



CORAL HARBOUR
PRELIMINARY SYSTEM INTEGRATION STUDY

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CONTENTS

1. Introduction	4
2. Analysis of Electricity Generation Data Provided	5
2.1. Naujaat Demand Data	7
2.2. Weighting of Naujaat Data	11
3. System integration Time Series Modelling	12
4. Results	16
5. Lowest Cost of Energy	21
6. Conclusions & Recommendations	24
Appendix A – Wind Power Technical Losses.....	26

1. INTRODUCTION

Green Cat Renewables (herein GCR) have been retained by Northern Energy Capital (NEC) on behalf of Sakku Investment Corporation (herein 'SIC' and the 'Developer') to conduct a preliminary renewable energy system integration study for the community of Coral Harbour, Nunavut. Coral Harbour currently relies on diesel generators to meet the local electricity demand. The community is currently powered by three (2 x 500kW – derated to 480kW max and 1 x 720kW) diesel generators, with a fourth 500kW generator reserved for emergencies. Qulliq Energy Corporation (QEC), who are the local utility for the community, have provided monthly generation totals spanning four years for the community of Coral Harbour. Unfortunately, detailed daily data files, containing 10 second power generation data for each of the generators, were not available for this community due to the equipment installed. Therefore, for the purposes of this assessment, a number of daily data files measured at the community of Naujaat will be used and adjusted accordingly. These daily files for the community of Naujaat contain 10 second power generation data from each of the three generators installed there, as well as the total load. It is assumed that the load data provided by QEC are equivalent to the demand for the Naujaat community (under the assumption that no additional generators produce power for the local grid).

The following study considers the use of wind, solar 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. This study follows on from part 1 of the feasibility study: Coral Harbour Technology Comparison Analysis, issued to the Developer in September 2020¹. A fixed tilt, bi-facial south facing solar array is the recommended solar configuration for this site and has been included as such in this study. Additionally, and for comparison, a single EWT wind turbine was considered. GCR has assumed a 1MW DW61 wind turbine with a 46m hub height for this purpose.

¹ Coral Harbour Technology Comparison Analysis v1.0 (2020.09.04).pdf

2. ANALYSIS OF ELECTRICITY GENERATION DATA PROVIDED

QEC provided monthly total electricity demand (in kWh) and diesel consumption (in litres)² for the Coral Harbour community, as tabulated in **Table 2-1**. The average seasonal profile of consumption over the four-year period is shown on **Figure 1**, on the following page. Unfortunately, QEC were unable to provide detailed daily data for the Coral Harbour community. Therefore, in the absence of this detailed daily data, GCR have compared the Coral Harbour data against the community of Naujaat data, in order to evaluate the correlation between the two communities. This would then allow the detailed daily data for Naujaat to be adjusted and utilised for the Coral Harbour community. The monthly total electricity demand (in kWh) and diesel consumption (in litres)³ for the Naujaat community is tabulated in **Table 2-2** below. **Figure 1**, on the following page, illustrates the demand profile of the two communities.

Table 2-1 Monthly electricity demand and oil consumption data provided for Coral Harbour.

Month/Year	2015/2016		2016/2017		2017/2018		2018/2019	
	Electricity Demand (kWh)	Oil Consumption (l)	Electricity Demand (kWh)	Oil Consumption (l)	Electricity Demand (kWh)	Oil Consumption (l)	Electricity Demand (kWh)	Oil Consumption (l)
April	293,600	89,160	293,000	90,099	292,200	84,387	288,400	83,621
May	270,800	80,073	278,200	84,743	278,400	78,845	279,600	85,949
June	244,600	70,880	251,000	77,883	252,200	72,214	245,600	73,546
July	253,000	73,532	248,600	74,479	249,800	70,569	250,200	74,067
August	256,200	74,019	259,600	75,575	264,600	74,913	264,400	74,805
September	264,800	77,466	266,600	77,530	273,400	76,538	269,600	79,211
October	304,400	89,513	301,400	88,536	302,000	88,394	299,200	87,317
November	313,600	84,645	308,200	90,400	315,000	90,950	319,400	92,227
December	349,000	109,782	343,200	98,924	345,800	98,714	388,200	99,477
January	333,000	98,800	344,800	100,977	361,000	103,426	330,600	109,180
February	322,000	95,683	315,200	90,677	270,800	92,978	328,000	94,188
March	320,200	95,809	331,000	95,615	321,200	93,580	345,400	88,605

Table 2-2 Monthly electricity demand and oil consumption data provided for Naujaat

Month/Year	2015/2016		2016/2017		2017/2018		2018/2019	
	Electricity Demand (kWh)	Oil Consumption (l)	Electricity Demand (kWh)	Oil Consumption (l)	Electricity Demand (kWh)	Oil Consumption (l)	Electricity Demand (kWh)	Oil Consumption (l)
April	358,298	93,046	372,583	97,313	364,615	97,140	380,600	105,262
May	339,637	92,584	353,647	94,555	342,562	87,612	366,543	101,205
June	292,935	77,013	306,094	75,330	312,787	83,645	326,494	90,573
July	271,034	80,761	309,704	80,188	305,283	81,029	329,166	91,282
August	256,712	80,972	330,015	85,441	330,770	88,636	333,680	110,394
September	311,815	89,910	334,709	85,982	325,666	89,810	349,233	79,513
October	359,451	96,438	362,485	92,816	362,620	96,643	392,127	106,974
November	368,974	99,322	372,760	96,200	392,850	105,704	395,743	107,912
December	388,425	104,967	404,454	105,048	422,000	111,175	444,799	121,215
January	386,147	104,149	405,647	107,362	413,991	113,458	456,849	111,924
February	384,681	100,205	363,000	90,896	399,570	111,940	419,314	109,648
March	397,096	104,605	399,684	111,630	413,411	111,064	442,142	118,530

