brightwind

Wind and Solar Resource Study
Ireland

Site-specific study of Irish sites R01C

Prepared for Irish Solar Energy Association and Wind Energy Ireland | 13th June 2023

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Version History

Report	Revision	Date	Changes
1	A	12-05-2023	First Issue
1	B	31-05-2023	Updated remarks and additional results tables
1	C	13-06-2023	Updated cover page

Executive Summary

This report investigates the impact of adding solar production to existing grid nodes where operational windfarms are present.

Five nodes are chosen across Ireland for which operational windfarm production data and solar irradiance data are available within an acceptable proximity. The client has provided all operational windfarm production while in-situ measurements of solar data are acquired from Brightwind's data monitoring platform, with the owner's consent. A representative solar farm model is created at each node and scaled to its co-located windfarm capacity, thus providing indicative solar farm production estimates.

The impact of combined production is assessed based on the following three parameters:

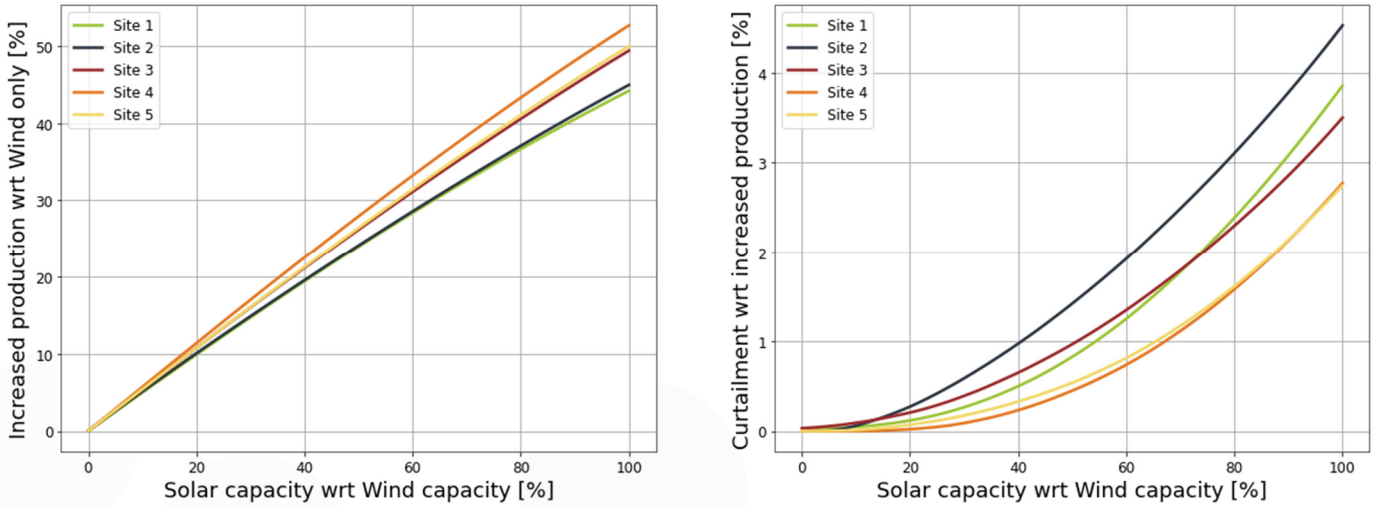
- The increase in overall production at the grid node due to the solar resource, considering a maximum export capacity (MEC) limit. It is assumed that the MEC is equal to the operational windfarm capacity.
- The number of hours at which solar production exceeds the MEC of the node.
- The level of curtailment necessary to remain within the existing MEC of the node.

The above parameters are calculated for windfarm production combined with solar production scaled from 0 % and to 100 % of the windfarm capacity. The solar production is sized with a DC/AC ratio of 1.5. This shows that solar production co-located with wind production increases the overall output while incurring increasing curtailment, as shown below. However, the relationship between additional production and curtailment is non-linear.

This suggests that significantly more energy can be produced in Ireland by including solar and wind production in common grid regions, without any additional reinforcement to the existing grid infrastructure.

Solar capacity as percent of wind capacity	Production increase [%]	Hours exceeding MEC [hrs/y]	Curtailment [%]
0 %	0.0	0.0	0.0
5 %	2.7	22.6	0.0
20 %	10.6	81.1	0.1
50 %	25.7	240.1	0.8
100 %	48.2	622.0	3.5

Mean impact of increased solar production on all sites.



Impact of increasing solar capacity on combined production and curtailment.

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1 Introduction

The study is based on five nodes consisting of an operational windfarm and a nearby solar development area. Details of the node locations, distance between co-located nodes, and windfarm capacity are provided in the table below.

Site	Location	Distance between wind and solar [km]	Windfarm capacity [MW]
1	West Cork	22	25
2	East Cork	11	2
3	Clare	33	14
4	Waterford	5	20
5	North Cork	30	33

Table 1-1: Details of wind and solar locations studied.

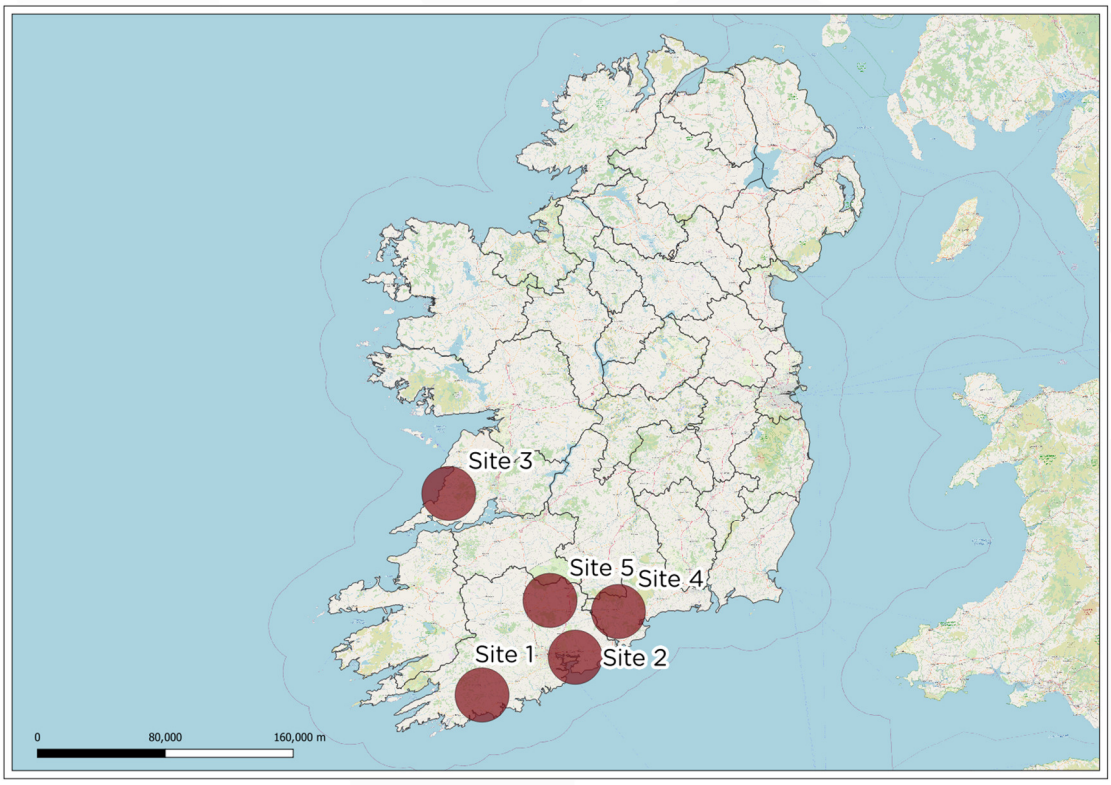


Table 1-2: Node locations studied.

2 Data Analysis

2.1 Wind resource

The client has provided operational windfarm data for each node location. The wind production used in this study is taken at the metered connection point as advised by the client.

