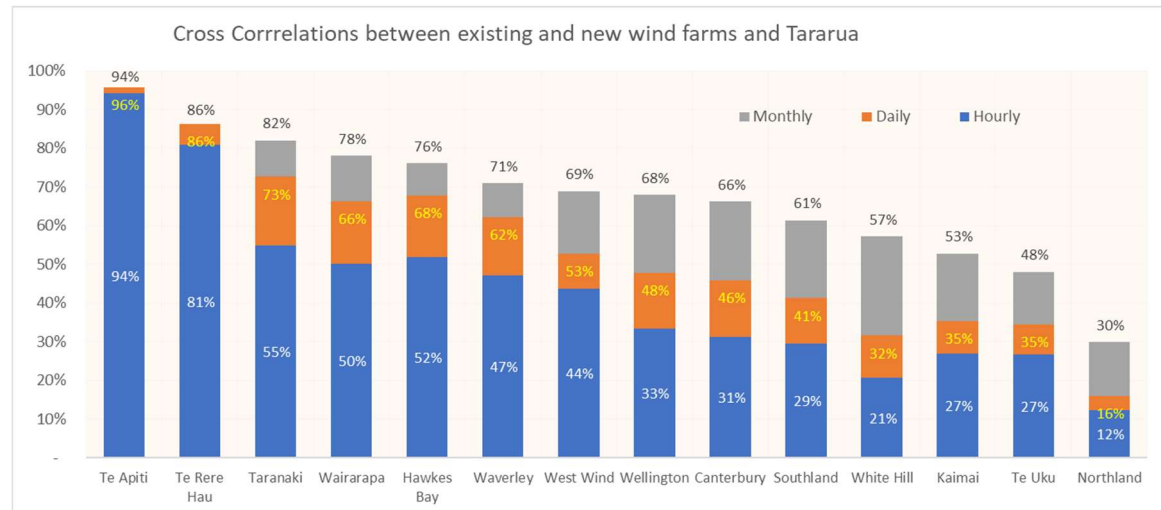


FIGURE 8: DAILY, MONTHLY AND ANNUAL VARIATION BY WIND PROFILE



### 3.1.3 CROSS CORRELATION

The chart below shows the cross correlation between each regional wind farm profile and Tararua, on the different time scales.



**FIGURE 9: CROSS CORRELATIONS BETWEEN WIND FARMS**

Note the relatively high cross correlation between wind in different regions. This is most pronounced on a monthly basis but is still significant on a daily basis. As expected, hourly cross correlations are much lower.

The full set of cross correlations between the regional wind profiles is given in the table (4) below.