² Coral Harbour & Naujaat data.docx, provided by email to GCR by NEC on 22-07-2020

³ Coral Harbour & Naujaat data.docx, provided by email to GCR by NEC on 22-07-2020

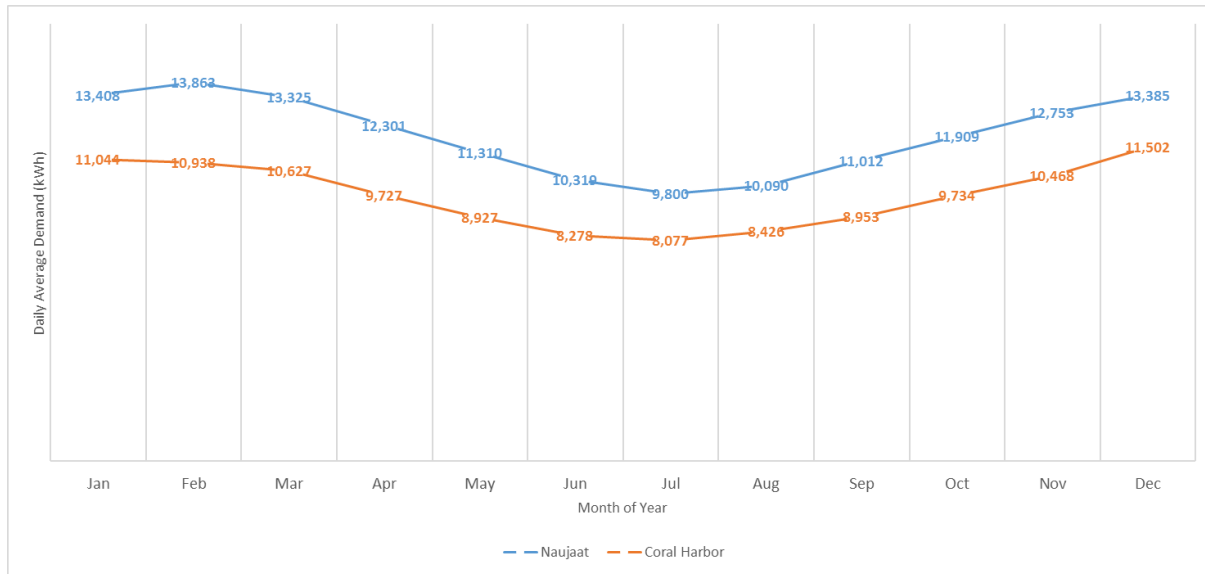


Figure 1 – Naujaat & Coral Harbour: seasonal distribution of demand (April 2015 to March 2019), according to the monthly data provided for review.

As can be seen above, in both communities 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. Within the same document, an indication of the forecast demand was provided: 3,915MWh per annum at Coral Harbour by 2025.

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. As noted, unfortunately QEC were unable to provide detailed data for Coral Harbour. As can be seen in **Figure 1**, above, the seasonal distribution of demand at Coral Harbour is comparable to that of Naujaat (albeit at a lower average daily demand). GCR therefore adopted the detailed data provided for Naujaat for the use in the current assessment for Coral Harbour. One potential limitation of this approach is that the diurnal variation may differ slightly between the two sites. On balance, it is considered preferable to adopt this data than to derive a synthetic demand profile for Coral Harbour. The remainder of this section describes the data provided for Naujaat in detail and the approach taken to scaling that data for use as a representative dataset at Coral Harbour.

2.1. NAUJAAT DEMAND DATA

On the 22nd February 2021, QEC provided a zip file containing 697 individual files in .csv format for Naujaat⁴. 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. The file titled '2019 02 25 0000 (Tagname).csv' contained the following information:

Table 2-3 Contents of the tagname header file provided for Naujaat

;Tagname	TTagIndex	TagType	TagDataType
REPULSE_BAY\GEN1\G1_REAL_POWER	0	2	1
REPULSE_BAY\GEN2\G2_REAL_POWER	1	2	1
REPULSE_BAY\GEN3\G3_REAL_POWER	2	2	1
REPULSE_BAY\MISC\TOTAL_LOAD	3	2	1

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

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

Date	Time	Millitm	TagIndex	Value	Status	Marker	Internal
28/05/2020	00:00:02	532	0	0		B	-1
28/05/2020	00:00:02	532	1	0		B	-1
28/05/2020	00:00:02	532	2	131		B	-1
28/05/2020	00:00:02	532	3	479		B	-1
28/05/2020	00:00:09	419	0	0			0
28/05/2020	00:00:09	419	1	0			1
28/05/2020	00:00:09	419	2	128			2
28/05/2020	00:00:09	419	3	485			3

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).

After removing duplicate files and the tagname file, 485 files remain. A number of these files are incomplete however, with less than the full 34,560 lines of data. The records span the time interval 27/03/2018 to 28/05/2020 inclusive, with a number of prolonged gaps.

⁴ NAUJAAT DATA.zip, provided to GCR by QEC in a shared Dropbox folder 22-02-2021

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: G1, G2, G3 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 four tag indices, along with the observation count for each half hour long period. QEC indicated that the 'TOTAL_LOAD' measures the combined output of G1, G2 and G3, plus the emergency generator (which is not independently measured).