The operational data is assessed, cleaned and any erroneous values are removed. The monthly coverage is calculated to ensure months with lower than 100 % are excluded from the study. Details of the length of the production measurements and overall coverage are provided in the table below.

Site	Start Date	End Date	Overall Coverage [years]
1	30-Sep-2018	01-Jan-2023	4.3
2	01-Jan-2018	31-Dec-2022	5.0
3	01-Jan-2020	31-Dec-2022	3.0
4	30-Sep-2018	01-Jan-2023	4.3
5	30-Sep-2018	01-Jan-2023	4.3

Table 2-1: Wind measurement details.

Several periods of no generation are present during the operational datasets. Due to the nature of the records the cause of these outages are unknown. The client has made BrightWind aware of one period, Feb-2021, at Site 3 for which no production data is recorded. This period is therefore removed. All other periods of no generation can be considered reasonable during the course of normal windfarm operation and therefore remain in the records.

It is understood that the operational data is recorded at the metered connection point for all windfarms. However, the windfarms associated with Sites 1, 2 and 3 record peak generation which at times exceeds the MEC limitation during normal windfarm operation. The exceedance contributes to less than 0.6 % curtailment in all cases and thus is considered acceptable data.

2.2 Solar resource

Brightwind has provided the solar resource data from its internal data monitoring platform. The solar resource data consists of solar irradiance data measured at potential solar generation locations. This data is owned by a third party and is used with their consent on the condition that exact site locations remain anonymous.

The solar irradiance is assessed, cleaned and converted into a long-term context using Copernicus Atmosphere Monitoring Service (CAMS) reanalysis data. CAMS solar radiation from Feb-2004 to Feb-2023 inclusive is used for the correlation with site measurements, at an hourly averaging period. This creates long-term timeseries from Jan-2018 to Dec-2022 at each node location. Details of the length of the onsite measurements and the long-term correlation are provided in the table below.

Site	Start Date	End Date	Correlation R^2	Correlation points
1	10-Jan-2020	16-Feb-2021	0.980	9688
2	09-Jan-2020	17-Feb-2021	0.955	9735
3	25-Mar-2021	05-Feb-2023	0.999	16378
4	13-Nov-2020	05-Feb-2023	0.992	19376
5	13-Dec-2018	09-Jan-2020	0.949	9428

Table 2-2: Solar measurement details.

The long-term solar radiation is converted into expected production using PVsyst. A representative site is created using appropriate models for the PV modules and solar inverter. Typical losses are applied as standard for the region. The site is assumed to be flat with no external shading in the vicinity. A constant albedo factor of 0.2 was applied throughout the year. Each site is orientated to true south with the following configuration:

	Unit	Configuration
No. modules in width		2 modules
Bifacial		Yes
Tilt angle	°	15
Row spacing	m	2.5
Low point height	m	0.7
GRC	%	52
DC/AC ratio		1.5

Table 2-3: PVsyst model configuration.

Each model is sized to have a rated capacity of 1.12 MW_p and 0.75 MWAC, which has the following equipment characteristics:

PV Modules	Unit	Configuration
PV Modules		**Trina Solar TSM-DEG21C-20-650Wp Vertex**
Module technology		Monocrystalline silicon
Nominal power at STC	Wp	650
Module efficiency	%	22.4
Bifaciality factor	%	72
Module dimensions	mm	2384 x 1303 x 35
Solar Inverter		**Sungrow SG250-HX**

Table 2-4: PVsyst model configuration.

2.3 Combined resource

Given the variation in measurement duration, only concurrent data at each site is used. Additionally, the production records at each site are adjusted to remove any bias introduced by seasonal variation.

3 Results

To assess the impact of solar production being co-located with wind production, the production and curtailment of the combined resource is analysed on an hourly basis. The results are presented both annually and monthly, and around the minimum and peak consumption periods defined by ESB Networks, (Smith, 2023) as provided by the client.

Three parameters are considered:

1. The increase in overall production with combined wind and solar generation, considering any curtailment necessary to maintain the existing maximum export capacity (MEC) of the wind farm.
2. The total hours at which the solar production exceeds the MEC, indicating that some level of curtailment would be required.
3. The curtailment volume of the combined generation sources ensuring that the existing MEC limit is not exceeded.

These parameters are considered for the current windfarm production combined with the hypothetical solar production sized incrementally from 0 % to 100 % of the windfarm capacity.

3.1 Annual basis

It is found that increasing the solar capacity at each node increases the overall production after considering the necessary curtailment. Table 3-1 shows the mean effect of increasing solar production at all nodes, for hypothetical solar production sized at 0 %, 5 %, 20 %, 50 %, and 100 % of the co-located windfarm capacity.

Solar capacity as percent of wind capacity	Production increase [%]	Hours exceeding MEC [hrs/y]	Curtailment [%]
0 %	0.0	0.0	0.0
5 %	2.7	22.6	0.0
20 %	10.6	81.1	0.1
50 %	25.7	240.1	0.8
100 %	48.2	622.0	3.5

Table 3-1: Mean impact of increased solar production on all sites.

Figure 3-1 shows the increased production and overall curtailment for the entire range of solar production sizing.

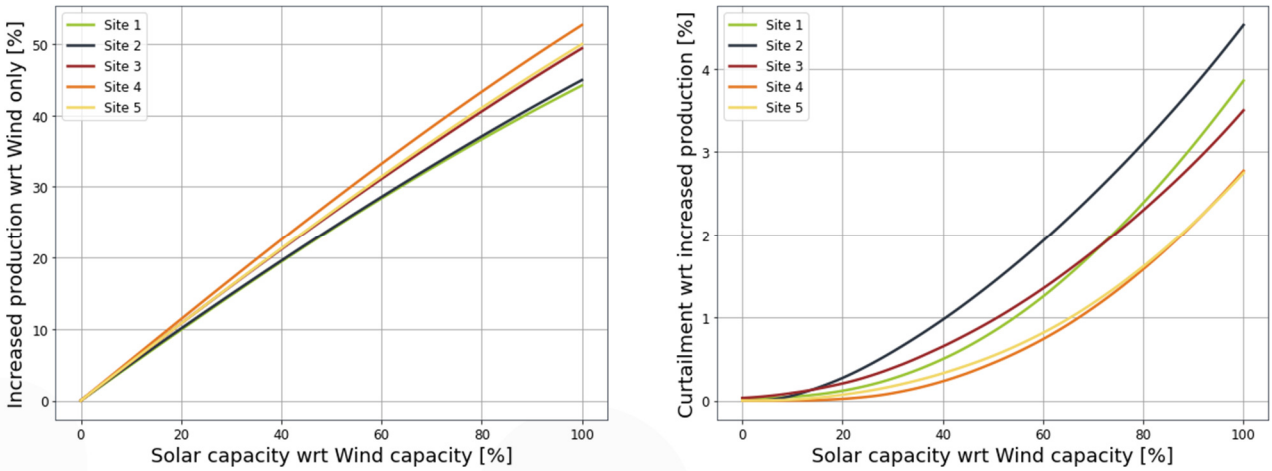


Figure 3-1: Impact on production and curtailment of increased solar capacity.

The windfarm production data used is recorded at the metered point of the wind farm, and thus the existing level of grid curtailment for sites 1,3,4 and 5 is inherent. Site 2 experiences no windfarm curtailment due to its de minimis capacity of 2 MW. Table 3-2 shows the effect of increasing solar production in the region for specific sizing of the hypothetical solar farm. Figure 3-2 shows this impact over the entire range of solar farm sizing.

Solar capacity as percent of wind capacity	Production increase [%]	Hours exceeding MEC [hrs/y]	Curtailment [%]
0 %	0.0	0.0	0.0
5 %	2.6	22.2	0.0
20 %	10.1	157.8	0.3
50 %	24.1	371.4	1.4
100 %	45.0	740.2	4.5

Table 3-2: Impact of increased solar production on Site 2.

