Baker Lake

Preliminary System Integration Study

Client: Northern Energy Capital & Kivalliq Alternative Energy
Reference: 20-039
Version 2

April 2022

NORTHERN ENERGY CAPITAL

Report Prepared for:
Northern Energy Capital & Kivalliq Alternative Energy

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Approved by	Stephanie Wood	Date	07/04/2022

Issue History	Date	Details
V1.0	31/01/2022	Issued for Client Review
V2.0	07/04/2022	First revision following Client feedback.

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1 Introduction

Green Cat Renewables (herein GCR) have been retained by Northern Energy Capital (NEC) on behalf of Kivalliq Alternative Energy (herein 'KAE' and the 'Developer') to conduct a preliminary renewable energy system integration study for the community of Baker Lake, Nunavut. Baker Lake currently relies on diesel generators to meet the local electricity demand. The community is currently powered by four Caterpillar diesel generators with rated capacities of 550kW, 850kW, 1,050kW and 1,100kW. Qulliq Energy Corporation (QEC), who are the local utility for the community, have provided monthly generation totals spanning four years and a set of daily data files containing 10 second power generation data from each of the generators, as well as the total load. It is assumed that the load data provided by QEC are equivalent to the demand for the community (under the assumption that no additional generators produce power for the local grid).

The following study considers the use of wind and battery energy storage systems (BESS), and how renewable energy systems of different sizes might interact with the demand in order to offset the diesel generation. A range of wind project sizes comprising 1, 2 and 3 turbines was considered. GCR has assumed 1MW DW61 wind turbines with a 46m hub height for this purpose.

2 Analysis of Electricity Generation Data Provided

QEC provided monthly data for the period April 2015 to March 2019 inclusive[1]. The data tables did not have headings, but through comparison with other files provided, the columns have been deduced to be total electricity demand (in kWh) and diesel consumption (in litres) as tabulated in Table 2-1. Figure 2-1 illustrates the average seasonal profile of consumption over the four-year period.

Table 2-1 – Monthly electricity demand and diesel consumption data provided for Baker Lake

Year / Month	2015/2016		2016/2017		2017/2018		2018/2019	
	Electricity Demand (kWh)	Diesel Consumption (l)	Electricity Demand (kWh)	Diesel Consumption (l)	Electricity Demand (kWh)	Diesel Consumption (l)	Electricity Demand (kWh)	Diesel Consumption (l)
April	761,671	185,353	770,655	200,905	785,750	205,609	787,047	205,413
May	692,395	186,221	659,479	167,361	699,626	178,352	729,807	195,581
June	599,385	158,794	588,186	150,144	618,108	161,099	621,030	160,887
July	573,161	144,271	609,694	157,652	618,663	159,661	616,177	159,363
August	621,195	160,041	628,169	164,326	642,501	167,770	664,338	168,788
September	664,489	170,466	646,839	165,970	663,513	175,331	688,062	180,492
October	768,916	194,913	728,788	193,151	782,019	204,177	779,488	206,323
November	800,076	202,752	781,005	196,216	871,847	221,040	866,357	227,124
December	884,410	228,263	888,247	227,255	891,024	243,374	895,444	228,573
January	876,844	222,505	906,559	254,422	911,443	239,568	951,849	241,466
February	846,321	220,847	825,703	194,591	872,687	227,946	841,848	218,249
March	828,374	214,509	872,938	227,431	866,563	222,454	868,439	227,998
Total	**8,917,237**	**2,288,935**	**8,906,262**	**2,299,424**	**9,223,744**	**2,406,381**	**9,309,886**	**2,420,257**

[1] Baker Lake & Rankin Inlet data for NEC.docx, provided by email to GCR by NEC.

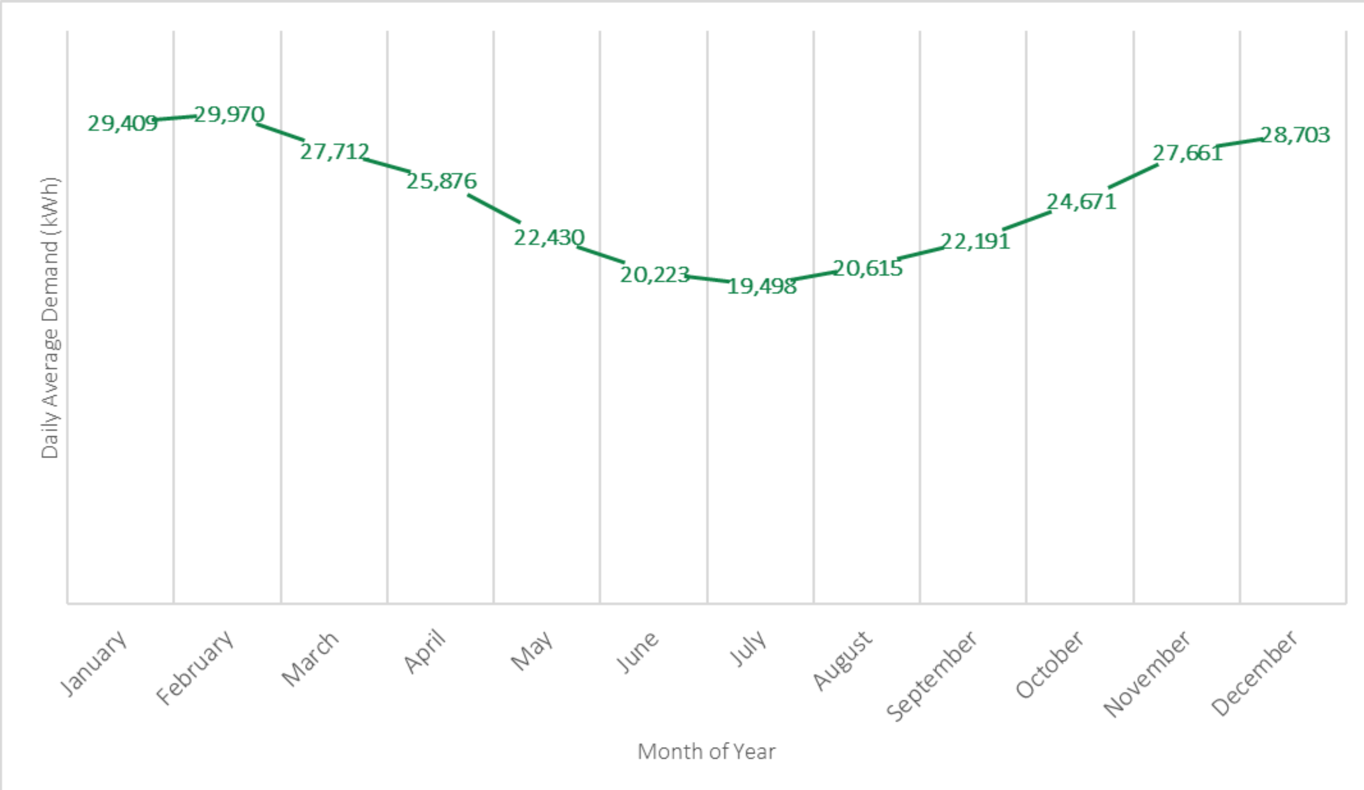

Figure 2-1 – Baker Lake seasonal distribution of daily average demand (April 2015 to March 2019), according to the monthly data provided for review.