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. It was observed that the G1, G2 and G3 readings are less reliable than the TOTAL_LOAD, with higher error counts and longer periods of missing data. Further, a number of instances where G1+G2+G3 is less than the TOTAL_LOAD were identified. This is presumably due to periods where the emergency generator is providing part of the load. Since detailed data for the individual generators is not required for this assessment, subsequent analysis will consider only the TOTAL_LOAD data.

The diurnal pattern of the quality-controlled data is shown in the following figure. 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 low levels of consumption during the night.

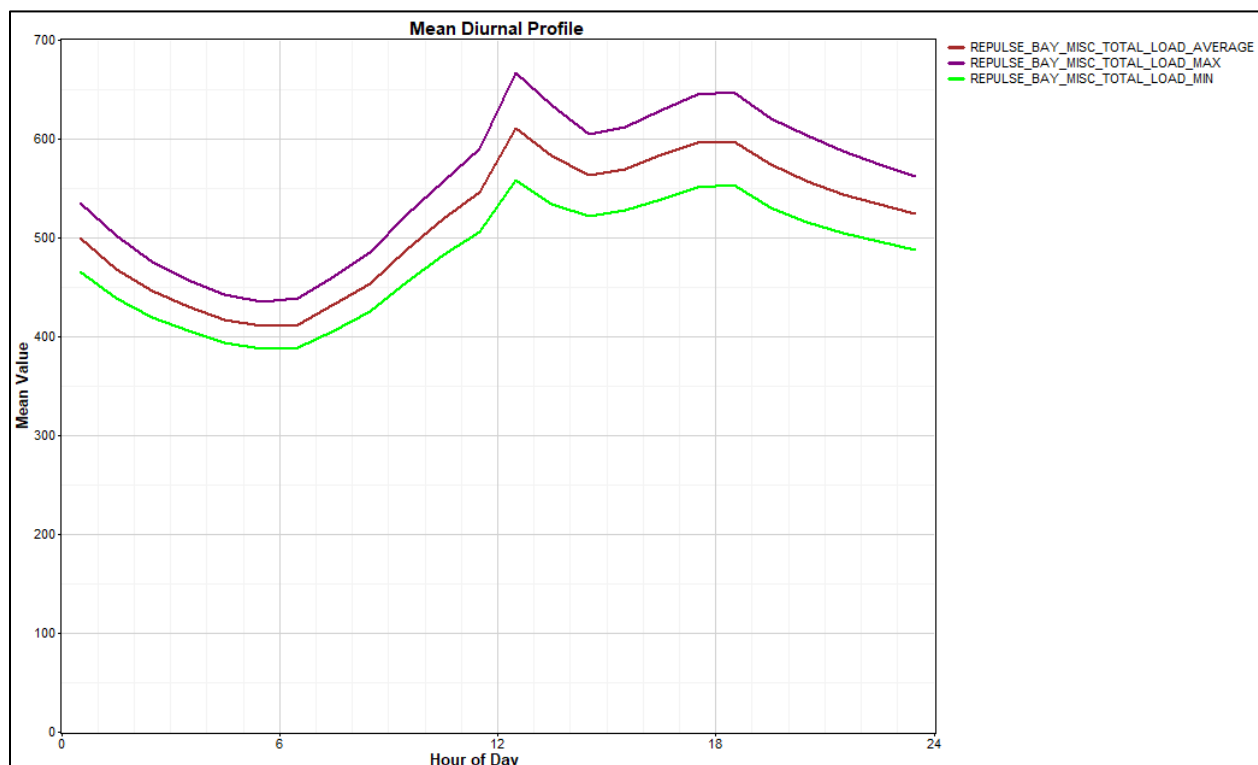


Figure 2 – Diurnal profile of generation at Naujaat.

The following histogram illustrates the frequency of power output in kW. As can be seen, the power output of the diesel generators is never less than 300kW at Naujaat. These low demand periods tend to occur at night or in the early hours of the morning.