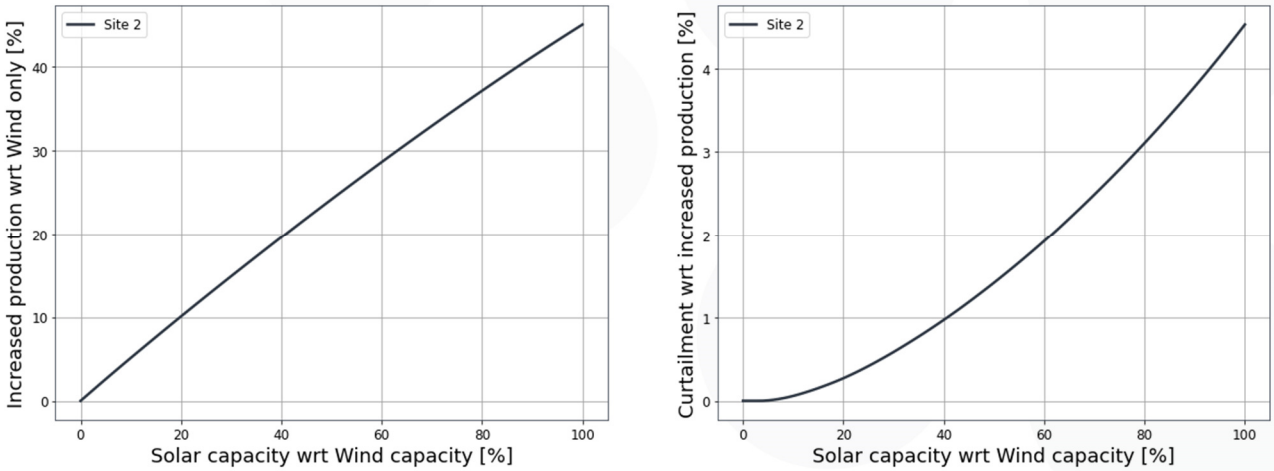


Figure 3-2: Impact on production and curtailment of increased solar capacity at Site 2.

3.2 Monthly basis

The curtailment of the combined production is analysed on a monthly basis. The MEC limit imposed is equal to the windfarm capacity.

The total hours per month and the time at which curtailment is needed is shown in Table 3-3 to Table 3-6 below. These are calculated for the windfarm production combined with solar production sized from 5 % to 100 % of the windfarm capacity. Only curtailment during daylight hours is considered to exclude times during which solar production is zero. Figure 3-3 shows the total hours, across all sites, which curtailment is necessary in a given month. This is provided for the solar production sized to 100 % of the MEC. The boxplot shows the median (orange) surrounded by the interquartile range (box) and the extent of the 5th-95th percentiles (whiskers).

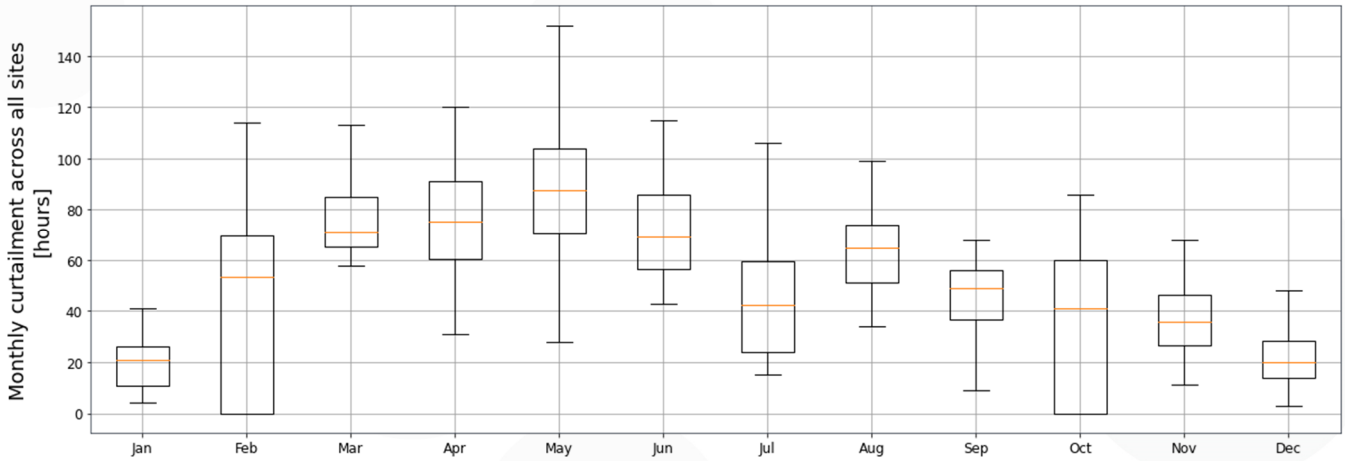


Figure 3-3: Hours per month which require curtailment.

The mean curtailment of each site in shown in Table 3-7 to Table 3-10 below. The peak and standard deviation of the curtailment is also provided. These are calculated for windfarm production combined with solar production sized from 5 % to 100 %, of the windfarm capacity. Figure 3-4 shows the curtailment in a given month, across all sites. This is provided for the solar production sized to 100 % of the MEC. The median curtailment, interquartile range and 5th-95th percentiles are shown on the boxplot.

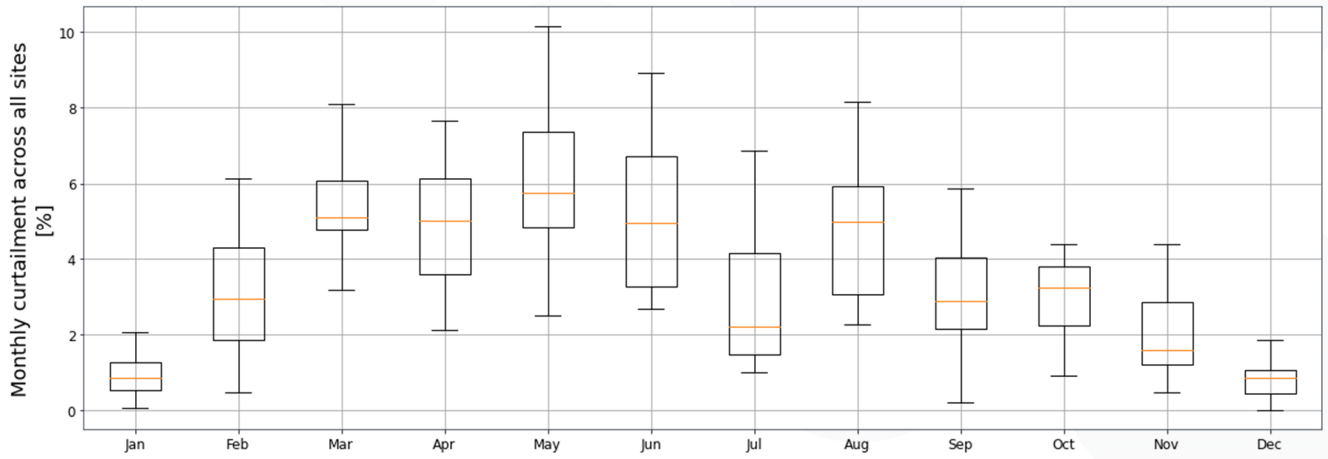


Figure 3-4: Average monthly curtailment.