As can be seen on the previous page, the demand is highest in the winter months, reducing in the summer months. The annual demand is reasonably consistent, with a detectable upward trend in the annual demand over the four years. QEC also provided an excel spreadsheet[2] containing forecast generation figures out to the year 2030. The forecast generation by the year 2030 is given as 10,221MWh.

While the monthly energy consumption records provide useful context, the resolution is not adequate to inform the Preliminary Integration Study. GCR therefore requested detailed demand/production data from QEC. QEC provided two sets of data:

1. '602_Feeder_SCADA_EXCEL_Baker Lake'
    a. Generator data: no data provided.
    b. Feeder data: 215 daily files containing 10s data.
2. '602 (Baker).zip':
    a. Generator data: 405 daily files containing 10s data.
    b. Feeder data: 208 daily files containing 10s data.

[2] Load forecast model master file for 2020-21 ext - Oct 7.xlsx

QEC indicated that these records are gathered by a programmable logic controller (PLC) installed on the site of the diesel generators. All available records have been provided where QEC have been able to do so.

Two files containing a description of the data were provided for the generator data:

1. 2018 03 27 0000 (Tagname).csv
2. 2019 01 03 0000 (Tagname).csv

The contents of the files were identical in both cases. The header data are shown in the following table.

Table 2-2 – Contents of the generator tagname header file provided for Baker Lake

;Tagname	TTagIndex	TagType	TagDataTyp
BAKER\GEN1\G1_REAL_POWER	0	2	1
BAKER\GEN2\G2_REAL_POWER	1	2	1
BAKER\GEN3\G3_REAL_POWER	2	2	1
BAKER\MISC\TOTAL_LOAD	3	2	0
BAKER\GEN4\G4_REAL_POWER	4	2	1

A single feeder data header file was provided for the site '2018 03 27 0000 (Tagname).csv', containing the data shown in the table below:

Table 2-3 – Contents of the feeder tagname header file provided for Baker Lake

;Tagname	TTagIndex	TagType	TagDataTyp
BAKER\F1\F1_REAL_POWER	0	2	1
BAKER\F2\F2_REAL_POWER	1	2	1
BAKER\F3\F3_REAL_POWER	2	2	1
BAKER\SS1\SS1_REAL_POWER	3	2	1
BAKER\SS2\SS2_REAL_POWER	4	2	1

The daily generator files contained 10 second readings from each of the four generators, as well as the total load. The records provided are structured as follows:

Table 2-4 – Header and first eight lines of generator data from the file '2018 03 28 0000 (Float).csv'

;Date	Time	Millitm	TagIndex	Value	Status	Marker	Internal
03/28/2018	00:00:01	186	0	0		B	-1
03/28/2018	00:00:01	186	1	0		B	-1
03/28/2018	00:00:01	186	2	800		B	-1
03/28/2018	00:00:01	186	3	1208		B	-1

03/28/2018	00:00:01	186	4	16		B	-1
03/28/2018	00:00:04	535	0	0			0
03/28/2018	00:00:04	535	1	0			1
03/28/2018	00:00:04	535	2	798			2
03/28/2018	00:00:04	535	3	1202			3
03/28/2018	00:00:04	535	4	16			4
03/28/2018	00:00:14	615	0	0			5
03/28/2018	00:00:14	615	1	0			6
03/28/2018	00:00:14	615	2	792			7
03/28/2018	00:00:14	615	3	1214			8
03/28/2018	00:00:14	615	4	16			9

The daily feeder data files contained 10 second readings from F1, F2, F3 SS1 & SS2. The records provided are structured as follows:

Table 2-5 – Header and first eight lines of feeder data from the file '2018 03 28 0000 (Float).csv'

;Date	Time	Millitm	TagIndex	Value	Status	Marker	Internal
03/28/2018	00:00:01	726	0	345		B	-1
03/28/2018	00:00:01	726	1	560		B	-1
03/28/2018	00:00:01	726	2	251		B	-1
03/28/2018	00:00:01	726	3	24		B	-1
03/28/2018	00:00:01	726	4	2		B	-1
03/28/2018	00:00:04	540	0	345			0
03/28/2018	00:00:04	540	1	560			1
03/28/2018	00:00:04	540	2	251			2
03/28/2018	00:00:04	540	3	24			3
03/28/2018	00:00:04	540	4	2			4
03/28/2018	00:00:14	662	0	338			5
03/28/2018	00:00:14	662	1	554			6
03/28/2018	00:00:14	662	2	250			7
03/28/2018	00:00:14	662	3	24			8
03/28/2018	00:00:14	662	4	2			9

QEC indicated in a telephone conversation with GCR that the 'Value' column represents the instantaneous power reading in kW, taken at ~10 second intervals. A number of occurrences of 'E' in the status field were noted, often corresponding with a value of 0 in the value field. QEC indicated that occurrences of 'E' represent errors in the data in the data recording or communications systems. It has been inferred from the data provided that the timestamps are recorded in local time throughout (GMT-6 in the winter months and GMT-5 in the summer months).

Due to the volume of data provided, GCR developed a VBA macro to process the 10 second values into a useable time series. The macro recorded the half-hourly average 'Value' for each: F1, F2, F3, SS1, SS2, G1, G2, G3, G4 and TOTAL_LOAD, alongside the max and min TOTAL_LOAD. The number of occurrences of 'E' in the marker field were also extracted from the data for each of the tag indices, along with the observation count for each half hour long period. QEC indicated that the 'TOTAL_LOAD' measures the combined output of all generators. NB: GCR noted that the data for G4 are either 0 or 16 throughout, suggesting that these records may be erroneous. The sum of the individual generators is often less than the total load, but occasionally matches perfectly.

The sum of the feeder data is a reasonably close match with the Total Load data from the generators, however there is a ~6% difference (feeder data is lower than the total load). GCR has checked the total energy consumption presented in Table 2-1 and found that the generator data is a better match with the total demand data. GCR has elected to use the generator total load data as the primary source of data at this site.

The data were then subject to quality control and validation using Windographer software. Any half hourly period with an 'E' count of greater than 0 were discarded. Similarly, periods adjacent to 'E' counts of greater than 0 were visually inspected and discarded if the corresponding 'Value' data were observed to be erratic or spurious e.g. significant differences in the max and min, large changes in readings from one half hour to the next or otherwise off-trend data points.

The diurnal pattern and frequency histogram of the quality-controlled data is shown in the following figures. As can be seen, the daily profile follows a fairly typical pattern, with high levels of consumption around lunch time and in the evening, and lower levels of consumption during the night and early morning. The total output of the generators is rarely below 600kW, with the lowest demand occurring in the early hours of the morning in summer. The figures on the following page include the average of: maximum, average and minimum load for each hour of the day.