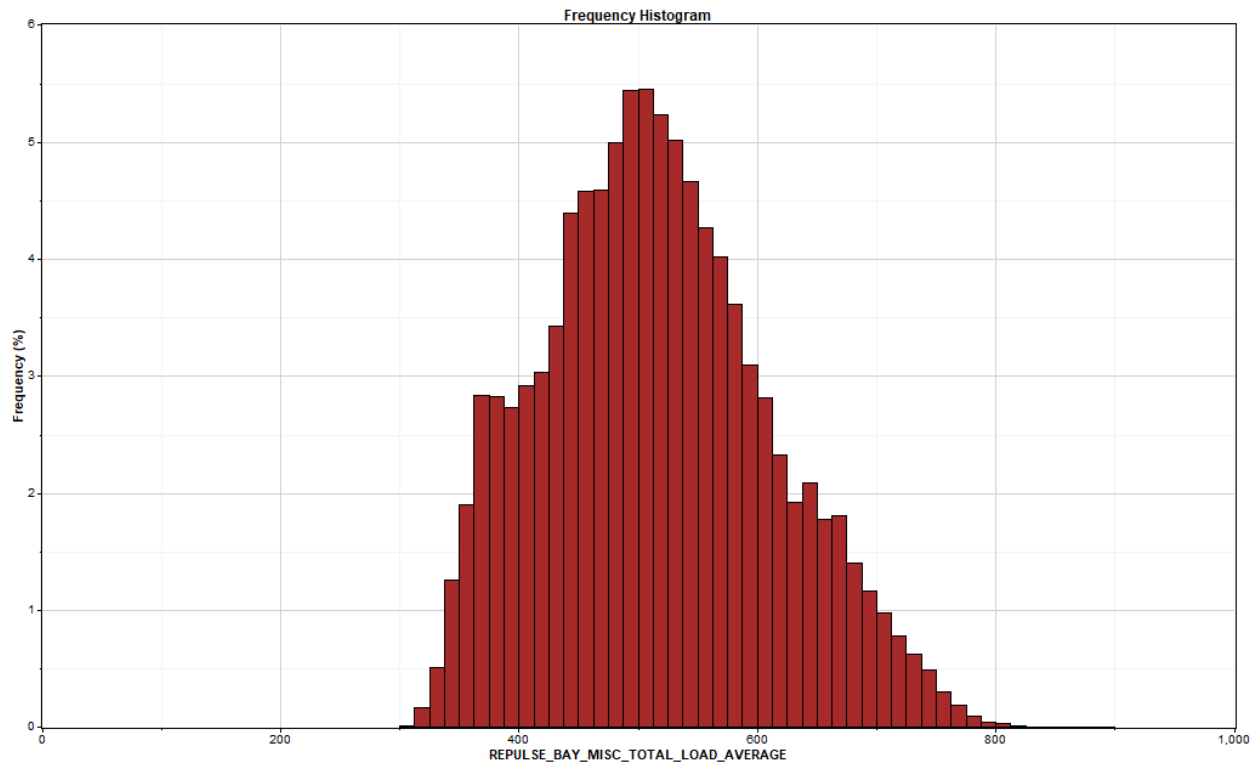


Figure 3 – Frequency histogram of generator output at Naujaat.

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

Table 2-5 Naujaat data recovery for each day and month expressed as the number of retained half hourly data points after quality control.

Month/day of month	1	2	3	4	5	6	7	8	9	10	11	12
1	0	46	42	39	48	12	48	48	0	0	1	0
2	0	46	47	48	48	45	47	48	0	0	28	0
3	16	44	13	48	48	42	47	48	0	0	47	12
4	48	28	25	48	48	31	47	48	0	15	48	42
5	48	46	41	48	48	14	47	48	24	39	48	48
6	48	43	45	48	47	36	48	47	45	45	26	46
7	48	46	45	48	47	47	48	48	48	48	0	48
8	48	47	44	47	48	48	47	48	48	47	0	47
9	48	44	47	48	48	25	47	48	48	47	0	48
10	48	45	46	48	48	0	28	47	48	47	0	47
11	48	47	47	48	48	0	46	48	48	47	0	47
12	48	40	46	48	48	0	18	48	48	46	0	48
13	48	25	0	48	48	24	48	48	48	47	0	47
14	48	45	15	48	47	45	48	48	47	47	0	25
15	48	47	36	48	44	48	48	48	40	47	0	0
16	48	40	47	48	48	48	45	48	48	46	0	0
17	48	48	48	48	48	48	23	48	42	47	0	0
18	47	47	48	48	48	48	28	46	44	48	0	0
19	47	46	47	48	48	48	47	45	35	26	0	0
20	48	48	47	48	48	48	48	48	45	0	0	0
21	48	48	43	48	48	47	48	47	48	0	0	0
22	45	41	47	48	48	48	48	48	44	17	0	0
23	47	41	3	48	43	33	48	48	37	48	0	0
24	46	38	13	48	48	40	48	48	45	48	0	0
25	48	33	0	48	48	48	48	48	48	48	0	0
26	45	42	0	48	48	48	48	48	47	48	0	0
27	6	42	45	48	48	48	48	48	48	48	0	0
28	23	44	48	48	42	48	48	46	8	48	0	0
29	29	-	46	48	44	47	48	36	6	48	0	0
30	35	-	45	48	47	47	48	0	0	28	0	0
31	48	-	48	-	16	-	48	0	0	0	-	0

The overall data recovery is poor at around 75% of the year, with significant, prolonged gaps in the records, particularly in the months of November and December. Using this data as is will lead to a 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 derived 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);
3. Half hour long gaps were interpolated from adjacent timestamps (~0.9% 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 13th July, and so on. (~19.7% of data);
5. Any residual gaps were then filled according to the following data substitution scheme:
 - a. Take data from 1 day ahead (~3.4% of data);
 - b. Take data from 1 day behind (~1.1% of data);
 - c. Take data from 2 days ahead (~0.2% of data);
 - d. Take data from 2 days behind (<0.1% of data).

The resulting time series contains data for each 48-hour period, 365 days per year. The total annual energy demand in the Naujaat time series is 4,675MWh. For comparison: the demand in the last full twelve months of monthly data provided for Naujaat (April 2018 to March 2019 inclusive) was 4,637MWh – a difference of around 0.8%.

2.2. WEIGHTING OF NAUJAAT DATA

The 2025 annual demand forecast for Coral Harbour was given as 3,915MWh, 16.3% less than the data provided for Naujaat. GCR has therefore scaled the half hourly time series derived for Naujaat to this figure by applying a scaling factor of 83.7%. This is a reasonable approximation assuming the seasonal and daily distribution of demand at Coral harbour is similar to Naujaat. While the seasonal profile is a reasonably good match, as evidenced in **Figure 1**, the diurnal variation in the Coral Harbour demand is not well understood. While this is a limitation with the current study, the profile used is considered to be far more realistic than the next best alternative – using a fully synthetic profile for Coral Harbour. To allow this to be further evaluated in the future, a request has been submitted to QEC for the installation of the appropriate monitoring equipment at the Coral Harbour power station in order to collect detailed demand data.