Month	Site 1		Site 2		Site 3		Site 4		Site 5	
	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range
1	4.0	10:00 - 16:00	0.0	-	7.0	09:00 - 15:00	0.0	-	0.0	-
2	5.8	08:00 - 17:00	0.0	-	10.0	08:00 - 17:00	0.0	-	0.2	11:00 - 11:00
3	4.5	08:00 - 18:00	2.2	09:00 - 14:00	11.0	07:00 - 18:00	0.0	-	1.5	09:00 - 15:00
4	1.2	10:00 - 15:00	3.2	09:00 - 16:00	0.7	15:00 - 17:00	0.0	-	0.5	14:00 - 16:00
5	0.8	11:00 - 17:00	4.2	08:00 - 16:00	1.3	10:00 - 17:00	0.2	16:00 - 16:00	1.2	09:00 - 14:00
6	1.5	13:00 - 18:00	3.6	07:00 - 16:00	0.3	08:00 - 08:00	0.0	-	0.0	-
7	0.2	13:00 - 13:00	2.4	08:00 - 15:00	0.0	-	0.0	-	0.0	-
8	1.0	13:00 - 17:00	3.6	09:00 - 14:00	5.3	06:00 - 15:00	0.2	14:00 - 14:00	0.2	11:00 - 11:00
9	0.2	09:00 - 09:00	1.8	09:00 - 16:00	1.0	09:00 - 17:00	0.0	-	0.2	14:00 - 14:00
10	4.0	07:00 - 16:00	0.0	-	3.7	10:00 - 16:00	0.0	-	0.8	11:00 - 15:00
11	6.8	08:00 - 16:00	1.2	10:00 - 12:00	4.0	08:00 - 15:00	0.0	-	0.2	12:00 - 12:00
12	5.2	09:00 - 15:00	0.0	-	6.0	11:00 - 15:00	0.0	-	0.0	-

Table 3-3: Total hours and hourly range during which curtailment is necessary for combined wind and solar production. Solar farm sizing of 5 % MEC.

Month	Site 1		Site 2		Site 3		Site 4		Site 5	
	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range
1	7.8	10:00 - 16:00	3.0	11:00 - 15:00	9.3	09:00 - 16:00	0.0	-	0.8	10:00 - 12:00
2	12.0	08:00 - 17:00	10.6	09:00 - 16:00	15.3	08:00 - 17:00	1.2	11:00 - 13:00	2.8	09:00 - 16:00
3	12.5	08:00 - 18:00	19.6	08:00 - 17:00	21.3	07:00 - 18:00	3.0	10:00 - 14:00	10.0	08:00 - 17:00
4	4.2	08:00 - 16:00	16.4	07:00 - 17:00	3.0	10:00 - 17:00	2.5	09:00 - 15:00	5.8	09:00 - 17:00
5	8.0	08:00 - 17:00	18.8	06:00 - 18:00	8.3	09:00 - 18:00	5.0	09:00 - 16:00	6.0	07:00 - 16:00
6	5.5	09:00 - 18:00	15.2	06:00 - 18:00	4.3	08:00 - 15:00	1.2	09:00 - 14:00	2.2	06:00 - 17:00
7	2.0	12:00 - 14:00	14.6	06:00 - 18:00	0.7	13:00 - 14:00	0.0	-	0.2	12:00 - 12:00
8	3.8	07:00 - 18:00	17.6	07:00 - 18:00	12.7	06:00 - 17:00	1.8	10:00 - 15:00	4.2	09:00 - 15:00
9	0.8	09:00 - 15:00	19.4	07:00 - 17:00	3.0	09:00 - 17:00	0.0	-	2.2	10:00 - 17:00
10	11.4	07:00 - 16:00	3.0	08:00 - 15:00	8.0	07:00 - 16:00	0.2	13:00 - 13:00	5.6	10:00 - 16:00
11	10.4	08:00 - 16:00	14.0	08:00 - 15:00	4.0	08:00 - 15:00	0.8	11:00 - 15:00	6.0	09:00 - 15:00
12	7.4	09:00 - 15:00	5.6	10:00 - 14:00	9.0	09:00 - 15:00	0.0	-	1.4	09:00 - 13:00

Table 3-4: Total hours and hourly range during which curtailment is necessary for combined wind and solar production. Solar farm sizing of 20 % MEC.

Month	Site 1		Site 2		Site 3		Site 4		Site 5	
	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range
1	12.2	10:00 - 16:00	12.0	09:00 - 15:00	14.7	09:00 - 16:00	1.0	12:00 - 13:00	2.2	09:00 - 13:00
2	28.2	08:00 - 17:00	29.6	08:00 - 16:00	26.0	08:00 - 17:00	12.5	09:00 - 15:00	14.8	09:00 - 16:00
3	41.2	08:00 - 18:00	41.4	07:00 - 17:00	42.3	07:00 - 18:00	31.5	08:00 - 16:00	24.0	07:00 - 17:00
4	26.8	07:00 - 17:00	40.6	06:00 - 18:00	12.3	08:00 - 17:00	17.5	07:00 - 17:00	15.8	08:00 - 17:00
5	33.8	06:00 - 18:00	39.0	06:00 - 18:00	24.7	08:00 - 18:00	18.2	08:00 - 17:00	28.0	06:00 - 18:00
6	30.8	07:00 - 19:00	34.2	05:00 - 18:00	23.7	07:00 - 17:00	15.0	07:00 - 17:00	19.0	05:00 - 19:00
7	13.0	07:00 - 17:00	35.8	05:00 - 19:00	8.7	09:00 - 16:00	6.8	08:00 - 16:00	5.8	08:00 - 16:00
8	22.2	07:00 - 18:00	41.4	06:00 - 18:00	27.3	06:00 - 18:00	14.5	08:00 - 17:00	12.2	08:00 - 17:00
9	11.5	08:00 - 16:00	39.6	07:00 - 17:00	13.7	08:00 - 17:00	3.2	09:00 - 15:00	7.5	09:00 - 17:00
10	28.8	07:00 - 17:00	6.6	07:00 - 16:00	19.3	07:00 - 16:00	3.4	11:00 - 15:00	15.8	07:00 - 17:00
11	23.8	08:00 - 16:00	29.6	08:00 - 16:00	11.0	08:00 - 15:00	9.8	10:00 - 16:00	15.6	08:00 - 15:00
12	14.0	09:00 - 15:00	21.6	09:00 - 15:00	15.7	09:00 - 15:00	2.6	11:00 - 13:00	6.8	09:00 - 15:00

Table 3-5: Total hours and hourly range during which curtailment is necessary for combined wind and solar production. Solar farm sizing of 50 % MEC.

Month	Site 1		Site 2		Site 3		Site 4		Site 5	
	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range	Total hours	Hourly range
1	26.8	09:00 - 16:00	25.0	09:00 - 15:00	23.3	09:00 - 16:00	10.2	10:00 - 15:00	12.0	09:00 - 15:00
2	59.2	08:00 - 17:00	53.0	08:00 - 16:00	36.0	08:00 - 17:00	36.5	08:00 - 16:00	39.0	08:00 - 17:00
3	84.5	08:00 - 18:00	74.4	07:00 - 17:00	74.7	07:00 - 18:00	73.0	07:00 - 17:00	65.5	07:00 - 17:00
4	88.0	07:00 - 17:00	88.6	06:00 - 18:00	60.7	07:00 - 17:00	69.0	07:00 - 17:00	62.2	07:00 - 18:00
5	98.0	06:00 - 18:00	92.2	05:00 - 19:00	86.3	07:00 - 18:00	76.2	07:00 - 18:00	82.8	06:00 - 19:00
6	83.2	06:00 - 19:00	84.2	05:00 - 19:00	64.3	06:00 - 19:00	61.5	06:00 - 18:00	63.0	05:00 - 19:00
7	41.8	07:00 - 18:00	76.4	05:00 - 19:00	28.0	07:00 - 17:00	33.8	07:00 - 18:00	33.5	08:00 - 17:00
8	78.2	06:00 - 18:00	88.6	06:00 - 18:00	54.7	06:00 - 18:00	59.0	07:00 - 17:00	52.2	08:00 - 17:00
9	51.5	08:00 - 17:00	64.0	06:00 - 18:00	37.7	08:00 - 17:00	37.0	08:00 - 16:00	35.8	08:00 - 17:00
10	66.6	07:00 - 17:00	12.6	07:00 - 16:00	55.7	07:00 - 17:00	13.8	08:00 - 16:00	47.0	07:00 - 17:00
11	49.2	08:00 - 16:00	48.2	08:00 - 16:00	23.3	08:00 - 15:00	25.2	09:00 - 16:00	30.6	08:00 - 16:00
12	30.4	09:00 - 15:00	33.0	09:00 - 15:00	22.7	09:00 - 15:00	11.8	09:00 - 14:00	14.6	09:00 - 15:00

Table 3-6: Total hours and hourly range during which curtailment is necessary for combined wind and solar production. Solar farm sizing of 100 % MEC.