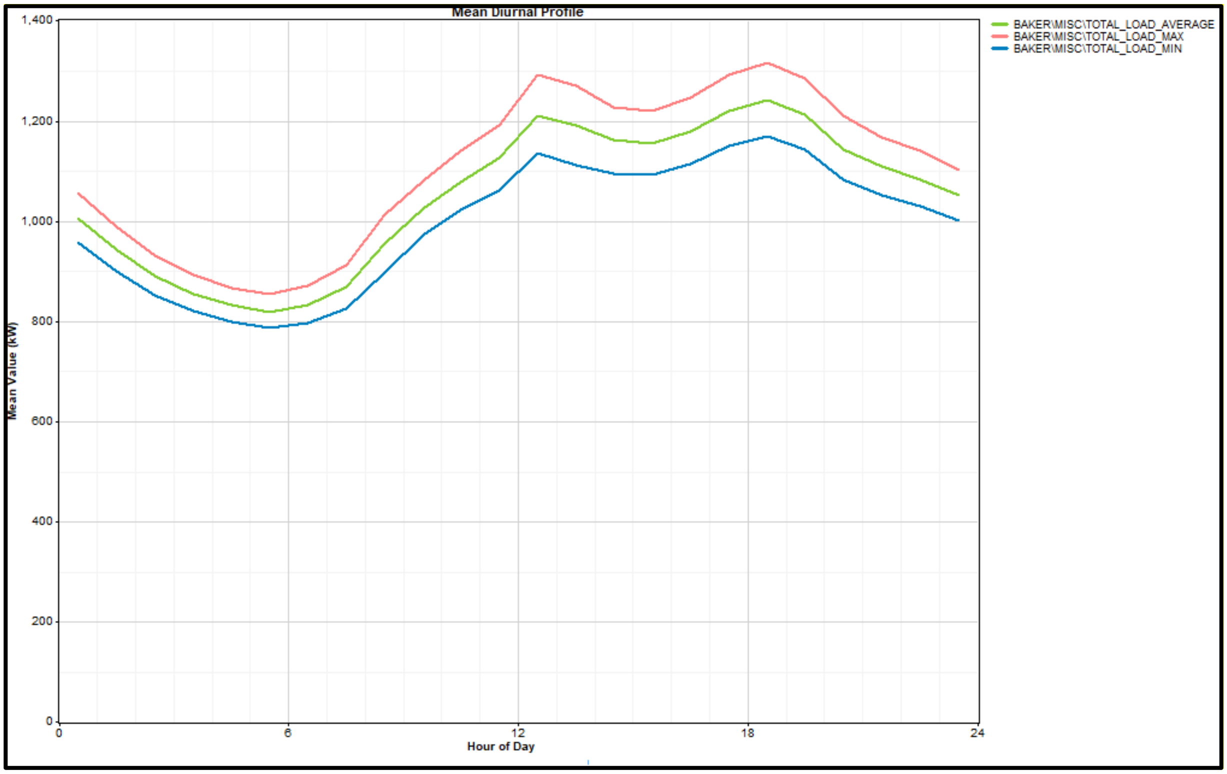

Figure 2-2 – Diurnal profile of generation at Baker Lake (annual)

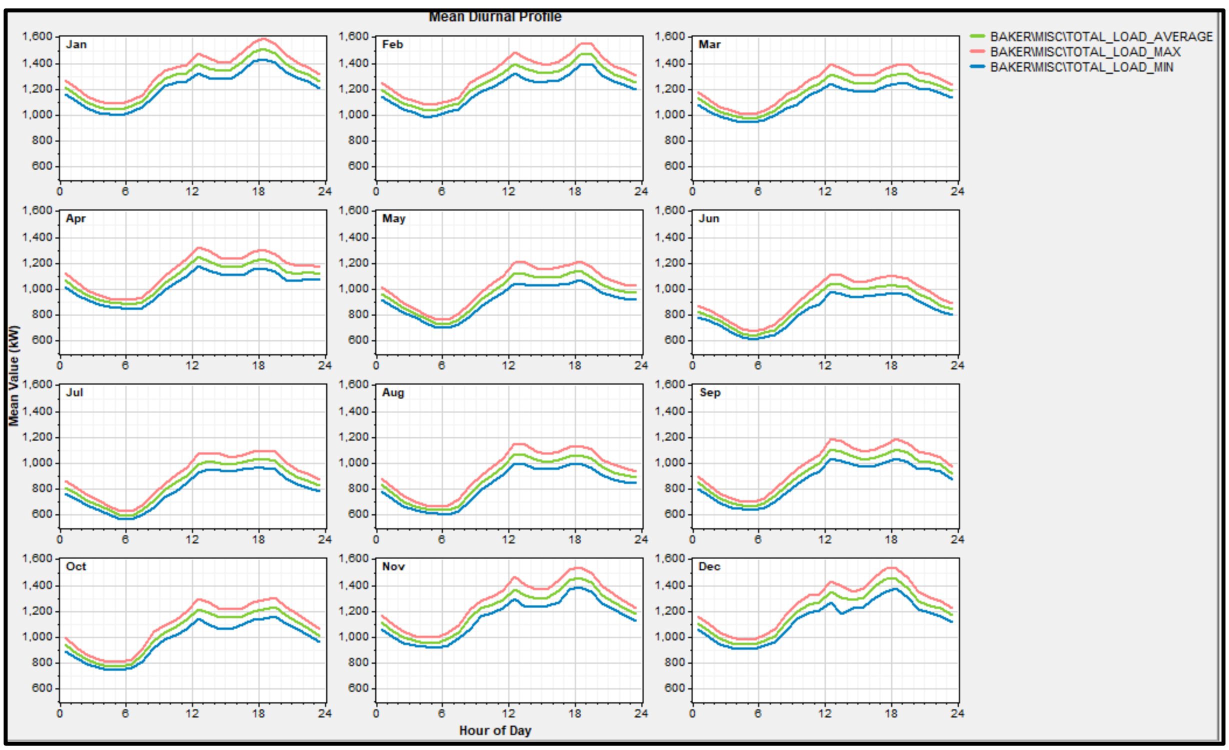

Figure 2-3 – Diurnal profile of generation at Baker Lake (by month)