3. SYSTEM INTEGRATION 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 and solar time series output (which are limited to hourly resolution). The average demand is compared with the net wind⁵ and net solar AC power output for each hour for a full year (8760 hours).

The solar time series is based on the following configuration: 130kWp (DC), 100kW AC fixed tilt, bi-facial array. Full details can be found in the September 2020 technology comparison study. A scaling factor is used to scale the solar generation data from 0kW to 2000kW (AC), in 100kW increments. This is a reasonable approximation assuming the characteristics of the system remain constant regardless of the size. In practice, the larger systems might employ a smaller number of large inverters, for example.

The wind power time series is based on ERA-5⁶ wind speed, temperature and pressure data for the node nearest the site (64.250N, 83.250W). The ERA-5 wind speed has been scaled to match the AWS wind speed estimate at 40m AGL of 5.85m/s (as provided by the Developer). The wind speed in each hour has also been modified by the air density (calculated from ERA-5 temperature and pressure data) in order to better capture the impact of changes in air density throughout the year (which is significant in this case). Sales power curve data for the EWT DW61 1MW⁷ have been used to estimate the gross power production for each hour. Technical losses have been incorporated to produce an estimate of the net wind⁵ 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 high-level study. The time series of wind power output for the year 2013 has been added to the timeseries. 2013 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 and solar production is provided in **Figure 4**. As can be seen, the seasonal profile of wind generation is a closer match with the demand at this site when compared against the solar generation profile.

⁵ Please refer to Appendix A – Wind Power Technical Losses

⁶ ERA-5 reanalysis data, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF)

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

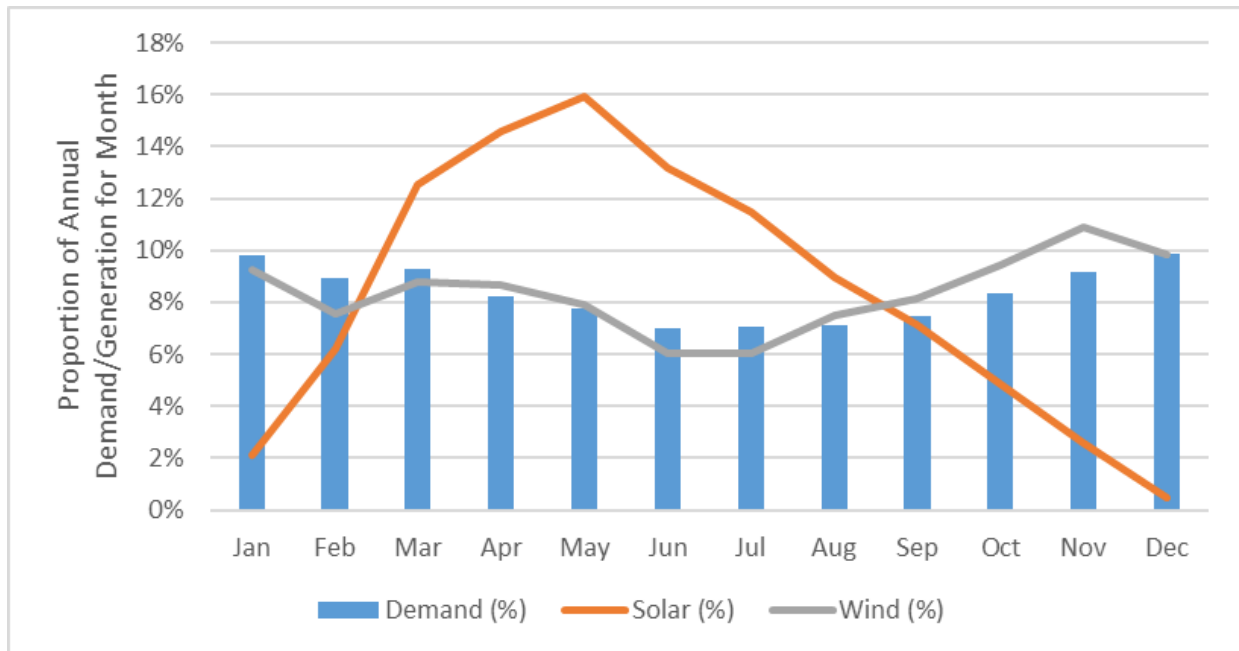


Figure 4 – Seasonal distribution of demand (derived from Naujaat and scaled to match the annual net demand of Coral Harbour) and wind and solar power generation. Solar based on Typical Meteorological Year (TMY). Wind based on long term period 1979 to 2020 inclusive.

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 and/or solar array). 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 e.g. 800kWh for a 1000kWh system. 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 consumption⁸ and battery performance degradation are not considered.

A series of BESS sizes have been modelled: 0kW (no BESS), and 1000kW, with 1, 2, 3 and 4 hours of storage (1000kWh, 2000kWh, 3000kWh and 4000kWh). A battery size of 1000kW has been selected as this will be

⁸ The parasitic load is a more major consideration during when there is low generation and inclement weather conditions (e.g. a solar only system during the winter months, when the system may not charge for months and will be dormant for that period)

capable of covering the peak demand in the event of a sudden drop in renewable output e.g. renewable generator downtime at a time when the diesel generators are switched off. 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): the diesel generator is assumed to be able to produce either 0kW, or from 260kW⁹ (minimum load assumed) to the net demand; the diesel generator is switched off if the renewable energy production exceeds the demand, otherwise, the diesel output is between 260kW and the net demand. In the model that includes the BESS: it is assumed that if required, that the average hourly output of the diesel could be less than the minimum assumed load (of 260KW). This could be achieved by running the diesel for part of the hour to charge the BESS sufficiently to meet the net demand for that hour.