Month	Site 1			Site 2			Site 3			Site 4			Site 5		
	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]
1	0.0%	4.0%	1.1%	0.0%	0.0%	0.0%	0.0%	2.6%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.1%	3.7%	0.9%	0.0%	0.0%	0.0%	0.1%	3.3%	0.7%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%
3	0.0%	4.7%	0.9%	0.0%	1.1%	0.4%	0.1%	4.9%	1.3%	0.0%	0.0%	0.0%	0.0%	1.1%	0.4%
4	0.0%	4.7%	1.5%	0.0%	0.9%	0.3%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	0.2%
5	0.0%	4.6%	0.9%	0.0%	1.2%	0.3%	0.0%	1.7%	0.5%	0.0%	0.2%	0.0%	0.0%	1.2%	0.5%
6	0.0%	3.8%	1.4%	0.0%	1.3%	0.3%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	0.0%	0.1%	0.0%	0.0%	0.9%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	0.0%	2.7%	1.2%	0.0%	3.2%	0.7%	0.1%	4.5%	1.3%	0.0%	2.1%	0.0%	0.0%	0.1%	0.0%
9	0.0%	3.6%	1.9%	0.0%	1.2%	0.4%	0.0%	2.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%
10	0.0%	3.1%	0.8%	0.0%	0.0%	0.0%	0.0%	2.9%	0.8%	0.0%	0.0%	0.0%	0.0%	2.1%	0.9%
11	0.0%	3.1%	0.7%	0.0%	1.0%	0.3%	0.0%	2.9%	0.9%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%
12	0.0%	2.5%	0.5%	0.0%	0.0%	0.0%	0.0%	2.7%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 3-7: Monthly curtailment statistics, normalised by windfarm capacity, for combined wind and solar production. Solar sizing at 5 % of MEC.

Month	Site 1			Site 2			Site 3			Site 4			Site 5		
	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]
1	0.1%	12.1%	3.2%	0.0%	7.3%	2.4%	0.1%	7.8%	2.1%	0.0%	0.0%	0.0%	0.0%	2.4%	0.6%
2	0.2%	11.7%	3.1%	0.1%	8.5%	2.2%	0.4%	9.0%	2.7%	0.0%	5.5%	1.9%	0.0%	12.3%	3.5%
3	0.2%	15.9%	3.2%	0.4%	12.3%	3.7%	0.4%	15.7%	3.6%	0.0%	4.7%	1.5%	0.2%	11.6%	3.3%
4	0.1%	15.6%	4.9%	0.3%	12.0%	3.9%	0.0%	5.0%	1.7%	0.0%	5.2%	1.7%	0.1%	12.1%	3.2%
5	0.2%	15.7%	3.6%	0.5%	12.4%	3.9%	0.2%	13.0%	3.8%	0.1%	10.1%	2.1%	0.1%	12.2%	3.4%
6	0.1%	13.7%	4.5%	0.4%	12.3%	3.8%	0.1%	9.2%	2.5%	0.0%	4.0%	1.5%	0.0%	9.3%	2.7%
7	0.0%	8.5%	2.4%	0.3%	11.7%	3.7%	0.0%	5.9%	1.1%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%
8	0.1%	13.0%	4.3%	0.4%	12.0%	3.6%	0.5%	15.5%	3.8%	0.0%	11.7%	3.7%	0.1%	7.9%	1.9%
9	0.0%	14.4%	6.1%	0.4%	12.2%	3.4%	0.1%	12.6%	3.6%	0.0%	0.0%	0.0%	0.0%	11.4%	4.2%
10	0.1%	14.2%	3.2%	0.3%	10.1%	3.5%	0.1%	8.9%	2.3%	0.0%	3.9%	0.0%	0.1%	13.3%	3.9%
11	0.1%	11.1%	2.3%	0.2%	11.9%	3.1%	0.1%	7.6%	2.5%	0.0%	4.2%	1.7%	0.1%	10.4%	2.5%
12	0.1%	6.1%	1.6%	0.0%	6.3%	1.6%	0.1%	9.0%	2.4%	0.0%	0.0%	0.0%	0.0%	6.1%	2.2%

Table 3-8: Monthly curtailment statistics, normalised by windfarm capacity, for combined wind and solar production. Solar sizing at 20 % of MEC.

Month	Site 1			Site 2			Site 3			Site 4			Site 5		
	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]
1	0.4%	28.4%	7.2%	0.2%	21.9%	5.3%	0.3%	20.9%	5.3%	0.0%	15.0%	6.2%	0.1%	21.3%	6.3%
2	0.9%	32.9%	7.8%	1.1%	27.8%	7.1%	1.7%	25.7%	7.1%	0.4%	27.6%	6.8%	0.4%	34.2%	7.2%
3	1.3%	38.2%	8.3%	1.8%	34.8%	10.0%	1.8%	37.2%	9.4%	1.1%	27.5%	7.1%	1.0%	33.0%	9.8%
4	1.1%	37.6%	8.3%	1.9%	34.5%	9.7%	0.5%	27.5%	7.0%	0.7%	27.6%	7.9%	0.7%	34.6%	9.1%
5	1.4%	37.9%	9.3%	1.9%	34.8%	10.7%	1.4%	35.6%	9.8%	0.8%	29.9%	8.7%	1.1%	34.2%	8.5%
6	1.3%	36.0%	8.9%	1.9%	34.3%	11.5%	1.1%	31.0%	7.6%	0.6%	25.9%	6.8%	0.6%	30.8%	6.7%
7	0.5%	30.0%	6.8%	1.7%	33.4%	9.3%	0.4%	27.9%	7.6%	0.2%	17.0%	5.4%	0.2%	20.0%	5.6%
8	0.7%	33.9%	8.1%	2.0%	33.9%	9.9%	1.9%	37.6%	9.9%	0.7%	30.9%	6.7%	0.7%	28.6%	8.0%
9	0.4%	36.2%	6.9%	1.9%	34.2%	9.0%	0.6%	33.6%	7.4%	0.1%	12.0%	4.0%	0.3%	33.4%	9.8%
10	0.9%	36.2%	8.6%	1.2%	31.5%	10.4%	0.5%	26.3%	6.0%	0.3%	26.2%	7.9%	0.5%	35.7%	9.4%
11	0.5%	27.1%	6.2%	1.0%	33.8%	8.4%	0.3%	16.8%	4.6%	0.3%	24.9%	6.5%	0.5%	31.3%	7.8%
12	0.3%	19.3%	4.6%	0.3%	20.0%	4.4%	0.4%	21.8%	5.2%	0.0%	10.9%	3.1%	0.1%	24.2%	6.1%

Table 3-9: Monthly curtailment statistics, normalised by windfarm capacity, for combined wind and solar production. Solar sizing at 50 % of MEC.