TABLE 4: CROSS CORRELATION MATRICIES FOR SYSTEMIC WIND DATA

Hourly															
	TAP CF1	TAR CF1	WW CF1	TUK CF1	TWC CF1	NMA CF1	Nland CF1	Kai CF1	HB CF1	Wai CF1	Wav CF1	Tar CF1	Wel CF1	Cant CF1	Sland CF1
Te Aiti	100%														
Taranua	94%	100%													
West Wind	40%	44%	100%												
Te Uku	25%	27%	17%	100%											
Te Rere Hau	77%	81%	51%	41%	100%										
White Hill	21%	21%	13%	3%	20%	100%									
Northland	11%	12%	12%	60%	21%	(3%)	100%								
Kaimai	26%	27%	16%	67%	36%	5%	78%	100%							
Hawkes Bay	50%	52%	44%	43%	60%	20%	35%	52%	100%						
Wairarapa	48%	50%	50%	37%	58%	21%	31%	46%	97%	100%					
Waverley	44%	47%	46%	45%	54%	16%	43%	55%	79%	80%	100%				
Taranaki	53%	55%	46%	39%	61%	23%	32%	49%	96%	96%	86%	100%			
Wellington	30%	33%	56%	19%	38%	17%	18%	24%	63%	75%	67%	68%	100%		
Canterbury	30%	31%	36%	23%	36%	37%	19%	26%	54%	60%	47%	56%	57%	100%	
Southland	29%	29%	17%	20%	32%	58%	12%	21%	37%	36%	33%	38%	24%	47%	100%
Daily															
	TAP CF1	TAR CF1	WW CF1	TUK CF1	TWC CF1	NMA CF1	Nland CF1	Kai CF1	HB CF1	Wai CF1	Wav CF1	Tar CF12	Wel CF1	Cant CF1	Sland CF1
Te Aiti	100%														
Taranua	96%	100%													
West Wind	49%	53%	100%												
Te Uku	33%	35%	22%	100%											
Te Rere Hau	83%	86%	59%	50%	100%										
White Hill	32%	32%	22%	6%	30%	100%									
Northland	14%	16%	15%	75%	27%	(2%)	100%								
Kaimai	34%	35%	22%	84%	46%	7%	85%	100%							
Hawkes Bay	65%	68%	57%	56%	77%	27%	43%	62%	100%						
Wairarapa	63%	66%	65%	49%	76%	28%	38%	55%	98%	100%					
Waverley	59%	62%	60%	58%	70%	22%	50%	64%	85%	85%	100%				
Taranaki	70%	73%	61%	52%	80%	30%	39%	59%	97%	97%	90%	100%			
Wellington	44%	48%	79%	26%	54%	23%	23%	31%	70%	81%	75%	75%	100%		
Canterbury	45%	46%	54%	33%	53%	49%	25%	36%	67%	72%	59%	67%	69%	100%	
Southland	41%	41%	24%	27%	43%	68%	15%	26%	46%	44%	39%	46%	29%	59%	100%
Monthly															
	TAP CF1	TAR CF1	WW CF1	TUK CF1	TWC CF1	NMA CF1	Nland CF1	Kai CF1	HB CF1	Wai CF1	Wav CF1	Tar CF12	Wel CF1	Cant CF1	Sland CF1
Te Aiti	100%														
Taranua	94%	100%													
West Wind	68%	69%	100%												
Te Uku	47%	48%	51%	100%											
Te Rere Hau	82%	86%	73%	66%	100%										
White Hill	56%	57%	42%	27%	53%	100%									
Northland	30%	30%	38%	88%	45%	15%	100%								
Kaimai	51%	53%	51%	95%	68%	28%	90%	100%							
Hawkes Bay	72%	76%	73%	79%	89%	47%	65%	80%	100%						
Wairarapa	74%	78%	78%	75%	90%	48%	60%	76%	99%	100%					
Waverley	67%	71%	73%	84%	86%	46%	71%	84%	93%	93%	100%				
Taranaki	78%	82%	76%	76%	92%	51%	60%	78%	98%	99%	95%	100%			
Wellington	63%	68%	88%	58%	79%	40%	45%	59%	83%	89%	83%	86%	100%		
Canterbury	63%	66%	71%	59%	77%	61%	49%	60%	84%	86%	78%	82%	80%	100%	
Southland	60%	61%	45%	44%	64%	77%	32%	44%	65%	63%	60%	64%	47%	75%	100%

## 3.2 SOLAR DATA

The statistics for the synthetic solar data is summarised in the following tables. These show the mean (unconstrained) capacity factors and the observed % variation on an annual, monthly and daily basis.

The initial solar capacity factors are scaled to be approximately 25% over the year, on the assumption that single axis tracking is used, and the DC panel capacity is 1.3 oversized relative to the AC inverter capacity. This is typical for utility scale solar farms in Australia and the USA. The initial capacity factor is expected to decline at around 0.5% per annum and so the lifetime average capacity factor will be lower.

The capacity factors for utility scale solar in New Zealand is likely to be around 19% without single axis tracking and without significant oversizing.

Note that statistics are also provided for seasonally/daily adjusted data. This is the difference between the raw capacity factor in each hour and the mean expected in each month and hour over the year.

### 3.2.1 SUMMARY STATISTICS

TABLE 5: ANNUAL, MONTHLY AND DAILY SUMMARY STATISTICS

	Annual Max	Annual P10	Annual P90	Monthly Min	Mean Capacity Factor	Annual Volatility	Annual Cross Correl Akl
Northland	31%	27%	25%	25%	26%	5%	96%
Auckland	29%	26%	25%	24%	25%	4%	100%
Hawkes Bay	27%	26%	25%	24%	26%	3%	81%
Wellington	28%	25%	24%	23%	25%	4%	76%
Nelson	28%	26%	25%	24%	25%	3%	81%
Christchurch	27%	26%	24%	24%	25%	3%	59%

	Monthly Max	Monthly P10	Monthly P90	Monthly Min	Mean Capacity Factor	Monthly Stdev	Monthly Volatility	Monthly Cross Correl Auck	Monthly Serial Correl
Northland	40%	36%	15%	12%	26%	7.9%	30%	99%	81%
Auckland	39%	35%	15%	10%	25%	7.8%	31%	100%	81%
Hawkes Bay	41%	36%	14%	10%	26%	8.3%	32%	97%	80%
Wellington	41%	36%	13%	9%	25%	8.8%	36%	97%	80%
Nelson	42%	37%	13%	10%	25%	9.0%	35%	97%	81%
Christchurch	39%	36%	14%	9%	25%	8.4%	34%	96%	81%
Northland saj	6%	3%	(2%)	(5%)	(0%)	1.9%		20%	6%
Auckland saj	5%	3%	(3%)	(6%)	(0%)	1.9%		22%	11%
Hawkes Bay saj	5%	3%	(3%)	(8%)	(0%)	2.3%		12%	5%
Wellington saj	5%	3%	(3%)	(8%)	(0%)	2.3%		9%	(1%)
Nelson saj	5%	3%	(3%)	(8%)	(0%)	2.2%		10%	4%
Christchurch saj	5%	3%	(3%)	(8%)	(0%)	2.2%		7%	9%