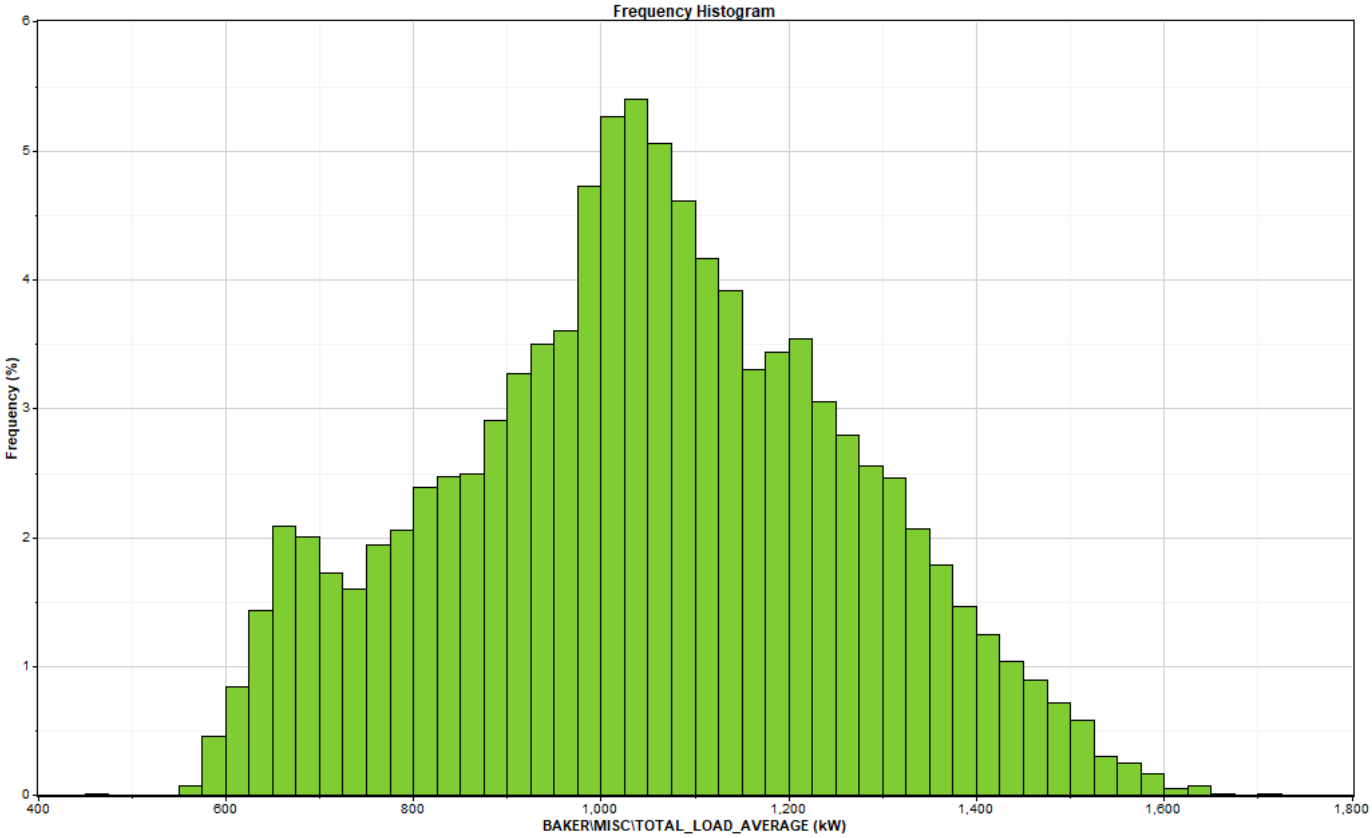

Figure 2-4 – Frequency histogram of generator output.

The data daily and monthly data recovery of this quality-controlled dataset is shown in the following table.

Table 2-6 – Baker Lake data recovery for each day and month expressed as the number of retained half hourly data points after quality control. NB values of zero indicate zero observations for that day and month in any of the years of data provided.

Month / Day of Month	1	2	3	4	5	6	7	8	9	10	11	12
1	0	48	47	48	48	48	0	48	48	0	0	48
2	0	48	47	48	48	48	0	48	48	0	31	48
3	17	48	48	48	48	48	0	48	48	0	48	45
4	48	47	47	48	48	48	0	48	48	15	4	48
5	48	47	48	48	48	48	0	48	48	39	48	48
6	48	48	48	48	48	48	0	48	48	45	48	48
7	48	48	48	48	48	48	0	48	48	48	48	48
8	48	48	48	48	48	48	0	48	48	48	48	48
9	48	48	48	48	48	25	0	48	48	48	48	48
10	48	48	46	48	48	0	0	48	48	48	48	48
11	48	48	48	48	48	0	0	48	48	47	48	48
12	48	48	48	48	48	0	0	48	48	47	48	48
13	48	48	47	47	48	24	48	48	48	47	48	48
14	48	48	48	48	48	48	48	48	48	47	17	25
15	48	48	48	48	48	48	48	48	48	47	0	0
16	48	45	47	48	48	48	48	48	48	47	0	0
17	48	48	48	48	48	48	48	48	48	48	16	0
18	48	48	48	48	48	47	48	46	48	48	48	0
19	48	48	48	48	48	48	47	48	32	25	48	0
20	48	48	48	48	48	27	48	48	45	0	48	0
21	48	48	48	48	48	0	47	47	48	0	48	0
22	48	45	48	48	48	0	48	48	48	19	48	0
23	48	40	2	48	48	0	48	48	46	48	48	0
24	48	41	13	48	48	0	48	47	47	48	48	0
25	43	43	0	48	48	0	48	48	47	48	46	0
26	23	47	0	48	48	0	48	48	48	48	48	0
27	48	41	48	48	48	0	48	48	48	48	48	0
28	48	45	48	48	48	0	48	48	7	48	48	0
29	48	-	48	48	48	0	48	45	6	48	48	0
30	48	-	48	48	48	0	48	42	0	28	48	0
31	43	-	48	-	48	-	48	48	0	0	-	0

The overall data recovery is poor at around 81% of the year, with significant, prolonged gaps in the records, particularly in the months of June, July, and December. Using this data as is will bias in the results due to the seasonal nature of both the renewable energy generation and the demand profile. Fortunately, the load profile follows a reasonably consistent diurnal and seasonal pattern. GCR has identified a degree of symmetry centred around mid-July:mid-January, that is to say: the generation for June is comparable with that of August, May is similar to September, and so on. This pattern is also observed in the monthly data provided for review.

GCR has produced a years' worth of demand data using the following data substitution methodology:

1. The quality-controlled data were exported from Windographer;
2. A fictitious 'representative year' half hourly time series was created. For each half hourly period, data were extracted from the records in the following order 2018, 2019 (when no values are available from 2018), 2020 (when no values are available from 2018 or 2019). Note that the order of the data substitution is not expected to significantly influence the results, as the resulting profile will be scaled (see below);
3. Half hour long gaps were interpolated from adjacent timestamps (~0.2% of data);
4. Remaining gaps (mainly long periods of time) were then filled using data from alternative dates, based on a line of symmetry through the 14th July e.g. data from the 15th July could be sourced from the 13thJuly, and so on. (~17.3% of data);
5. Any residual gaps were then filled according to the following data substitution scheme:
    a. Take data from 1 day ahead (~1.4% of data);
    b. Take data from 1 day behind (~0.2% of data);
    c. Take data from 2 days ahead (~0.0% of data);
    d. Take data from 2 days behind (<0.0% of data).

The resulting time series contains data for each 48-hour period, 365 days per year. The total annual energy demand in the time series is 9,349MWh. For comparison: the demand in the last full twelve months of monthly data provided (April 2018 to March 2019 inclusive) was ~9,310MWh – a difference of around 0.4%.

GCR has scaled the half hourly profile in order to better match the future demand of 10,221MWh in 2030; a scaling factor of 109.3% has been applied to each half hourly value. This is a reasonable approximation assuming the seasonal and daily distribution of demand is similar to the past.

3 Time Series Modelling

The scaled half hourly time series demand data derived above has been converted into an hourly time series for direct comparison with the wind time series output (which is limited to hourly resolution). The average demand is compared with the net wind[3] power output for each hour for a full year (8760 hours).

The wind power time series is based on ERA5[4] wind speed, temperature and pressure data for the node[5] nearest the site (64.250N, 96.000W). The ERA5 wind speed has been scaled to match the AWS wind speed estimate at 50m AGL of 6.96m/s (as provided by the Developer at the following position: 64.33700N, 9.00283W). The wind speed in each hour has also been modified[6] by the air density (calculated from ERA5 temperature and pressure data) in order to better capture the impact of changes in air density throughout the year (which is significant at this site).