Month	Site 1			Site 2			Site 3			Site 4			Site 5		
	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]	Mean [%]	Peak [%]	Std Dev. [%]
1	1.5%	57.2%	13.7%	1.2%	46.2%	10.7%	0.9%	42.8%	10.0%	0.5%	43.6%	10.0%	0.5%	52.8%	9.9%
2	3.8%	68.2%	16.4%	3.9%	63.8%	16.5%	5.0%	62.9%	16.3%	2.2%	64.5%	15.7%	1.9%	70.8%	13.9%
3	5.3%	75.4%	17.8%	5.6%	72.2%	19.5%	5.5%	73.0%	20.0%	5.4%	65.4%	17.5%	4.4%	70.0%	18.2%
4	5.7%	74.2%	17.6%	6.5%	72.1%	20.0%	3.6%	64.9%	14.9%	4.4%	64.9%	17.2%	3.7%	72.2%	16.1%
5	6.6%	74.9%	18.1%	6.3%	72.2%	20.7%	5.7%	73.4%	19.9%	4.8%	66.0%	16.5%	5.8%	70.8%	17.2%
6	6.1%	73.2%	18.2%	6.2%	71.3%	21.5%	5.1%	67.2%	18.4%	4.1%	62.3%	15.9%	4.3%	66.6%	15.4%
7	2.4%	66.0%	15.7%	5.7%	69.5%	19.0%	2.3%	64.5%	17.1%	1.9%	51.7%	13.5%	1.7%	54.5%	11.8%
8	5.1%	70.4%	15.4%	6.4%	70.5%	19.3%	5.1%	74.4%	20.4%	3.5%	63.0%	15.4%	3.3%	64.7%	15.9%
9	3.1%	72.4%	13.9%	5.3%	70.9%	19.5%	2.8%	68.7%	16.2%	2.0%	44.7%	11.0%	2.1%	70.0%	15.4%
10	3.9%	73.0%	17.6%	3.7%	67.8%	19.3%	3.0%	57.4%	12.6%	2.0%	63.4%	13.9%	2.4%	73.1%	16.3%
11	2.3%	58.7%	14.4%	3.0%	70.5%	17.7%	1.0%	44.4%	10.1%	1.6%	60.1%	15.4%	1.6%	66.0%	16.5%
12	1.1%	47.2%	10.2%	1.0%	42.9%	9.5%	1.0%	43.5%	10.1%	0.4%	37.8%	9.4%	0.5%	54.3%	12.2%

Table 3-10: Monthly curtailment statistics, normalised by windfarm capacity, for combined wind and solar production. Solar sizing at 100 % of MEC.

3.3 Minimum and peak demand periods

ESB Networks (Smith, 2023) defines the minimum and peak demand periods as follows:

- Summer minimum – Sunday of the August bank holiday.
- Winter peak – third Thursday in December.

The impact of combined production is shown for one week during the above periods for a representative year, 2022. Two solar production sizing scenarios are provided: 50 % and 100 % of windfarm capacity. Figure 3-5 and Figure 3-6 show the normalised wind and solar production individually and combined. During periods of combined production greater than then MEC, curtailment will be necessary to ensure the MEC limit is not exceeded.

The equivalent plots for the remaining sites can be found Appendix 1.

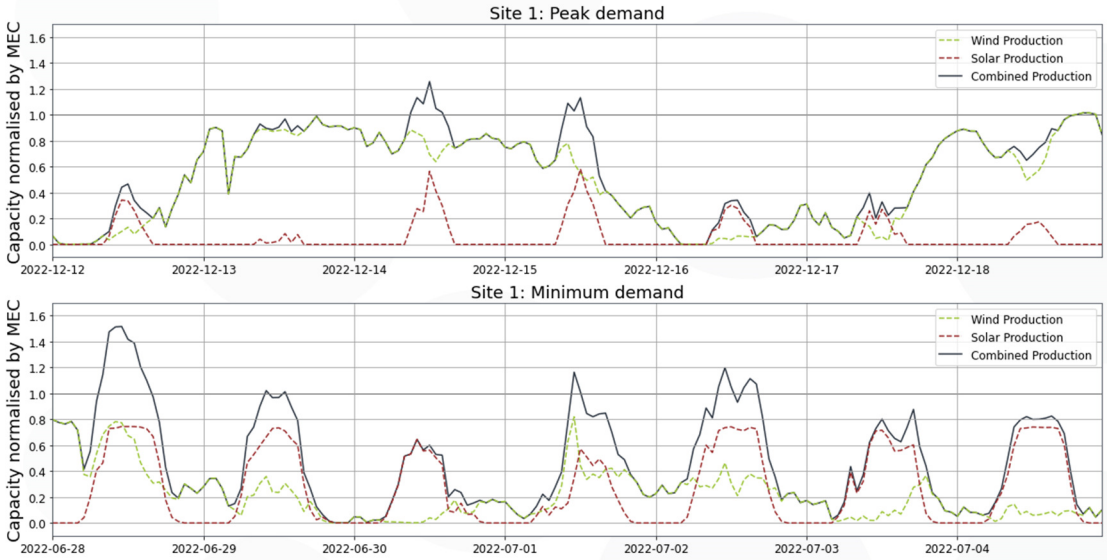


Figure 3-5: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 100 % of windfarm capacity.

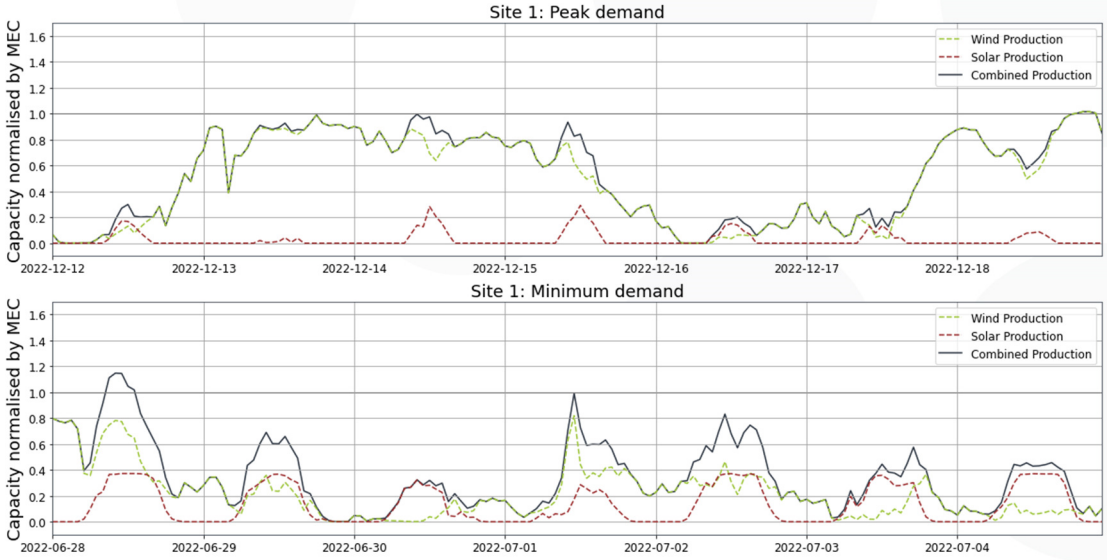


Figure 3-6: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 50 % of windfarm capacity.

4 Comments

1. This study demonstrates the potential impact of including solar production in grid regions with existing windfarm production on MEC constraints. Only changes in combined production and curtailment of the two resources are considered.

2. The five nodes included in this study are chosen based on available site data and only provide a representation of the potential impact to grid connection.

3. Curtailment is deemed to be necessary when the combined production of wind and solar production exceeds the MEC at any given time. It is assumed that the MEC is equal to the windfarm capacity for all sites aside from Site 5. The MEC of Site 5 is lower than windfarm capacity due to existing grid limitations.

4. The client has stated that the wind production data for this study is measured at the metered connection point to the grid and therefore curtailment of the wind production itself is inherent. However, it is noted that Sites 1 and 3 exceed their respective capacities slightly during normal operation. This exceedance contributes to the combined curtailment results.

5. Due to the nature of the wind production data, the causes of zero production are unknown. The client has noted one data gap during Feb-2021 at Site 3 which has been removed. All other periods of zero production may be considered part of normal windfarm operation and so are not removed.