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 generator(s) online in the event of a sudden drop in renewable power output e.g. wind and/or solar downtime, sudden cloud cover. 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 discussion 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 required 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 (300kW in this case). The minimum in the scaled demand data is around 260kW however. A minimum diesel load of 260KW has been adopted in this assessment.

Figure 5 and Figure 6 illustrate the logic used in the hourly simulation. These flow charts are not intended to be used as a live microgrid control algorithm.

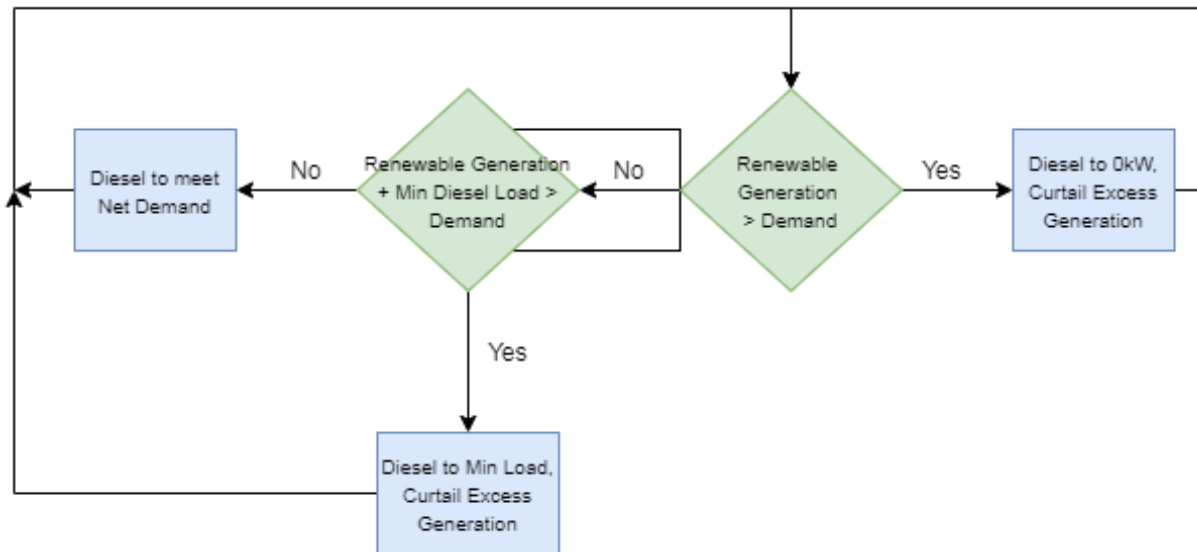


Figure 5 – Simple illustration of the hourly simulation logic for systems without BESS.

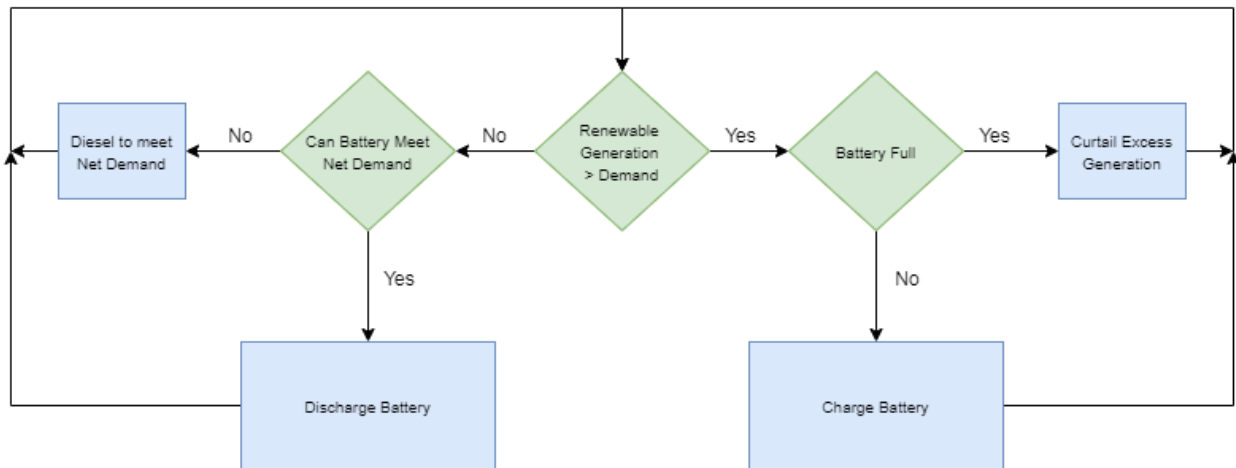


Figure 6 – Simple illustration of the hourly simulation logic for systems with BESS.

4. RESULTS

Table 4-1, Table 4-2 and Table 4-3 on the following pages present the results for the range of wind, solar and BESS system configurations modelled. The demand profile is based on the 8760-hour long time series derived from measurement at the settlement of Naujaat and scaled to the 2025 annual demand forecast of 3,915MWh for Coral Harbour:

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 3,915MWh 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. Solar could be curtailed by using the inverters Maximum Power Point Trackers (MPPT's) to control the output. The wind turbine could be curtailed in real time using via the SCADA system. A dump load could also be used to absorb excess generation.

Some selected examples from the results for illustration purposes:

1. A system with a wind turbine, 1 hour BESS and 0kW solar capacity could provide 1,626MWh (41.5% of demand) with an excess generation of 354MWh.
2. A system with 1,000kW AC of solar, no wind turbine and a 1 hour BESS could provide 1,346MWh (34.4% of demand) with an excess generation of 408MWh.