Sales power curve data for the EWT DW61 1MW[7] have been used to estimate the gross power production for each hour. Technical losses have been incorporated to produce an estimate of the net wind[3] power output for each hour. It is assumed that the turbine is equipped with anti-icing and de-icing options and includes a 'cold weather' package. There may be times when these systems consume power – this has not been modelled in this preliminary study. The time series of wind power output for the year 2017 has been added to the timeseries model as this year was found to be closest to average conditions at this site. It is important to highlight high levels of uncertainty in the wind power time series data.

A summary of the seasonal variation in daily average demand and wind production is provided in **Figure 3-1**. As can be seen, the seasonal profile of wind generation is a close match with the demand profile.

[3] Please refer to Appendix A – Wind Power Technical Losses

[4] ERA5 reanalysis data, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF)

[5] ERA-5 nodes have a horizontal spatial resolution of approximately 30km. Hourly ERA-5 data therefore represent conditions over a wide area (not a specific point in space).

[6] Based on the IEC 61400-12 method.

[7] EWT Document reference: **S-1209901**, revision 00, dated 13-04-2017

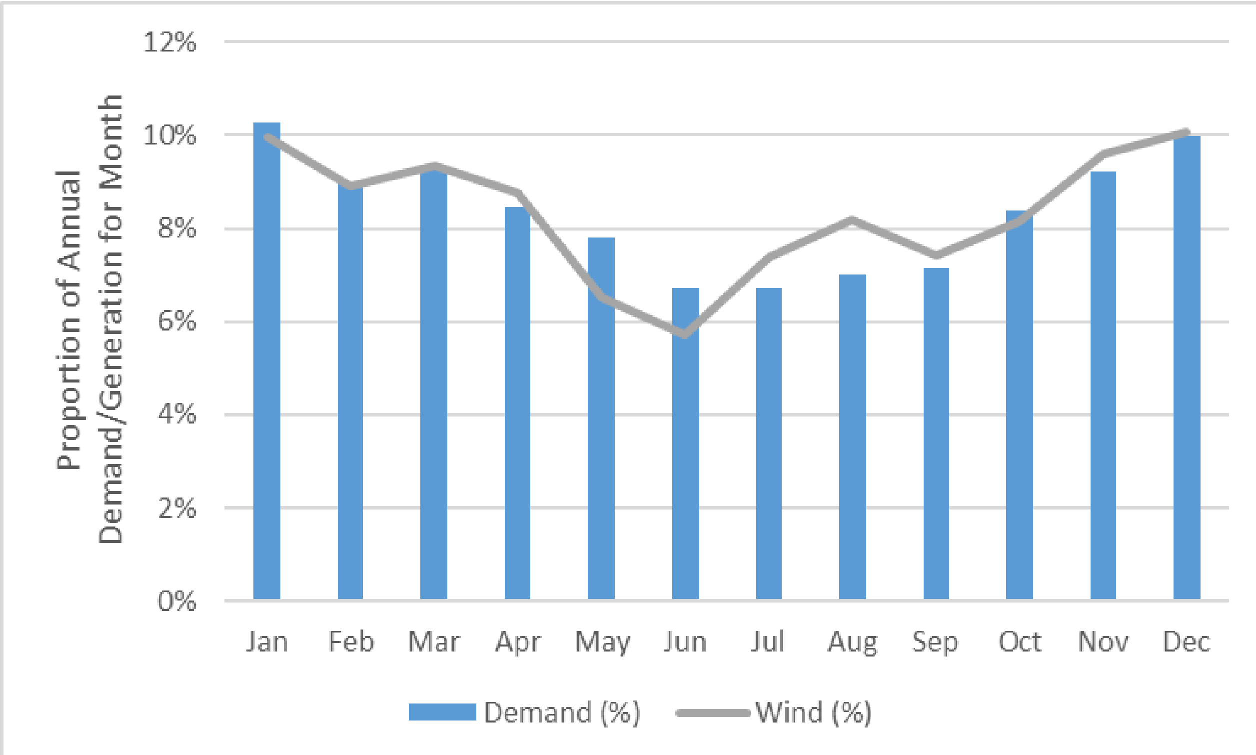

Figure 3-1 – Seasonal distribution of demand and wind power generation. Wind based on long term period 1979 to 2020 inclusive.

The net demand and generation was calculated for each hour. Where there is excess generation, and where a BESS is modelled, the BESS has the opportunity to absorb the power for later use. Where the demand exceeds the renewable generation, the BESS will release the stored energy at a rate not greater than the net demand (after contributions from the wind turbine). The energy flow to and from the BESS is also limited by the rated power and energy capacity of the BESS. For the purpose of modelling, the specifications below have been assumed for the BESS modelling:

1. It is assumed that 80% of the BESS installed capacity will be available for use i.e. 800kWh in every 1,000kWh installed capacity. This a reasonable assumption for a lithium-ion type BESS where a sensible strategy would be to limit the state of charge to between 10% and 90% to prolong the service life of the cells.
2. A charge and discharge efficiency of 95% is assumed, with a further 1% electrical loss assumed between the renewable generators to the BESS, and 1% loss from the BESS to the network. This results in a round trip efficiency of approximately 88%.
3. In this preliminary model, self-discharge, parasitic[8] consumption and battery performance degradation are not considered.

[8] The parasitic load is mainly a consideration during prolonged periods of calm weather.

A series of BESS sizes have been modelled: 0kW (no BESS), and 1,000kW, with 1, 2, 3 and 4 hours of storage (1,000kWh, 2,000kWh, 3,000kWh and 4,000kWh). A battery size of 1,000kW has been selected as this will be capable of replacing the maximum generating output of one turbine in the event of a fault at rated power. It is assumed that the renewable generators and BESS have priority over the diesel generators in this model.

In the model with no battery (0kWh): a minimum diesel load of 330kW[9] is assumed. In the model that includes the BESS: If the renewable generation exceeds the demand, it is assumed the diesel generators can be switched off, otherwise, the minimum diesel load applies.

Systems with high levels of renewable energy penetration may lead to instability in the local grid, especially in scenarios where no BESS is included. It may be possible to mitigate these effects by incorporating a short duration energy storage system. Such a system would need to be able to absorb short timescale fluctuations in renewable energy output and demand, and have a duration that is at least sufficient to bring the diesel generators online in the event of a sudden drop in renewable power output e.g. downtime. The range of viable system configurations therefore depends on the stability of the system and the ramping capabilities of the generators and energy storage systems incorporated. An engineered solution should be investigated in conjunction with discussions with QEC as part of the detailed design, but it is expected that installing a suitably sized battery with the chosen renewable energy technology will provide the level of stability required by QEC.

[9] QEC indicated in a meeting with GCR that a preferred minimum diesel load of 60% per generator would be desirable. 550kW is the smallest diesel generator on the site currently.

The following figures illustrate the logic used in the hourly simulation. These flow charts are not intended to be used as a live microgrid control algorithm.