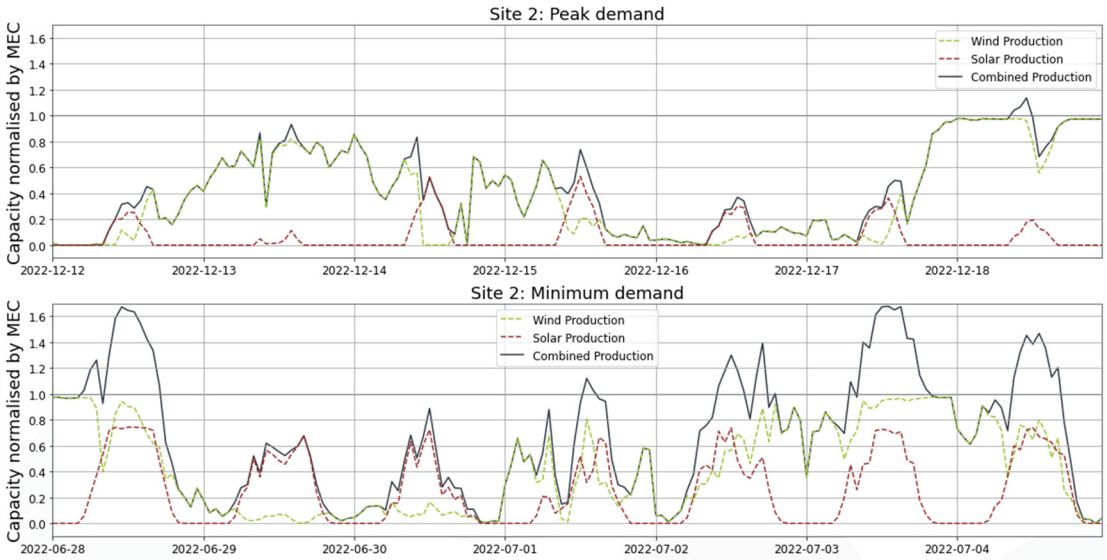
6. Historic solar production data is not available and has been produced using PVsyst from site irradiance measurements. A simplistic model is used with standard parameters for the region.

7. This study suggests that significant increases in production could be achieved in Ireland by including solar and wind production in common grid regions, without reinforcing the current grid infrastructure.

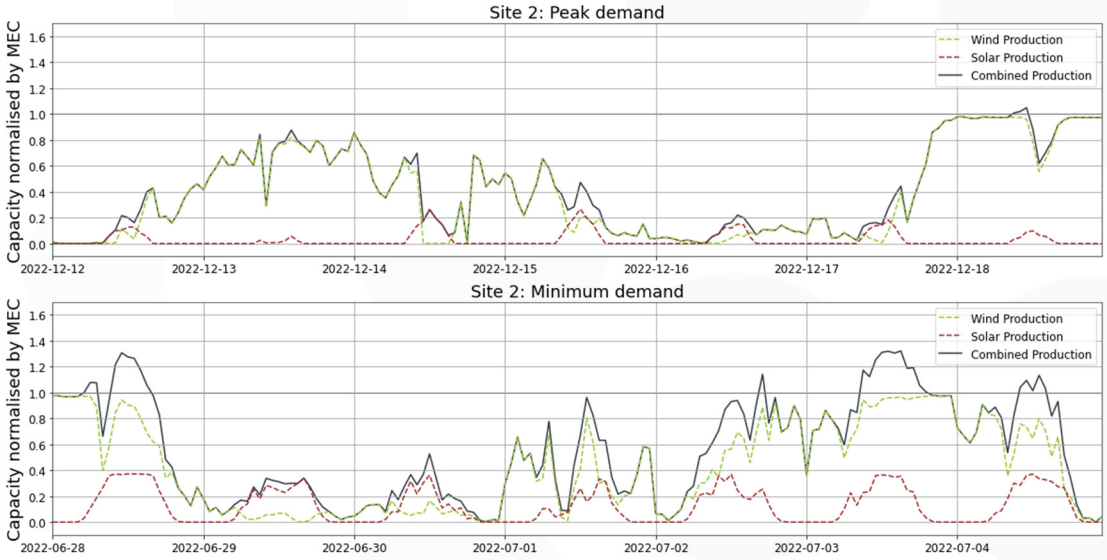
5 References

Smith, D. (2023). Email correspondance with Duggan, R. - 24/04/2023 15:05.

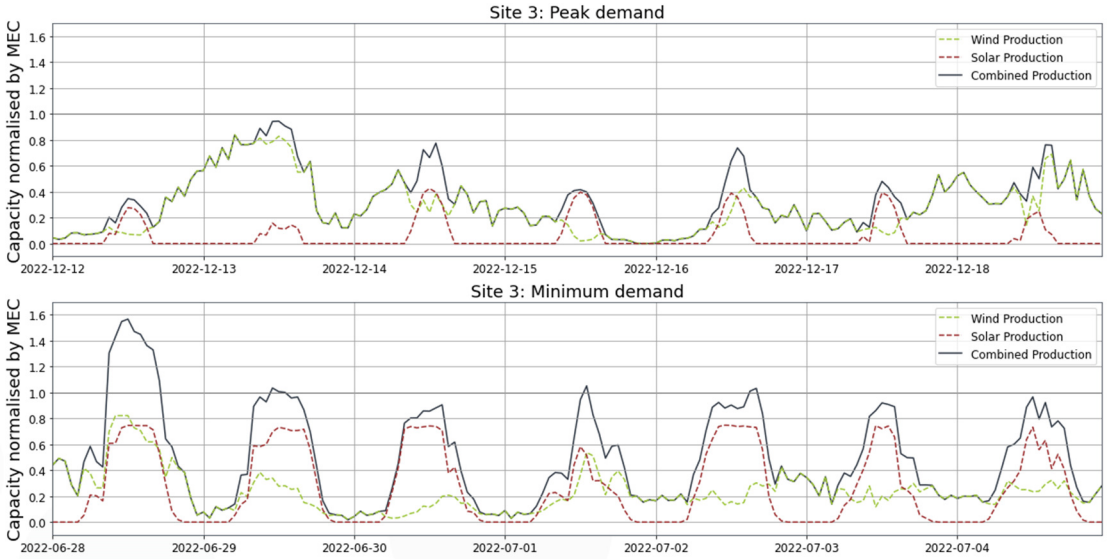
Appendix 1: Minimum and peak demand periods



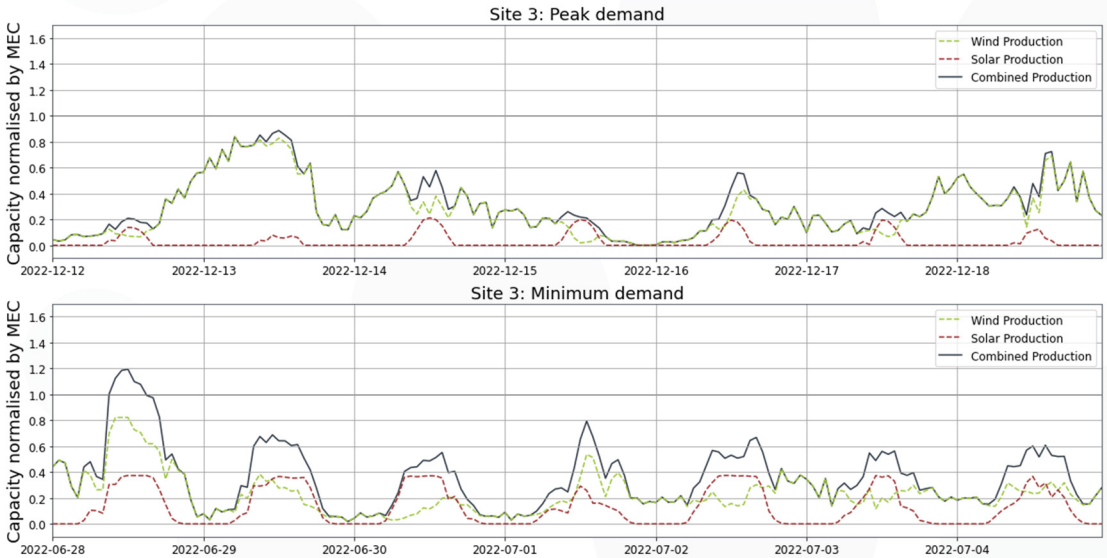
Site 2: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 100 % of windfarm capacity.