	Daily P5	Daily P10	Daily P25	Daily P75	Daily P90	Daily P95	Average	Daily Stdev	Daily Cross Correl Auck	Daily Serial Correl
Northland	43%	41%	35%	17%	10%	7%	26%	11%	91%	62%
Auckland	43%	40%	34%	17%	10%	7%	25%	11%	100%	61%
Hawkes Bay	44%	42%	35%	16%	9%	6%	26%	12%	74%	65%
Wellington	45%	42%	36%	15%	8%	6%	25%	12%	71%	66%
Nelson	44%	41%	35%	14%	7%	5%	24%	12%	68%	66%
Christchurch	45%	42%	35%	16%	8%	5%	25%	12%	59%	60%
Northland saj	11%	10%	6%	(6%)	(12%)	(15%)		8%	62%	29%
Auckland saj	12%	10%	7%	(6%)	(12%)	(15%)		8%	74%	27%
Hawkes Bay saj	12%	10%	7%	(7%)	(12%)	(16%)		9%	38%	36%
Wellington saj	11%	10%	7%	(6%)	(12%)	(16%)		9%	33%	32%
Nelson saj	13%	11%	7%	(7%)	(12%)	(16%)		9%	30%	35%
Christchurch saj	12%	11%	8%	(7%)	(13%)	(16%)		9%	20%	28%

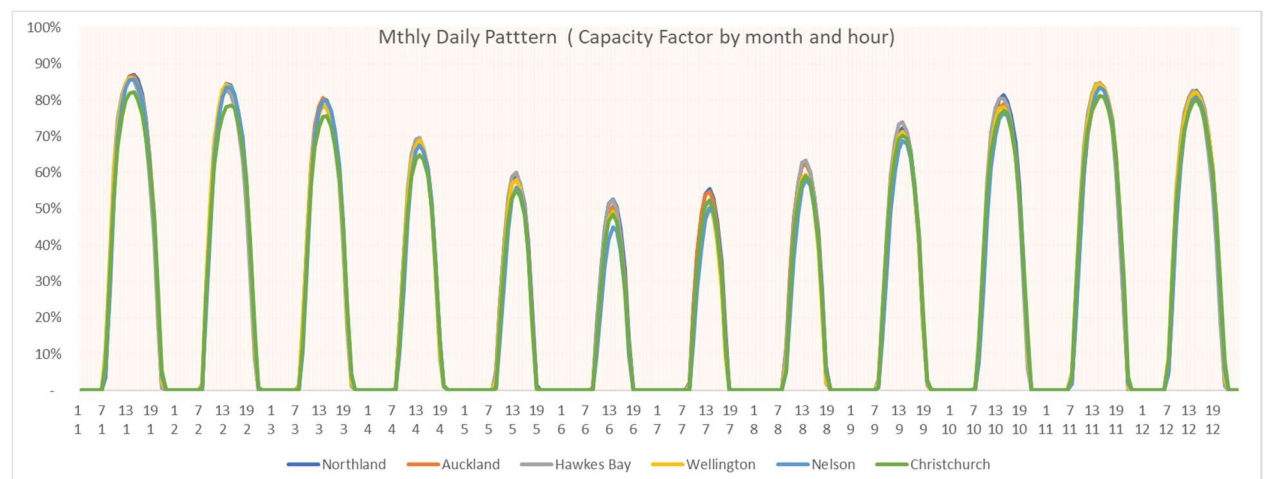
### 3.2.2 SOLAR SEASONAL AND DAILY PATTERNS

The charts below show the mean monthly and daily profiles for each regional solar profile relative to the average capacity factor in each region. These mean patterns are very similar since they generally reflect the position of the sun in the sky.





**FIGURE 10: SEASONAL AND DAILY PATTERN**



**FIGURE 11: SEASONAL AND DAILY PATTERN**

There are very strong seasonal and daily patterns for solar. These dominate the random fluctuation resulting from varying weather.

### 3.2.3 SOLAR VARIATION DAILY, MONTHLY AND ANNUAL



FIGURE 12: VARIATION BY DAY, MONTH AND YEAR

Note that the annual variation is much lower than for wind, around 3 to 5% compared with 6 to 10% for wind.