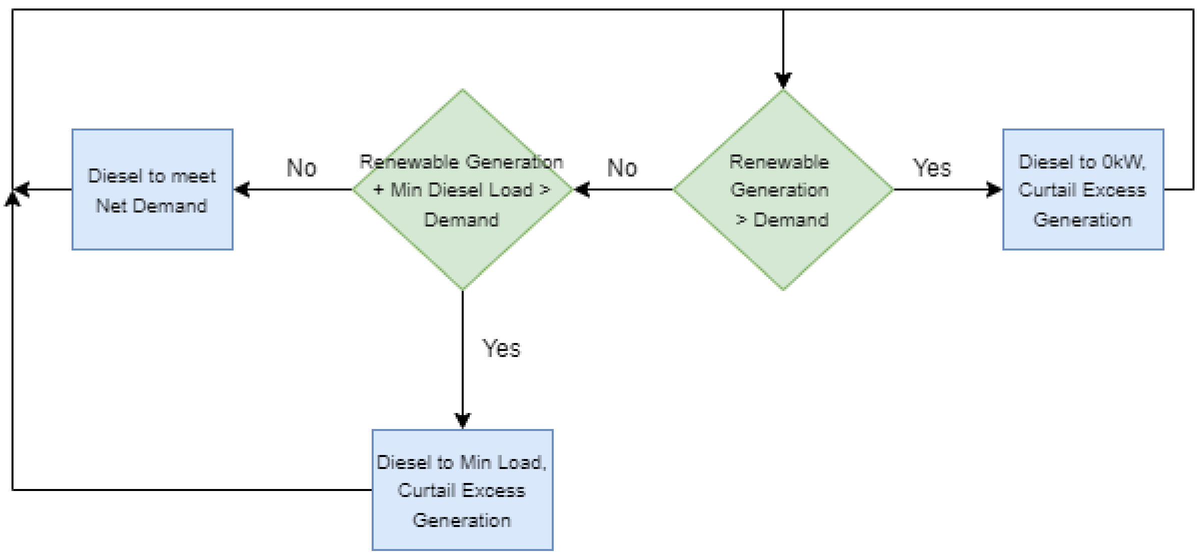

Figure 3-2 – Simple illustration of the hourly simulation logic for systems without BESS.

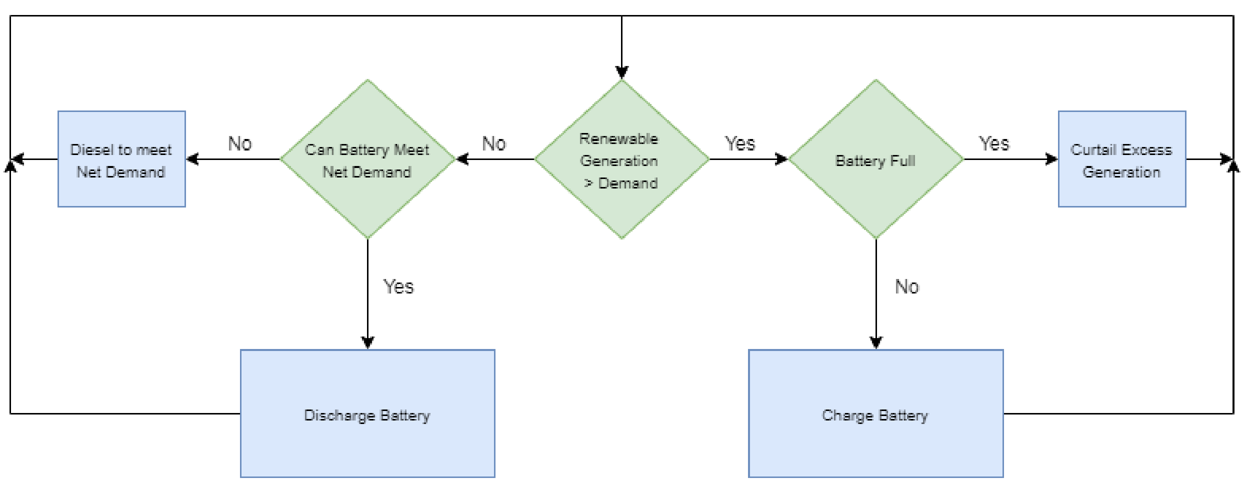

Figure 3-3 – Simple illustration of the hourly simulation logic for systems with BESS.

4 Results

Table 4-1,**Table 4-2** and **Table 4-3** present the results for a range of system configurations modelled. The demand profile is based on the 8760-hour long time series, scaled to the 2030 annual demand forecast of 10,221MWh:

1. **Demand Met.** This is the annual demand met by the renewable generation and BESS in MWh.
2. **Fraction of Total Demand Met.** This is the above measure divided by the total demand of 10,221MWh per annum.
3. **Excess Generation.** The annual excess generation in MWh that is not utilised directly by the demand or by the BESS and later released to the demand e.g. due to a lack of BESS, a fully charged BESS at times when the renewable generation exceeds the demand, excess power in exceedance of the BESS rated power. Excess generation would need to be curtailed in some way or otherwise utilised in order to balance the electrical system. The wind turbine could be curtailed in real time via the SCADA system. A dump load e.g. electric heating could also be used to absorb excess generation.

Some selected examples from the results for illustration purposes:

1. A system with a single wind turbine and a 1 hour BESS could provide 2,421MWh (23.7% of demand) with an excess generation of 47MWh.
2. A system with two wind turbines and a 1 hour BESS could provide 4,134MWh (40.4% of demand) with an excess generation of 802MWh.

Graphs illustrating the seasonal distribution of energy for these scenarios is provided in **Figure 4-1** and **Figure 4-2** on the following page.

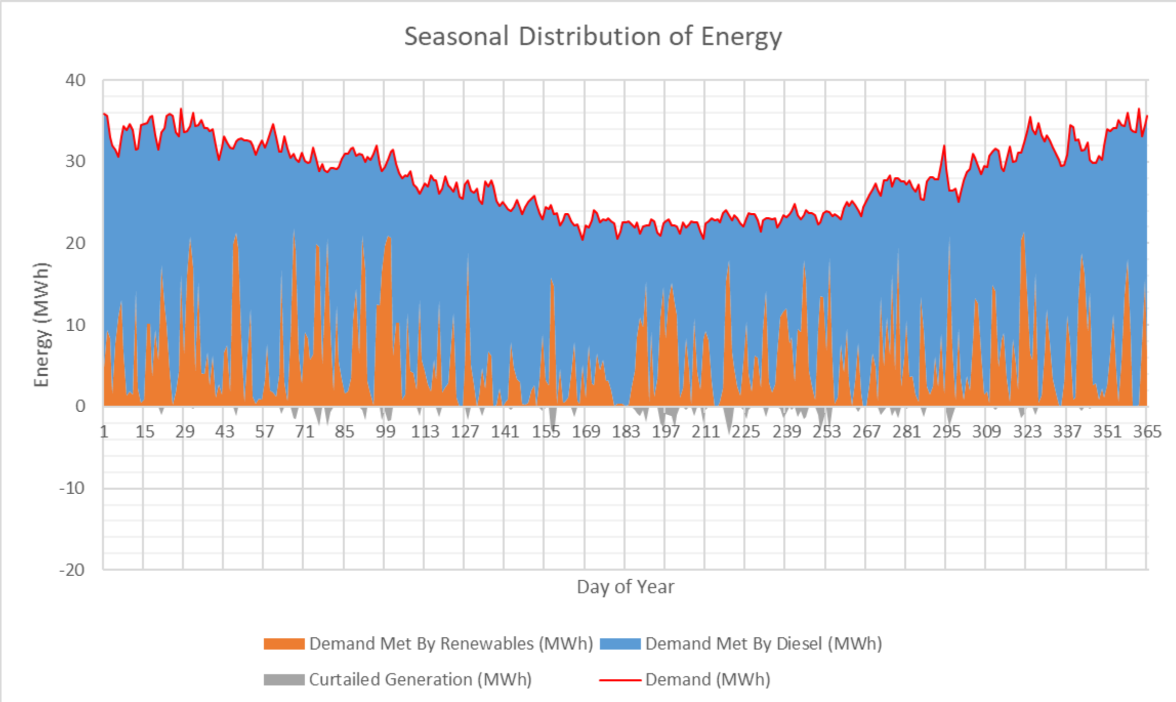

Figure 4-1 – Seasonal distribution of demand met by renewables and diesel, along with curtailed renewable generation. Results presented for a single EWT DW61 1MW 46mHH and a one-hour, 1.0MW BESS.