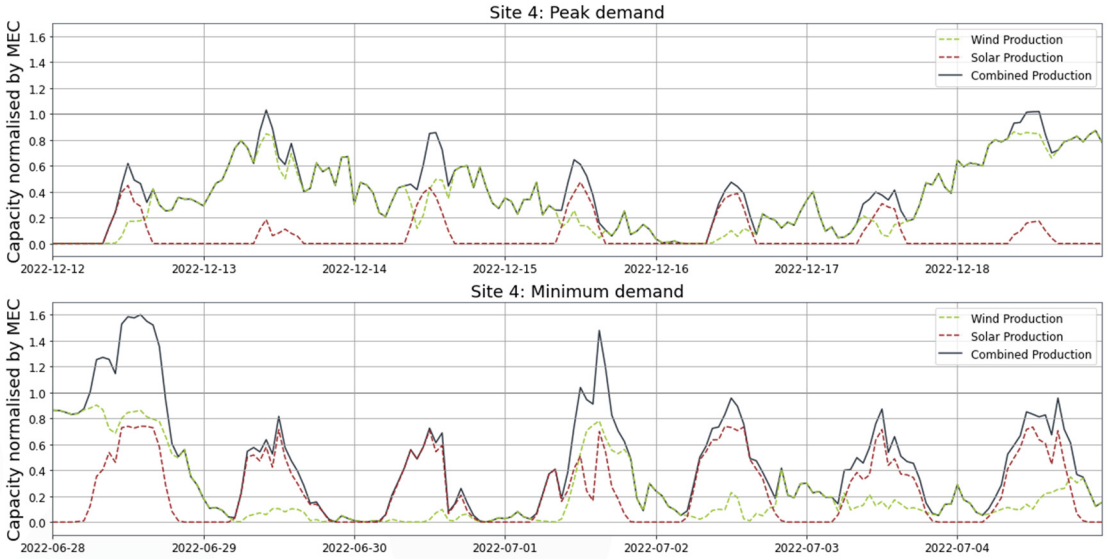
Site 2: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 50 % of windfarm capacity.



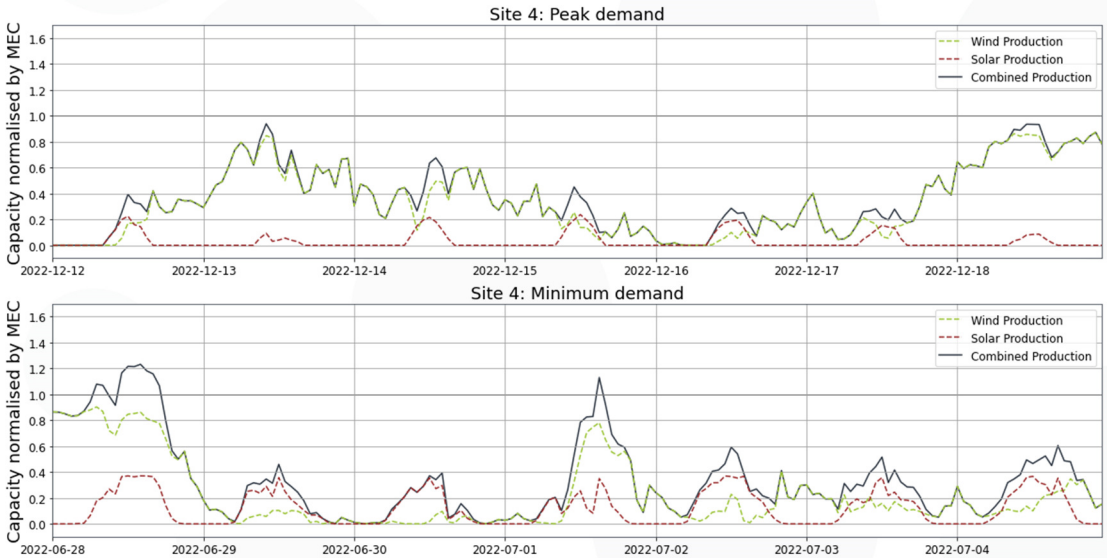
Site 3: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 100 % of windfarm capacity.



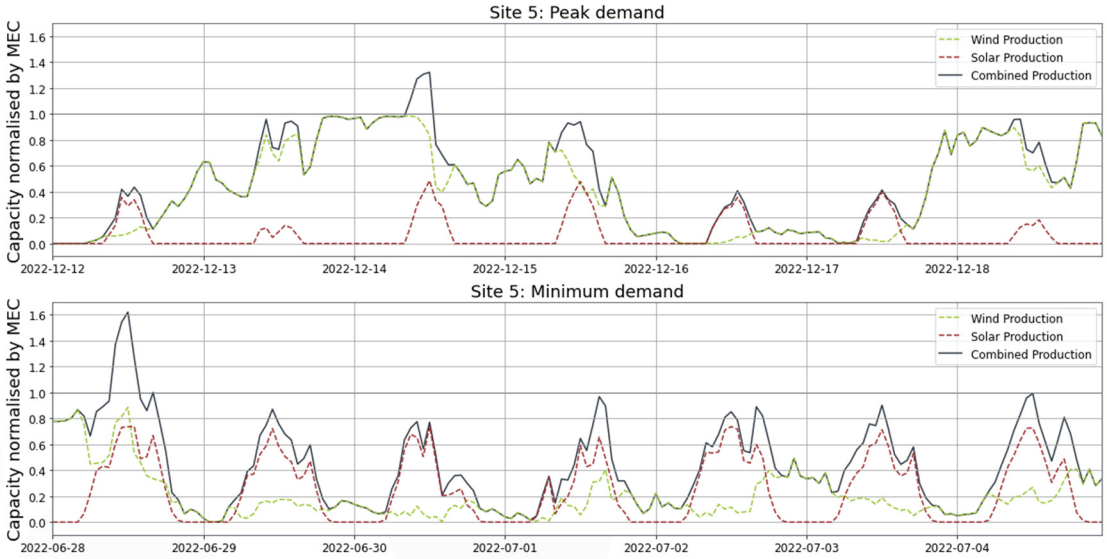
Site 3: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 50 % of windfarm capacity.



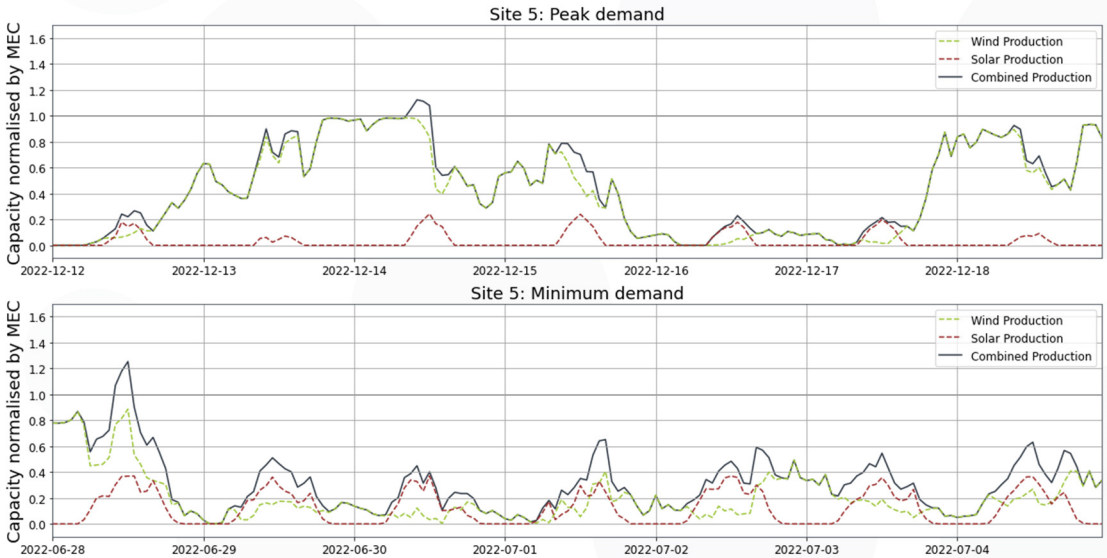
Site 4: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 100 % of windfarm capacity.



Site 4: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 50 % of windfarm capacity.



Site 5: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 100 % of windfarm capacity.



Site 5: Wind, solar, and combined production during the peak demand period. Solar capacity sized at 50 % of windfarm capacity.

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