### 3.2.4 SOLAR CORRELATIONS

The tables are charts below show the cross correlations between different regions. Note that the correlation measures for the seasonally adjusted outputs are considerably lower than for the raw data. The later include the highly predictable seasonal/daily patterns whereas the former only reflect the random variations due to changing weather.

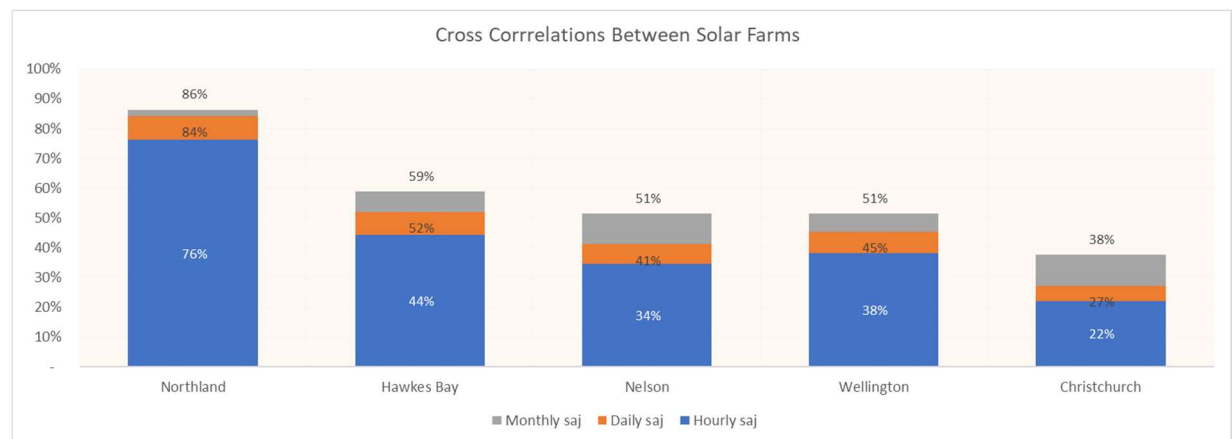


FIGURE 13 CROSS CORRELATION BETWEEN SOLAR FARMS

Hourly														
Raw	Northland	Auckland	Hawkes Bay	Wellington	Nelson	Christchurch	Seasonally adjusted	Northland	Auckland	Hawkes Bay	Wellington	Nelson	Christchurch	Christchurch saj
Northland	100%	96%					Northland saj	100%	76%					
Auckland	96%	100%					Auckland saj	76%	100%					
Hawkes Bay	88%	90%	100%				Hawkes Bay saj	35%	44%	100%				
Wellington	87%	89%	93%	100%			Wellington saj	28%	38%	62%	100%			
Nelson	86%	87%	86%	90%	100%		Nelson saj	25%	34%	29%	52%	100%		
Christchurch	83%	84%	85%	89%	89%	100%	Christchurch saj	16%	22%	28%	47%	50%	100%	

Daily														
Raw	Northland	Auckland	Hawkes Bay	Wellington	Nelson	Christchurch	Seasonally adjusted	Northland	Auckland	Hawkes Bay	Wellington	Nelson	Christchurch	Christchurch saj
Northland	100%	91%					Northland saj	100%	84%					
Auckland	91%	100%					Auckland saj	84%	100%					
Hawkes Bay	69%	74%	100%				Hawkes Bay saj	42%	52%	100%				
Wellington	63%	68%	65%	100%			Wellington saj	34%	45%	71%	100%			
Nelson	66%	71%	85%	80%	100%		Nelson saj	30%	41%	35%	61%	100%		
Christchurch	56%	59%	64%	79%	78%	100%	Christchurch saj	19%	27%	35%	59%	62%	100%	

Monthly														
Raw	Northland	Auckland	Hawkes Bay	Wellington	Nelson	Christchurch	Seasonally adjusted	Northland	Auckland	Hawkes Bay	Wellington	Nelson	Christchurch	Christchurch saj
Northland	100%	99%					Northland saj	100%	86%					
Auckland	99%	100%					Auckland saj	86%	100%					
Hawkes Bay	97%	97%	100%				Hawkes Bay saj	55%	59%	100%				
Wellington	96%	97%	96%	100%			Wellington saj	42%	51%	79%	100%			
Nelson	96%	97%	98%	98%	100%		Nelson saj	37%	51%	47%	65%	100%		
Christchurch	95%	96%	97%	97%	98%	100%	Christchurch saj	31%	38%	58%	71%	68%	100%	

## 3.2.5 ILLUSTRATIVE SOLAR PROFILES

The following charts show the typical daily and hourly variations for a selected year and month of data.

This illustrates the random daily variability due to cloud cover etc.