Graphs illustrating the seasonal distribution of energy for these two scenarios are provided in **Figure 7** and **Figure 8**, on the following page.

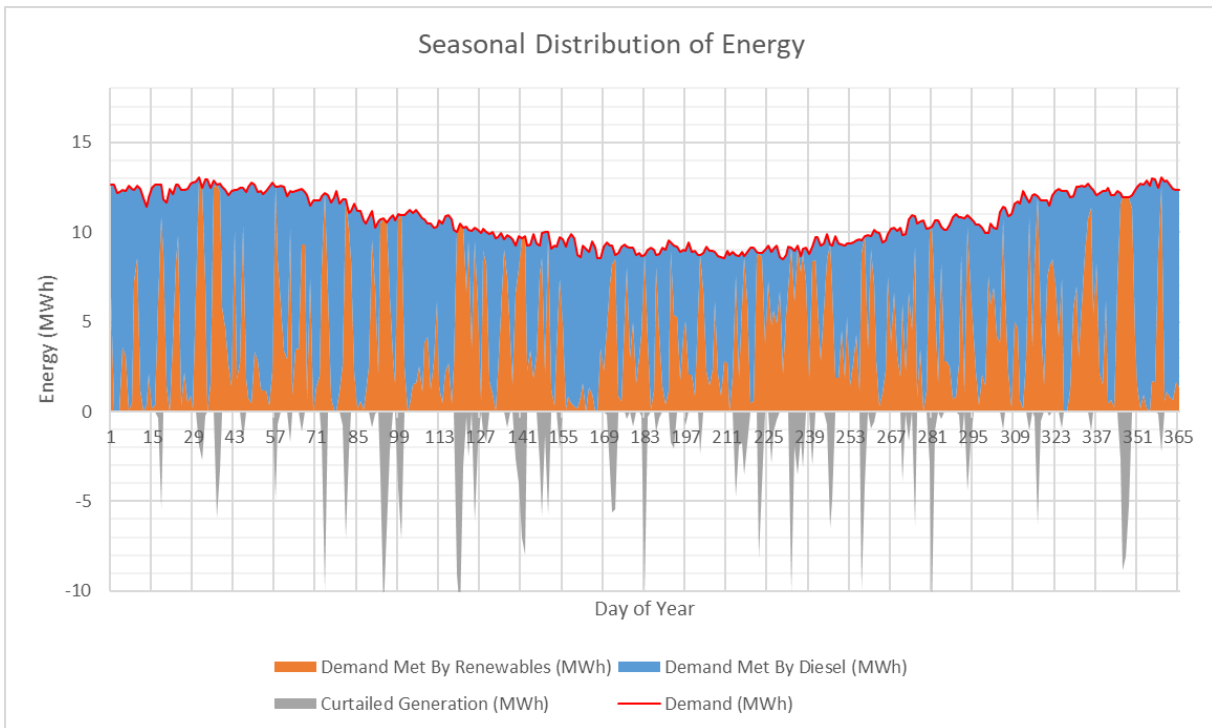


Figure 7 – Seasonal distribution of demand met by renewables and diesel, along with curtailed renewable generation. Results presented for an EWT DW61 1MW 46mHH and a one-hour, 1MW BESS.

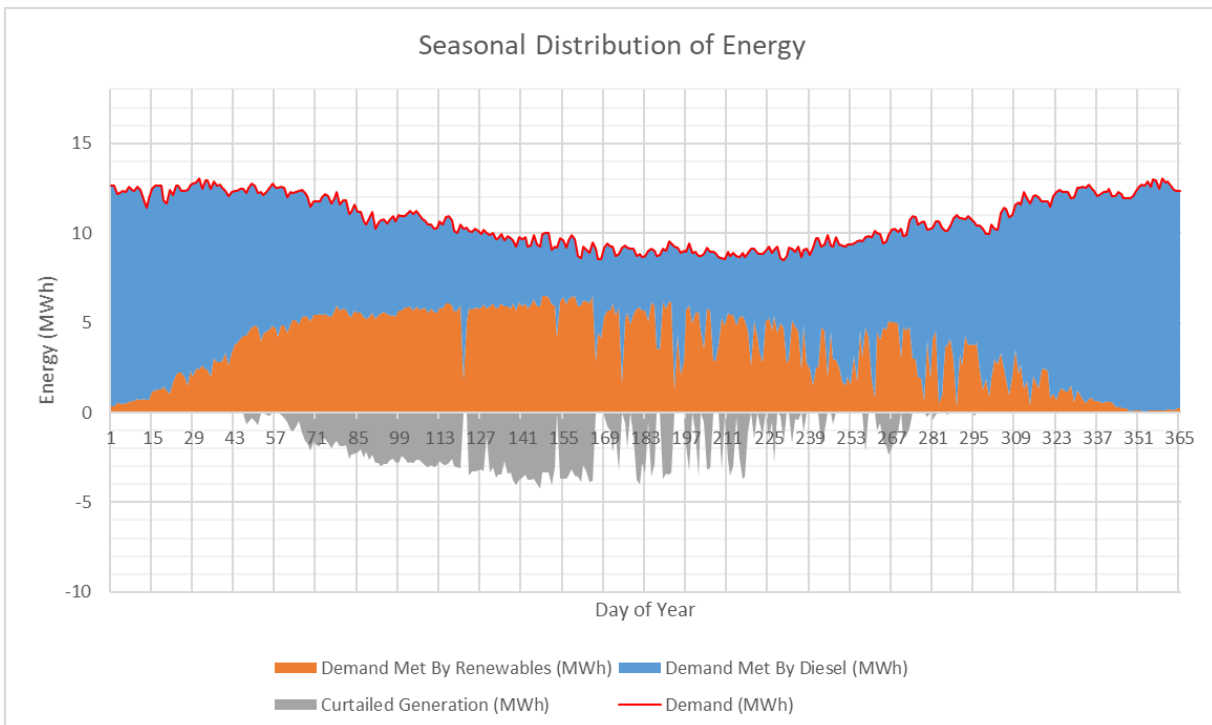


Figure 8 – Seasonal distribution of demand met by renewables and diesel, along with curtailed renewable generation. Results presented for 1000kW solar and a one-hour, 1MW BESS. ¹⁰