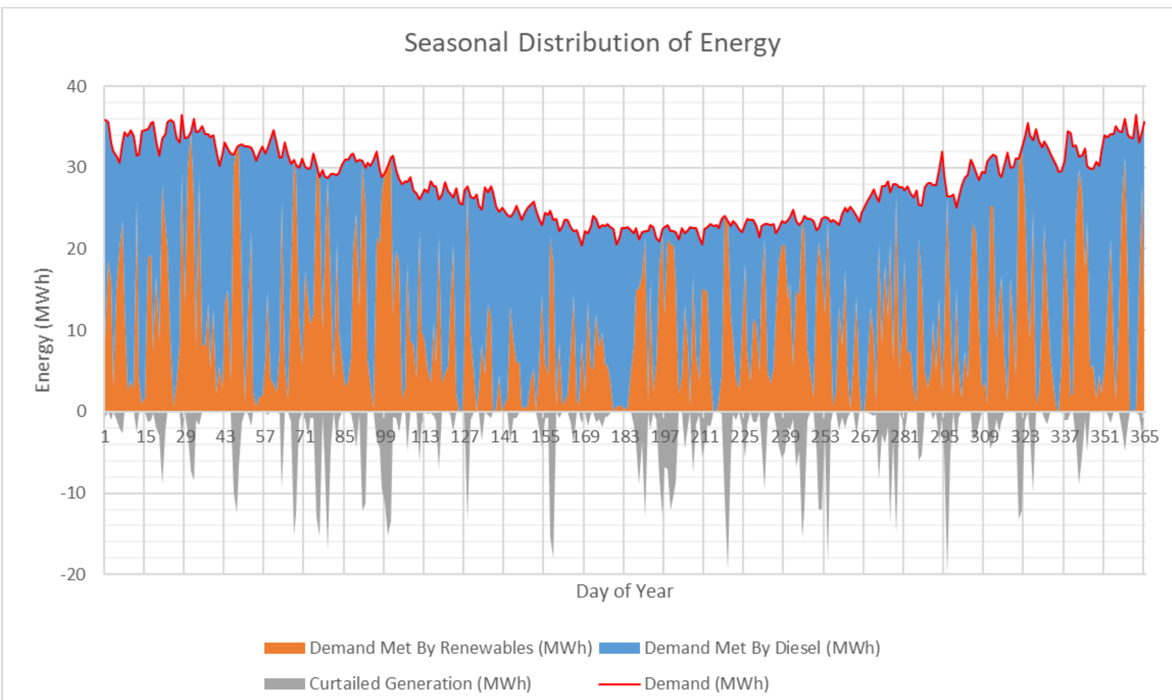

Figure 4-2 – Seasonal distribution of demand met by renewables and diesel, along with curtailed renewable generation. Results presented for 2 x EWT DW61 1MW 46mHH and a one-hour, 1.0MW BESS.

Table 4-1 – Baker Lake Demand Met

Wind Only						
Demand Met (MWh)		BESS System Size (kWh)				
		0	1,000	2,000	3,000	4,000
Number of Wind Turbines	1	2,334	2,421	2,444	2,453	2,458
	2	3,476	4,134	4,200	4,256	4,301
	3	4,024	5,027	5,112	5,182	5,245

Table 4-2 – Baker Lake Fraction of Total Demand Met

Wind Only						
Fraction of Total Demand Met (%)		BESS System Size (kWh)				
		0	1,000	2,000	3,000	4,000
Number of Wind Turbines	1	22.8%	23.7%	23.9%	24.0%	24.1%
	2	34.0%	40.4%	41.1%	41.6%	42.1%
	3	39.4%	49.2%	50.0%	50.7%	51.3%

Table 4-3 – Baker Lake Excess Generation

Wind Only						
Excess Generation (MWh)		BESS System Size (kWh)				
		0	1,000	2,000	3,000	4,000
Number of Wind Turbines	1	140	47	21	11	5
	2	1,472	802	727	664	613
	3	3,399	2,381	2,285	2,206	2,134

5 Conclusions & Recommendations

Detailed 10 second generation data have been processed into a years' worth of demand data for direct comparison with an hourly wind power output time series. The interaction between the demand, renewable generation and a BESS has been modelled for a range of wind and BESS configurations to allow the Developer to understand how system sizing impacts the results.

GCR provide the following conclusions and recommendations:

1. Relatively high levels of renewable penetration are possible while avoiding significant levels of excess generation. This is thanks to the relatively high minimum demand and continuous nature of the demand.
2. A BESS and/or alternatively, a short duration energy storage system may be required in order to maintain stability of the grid. Grid stability of the scenarios presented should be determined as part of the preliminary and detailed design stages in conjunction with discussions with QEC. An engineered control system will be required.
3. The BESS system has been modelled using 'demand following' logic in this study. This maximises renewable energy penetration for a given BESS size. A BESS system could also operate in cycle charging mode, whereby the diesel generators operate at maximum efficiency in order to charge the BESS, before shutting down and handing over to the BESS. Cycle charging may result in a reduction in diesel consumption (due to higher efficiency) but may lead to additional degradation of the BESS. A combination of demand following, and cycle charging logic could also be used.
4. It is important to note that there is a high degree of uncertainty in the wind energy generation profile. If wind power is deemed a desirable option, it is recommended that a more detailed wind power time series is developed based on measured data. Measurements should be gathered for a period no less than 12 months and a detailed wind resource assessment should be undertaken thereafter.
5. Modelling outcomes indicate that a single DW61 wind turbine with a 1-hour BESS could provide around 23.7% of the total annual demand for the community. This configuration would result in a negligible level of curtailment (~1.9% of potential net generation). Adding a second turbine would allow the project to provide around 40.4% of the annual demand with a moderate amount of curtailment (~16.2% of potential net generation) required to achieve this level of renewable penetration. Installing three or more turbines of this scale will result in a significant degree of curtailment.
6. If a high renewable penetration is a desirable outcome, it may also be worthwhile to consider larger turbines e.g. 2MW or 3MW turbines.
7. It is recommended that a hybrid solution including solar and wind is considered. Combining these two technologies is likely to allow the project to achieve a higher penetration for a given curtailment penalty.
8. It is recommended that the results presented here are combined with capital and operating costs in order to identify the most cost-effective solution.
9. Discussions with QEC should be undertaken to help define the best solution for integration onto the existing micro-grid.

Appendix A – Wind Power Technical Losses

GCR has adopted the losses categories outlined by DNV KEMA in 2013.

1. **Availability** – An allowance of 5% has been included to account for turbine downtime. This is in keeping with a typical availability warranty for a single turbine site. A further 0.5% has been included to allow for turbine maintenance.

   A nominal allowance of 0.5% each for balance of plant and grid downtime has been included here. This assumption could be revisited based on data from the grid operator at a later date.

2. **Wake effects** – Wake losses have not been included here; for multi turbine scenarios, it is assumed that the turbines will be spaced and orientated to minimise the wake interaction. This assumption could be revised based on a detailed energy yield calculation including the proposed layout.

3. **Turbine performance** – It is assumed that the turbine will perform according to the sales power curve data provided by the manufacturer. It is recommended that power curve warranty is obtained along with a warranted power curve.

4. **Electrical** – A nominal allowance of 2% has been included to account for electrical losses from the point of generation to the point of use. A further 1% has been included to account for facility parasitic consumption. Facility parasitic consumption will depend on the icing and cold weather options installed on the site and will vary according to the climatic conditions on the site. It is recommended that this is revisited in the future based on an in-depth study utilising site specific measurements.

5. **Environmental** – It has been assumed that the wind turbine's performance will be reduced due to the following external factors:

   a. Aerodynamic degradation not due to Icing – Assumed 0.5% over a typical 10 year financing period.

   b. Icing – In the absence of measured data at this site, GCR has adopted a nominal icing loss of 5% to account for icing losses. This is based on information provided in the VTT Wind Power Icing Atlas[10] which designates the site as IEA ice class II, with a corresponding estimated production loss range of 0.5% to 5%.

      Icing losses have been factored in by setting the hourly production to 0kW when the temperature is near zero degrees Celsius such that a 5% loss factor is achieved in the year selected for time series modelling (2017). This is a conservative treatment for the purposes of this study. In reality a proportion of the icing losses will take the form of performance degradation losses i.e. the power output would reduce for a given wind speed.

      Icing losses may be higher or lower in practise, and the impact on overall energy yield and the distribution of losses will depend on the performance of the icing package installed on the turbine. It is recommended that this category is revised based on detailed site measurements and an assessment of the performance of the manufacturer's icing package.

   c. Temperature threshold – It is understood that the turbine will shut down if the temperature is below the minimum operating temperature. It is assumed that the turbine installed at this site will be a 'cold climate' type (not standard). The minimum operating temperature for a cold climate type EWT is -40 degrees Celsius.

[10] *Wind Power Icing Atlas – WIceAtlas* (VTT, https://projectsites.vtt.fi/sites/wiceatlas/www.vtt.fi/sites/wiceatlas/index.html)

Hours where the temperature is below this threshold has been assigned a power output of 0kW in the time series. The impact is relatively modest at ~0.1%.

d. Force majeure – An allowance of 2% has been included to account for force majeure events - this is approximately equivalent to one week per year. This assumption could be refined based on a more detailed study of weather delays affecting transport between the site and the relevant EWT service centre(s).

e. Tree cover changes – Assumed to have a neutral effect over the long term period; there are no significant areas of woodland or forestry close to the site.

6. **Curtailment** – Various curtailment losses are possible:

   a. Wind sector management – Assumed none required – this is usually only applicable to larger developments that also have issues with turbine spacing.

   b. Grid & offtaker curtailment – These are modelled in time series depending on the scenario modelled.

   c. Planning restrictions – Curtailment losses attributable to planning restrictions (e.g. noise or shadow flicker) have not been considered in this assessment.

7. **Other** – No other losses have been accounted for

The overall conversion efficiency for the year selected for time series modelling (2017) is 85.1%.

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Table AA-5-1 – Definition of Technical Loss Categories in accordance wind DNV KEMA (2013)

Category Number	Category Name	Sub Category Number	Sub Category Name	Definition
1	Availability	1a	Turbine	Includes lost energy due to routine maintenance, faults, and component failures over the project lifetime.
		1b	Balance of plant	Losses due to downtime in components between the turbine main circuit breaker to and including project substation transformer and project-specific transmission line.
		1c	Grid	Losses due to downtime of power grid external to the wind power facility.
2	Wake effects	2a	Internal wake effects	Losses within the turbine array that is the subject of the energy assessment.
		2b	External wake effects	Losses on the turbines that are the subject of the energy assessment, from identified turbines that are not the subject of the energy assessment, which either already operate or which are expected to operate at commissioning of the facility being studied.
		2c	Future wake effects	Losses due to additional development in the vicinity of the turbines being studied, but which would occur after commissioning of the turbines being studied.
3	Turbine performance	3a	Power curve	Losses due to the turbine not producing to its reference power curve within test specifications (for which the turbines typically perform most favourably).
		3b	Wind flow	Losses due to turbulence, off-yaw axis winds, inclined flow, high shear, etc. These represent losses due to differences between turbine power curve test conditions and actual conditions at the site.
		3c	High wind hysteresis	Losses due to shutdown between high-wind cut-out and subsequent cut-back-in.
4	Electrical	4a	Electrical losses	Losses to the point of revenue metering, including, as applicable, transformers, collection wiring, substation, transmission.
		4b	Facility parasitic consumption	Losses due to parasitic consumption (heaters, transformer no-load losses, etc.) within the facility. This factor is not intended to cover facility power purchase costs, but does include the reduction of sold energy due to consumption “behind the meter.”
5	Environmental	5a	Performance degradation not due to icing	Losses due to blade degradation over time (which typically gets worse over time, but may be repaired periodically), and blade soiling (which may be mitigated om time to time with precipitation or blade cleaning).
		5b	Performance degradation due to icing	Losses due to temporary ice accumulation on blades, reducing their aerodynamic performance.

Category Number	Category Name	Sub Category Number	Sub Category Name	Definition
		5c	Shutdown due to icing, lightning, hail, etc.	Losses due to turbine shutdowns (whether by the local turbine controller, project-wide control system, or by an operator) due to ice accumulation on blades, lightning, hail, and other similar events.
		5d	High and low temperature	Losses due to ambient temperatures outside the turbine's operating range. (Faults due to overheating of components that occur when ambient conditions are within the turbine design envelope would be covered under turbine availability category above.)
		5e	Site access and other force majeure events	Losses due to difficult site access (for example: snow, ice, or remote project location). Note that this environmental loss and some other environmental losses may be covered under the availability definition, above. However, these "environmental" losses are intended to cover factors outside the control of turbine manufacturers.
		5f	Tree growth or felling	Losses due to growth of trees in the facility vicinity. This loss may be a gain in certain cases where trees are expected to be felled.
6	Curtailment	6a	Wind sector management	Losses due to commanded shutdown of closely spaced turbines to reduce physical loads on the turbines.
		6b	Grid and ramp-rate	Losses due to limitations on the grid external to the wind power facility, both due to limitations on the amount of power delivered at a given time, as well as limitations of the rate of change of power deliveries. This can be ongoing control of the Wind Turbine output over the project lifetime or temporary curtailment until grid reinforcements are carried out early in the project.
		6c	Offtaker curtailment	Losses due to the power purchaser electing to not take power generated by the facility.
		6d	Environmental (noise, visual, bird/bat)	Losses due to shutdowns or altered operations to reduce noise and shadow impacts, and for bird or bat mitigation This would include use of a low-noise power curve versus a standard one from time to time.
7	Other	7a	Other	Losses due to; the non-linear relationship of wind speed to energy, Air density correction if treated downstream of gross energy calculation,

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