¹⁰ In a typical summer day, the solar will charge the BESS during the day, discharge in the evening and the system would switch to diesel once the battery is depleted.

Table 4-1 Coral Harbour Demand Met

Excluding Wind							Including Wind						
Demand Met (MWh)	BESS System Size (kWh)						Demand Met (MWh)	BESS System Size (kWh)					
	0	1000	2000	3000	4000			0	1000	2000	3000	4000	
Solar System Size (kW AC)	0	0	0	0	0	0	Solar System Size (kW AC)	0	1,333	1,626	1,672	1,708	1,736
	100	176	177	177	177	177		100	1,460	1,766	1,814	1,851	1,881
	200	324	355	355	355	355		200	1,559	1,901	1,951	1,989	2,020
	300	415	532	532	532	532		300	1,634	2,030	2,081	2,120	2,154
	400	499	710	710	710	710		400	1,714	2,147	2,202	2,243	2,279
	500	672	883	883	883	883		500	1,834	2,254	2,314	2,358	2,396
	600	803	1,037	1,052	1,052	1,052		600	1,917	2,340	2,415	2,464	2,504
	700	886	1,143	1,207	1,218	1,218		700	1,973	2,399	2,497	2,557	2,600
	800	954	1,222	1,317	1,373	1,382		800	2,019	2,443	2,554	2,635	2,686
	900	1,012	1,289	1,400	1,485	1,536		900	2,057	2,479	2,598	2,690	2,757
	1000	1,056	1,346	1,469	1,571	1,650		1000	2,088	2,510	2,635	2,733	2,809
	1100	1,103	1,394	1,530	1,642	1,738		1100	2,117	2,535	2,666	2,769	2,851
	1200	1,140	1,435	1,582	1,704	1,811		1200	2,139	2,557	2,693	2,800	2,885
	1300	1,168	1,471	1,627	1,761	1,875		1300	2,157	2,577	2,716	2,829	2,916
	1400	1,193	1,504	1,667	1,811	1,933		1400	2,172	2,594	2,736	2,854	2,945
	1500	1,219	1,535	1,702	1,854	1,986		1500	2,188	2,611	2,755	2,875	2,970
	1600	1,242	1,562	1,735	1,893	2,034		1600	2,204	2,625	2,772	2,894	2,991
	1700	1,262	1,587	1,766	1,928	2,076		1700	2,214	2,638	2,788	2,911	3,011
	1800	1,281	1,610	1,794	1,960	2,112		1800	2,227	2,649	2,803	2,928	3,028
	1900	1,297	1,630	1,820	1,990	2,146		1900	2,238	2,660	2,816	2,943	3,044
	2000	1,313	1,649	1,844	2,019	2,176		2000	2,246	2,670	2,829	2,958	3,058

Table 4-2 Coral Harbour Fraction of Total Demand Met

Excluding Wind							Including Wind						
Fraction of Total Demand Met (%)		BESS System Size (kWh)					Fraction of Total Demand Met (%)		BESS System Size (kWh)				
		0	1000	2000	3000	4000			0	1000	2000	3000	4000
Solar System Size (kW AC)	0	0.0%	0.0%	0.0%	0.0%	0.0%	Solar System Size (kW AC)	0	34.1%	41.5%	42.7%	43.6%	44.3%
	100	4.5%	4.5%	4.5%	4.5%	4.5%		100	37.3%	45.1%	46.3%	47.3%	48.0%
	200	8.3%	9.1%	9.1%	9.1%	9.1%		200	39.8%	48.6%	49.8%	50.8%	51.6%
	300	10.6%	13.6%	13.6%	13.6%	13.6%		300	41.7%	51.8%	53.1%	54.2%	55.0%
	400	12.7%	18.1%	18.1%	18.1%	18.1%		400	43.8%	54.9%	56.2%	57.3%	58.2%
	500	17.2%	22.6%	22.6%	22.6%	22.6%		500	46.8%	57.6%	59.1%	60.2%	61.2%
	600	20.5%	26.5%	26.9%	26.9%	26.9%		600	49.0%	59.8%	61.7%	62.9%	64.0%
	700	22.6%	29.2%	30.8%	31.1%	31.1%		700	50.4%	61.3%	63.8%	65.3%	66.4%
	800	24.4%	31.2%	33.6%	35.1%	35.3%		800	51.6%	62.4%	65.2%	67.3%	68.6%
	900	25.8%	32.9%	35.8%	37.9%	39.2%		900	52.5%	63.3%	66.4%	68.7%	70.4%
	1000	27.0%	34.4%	37.5%	40.1%	42.2%		1000	53.3%	64.1%	67.3%	69.8%	71.7%
	1100	28.2%	35.6%	39.1%	41.9%	44.4%		1100	54.1%	64.8%	68.1%	70.7%	72.8%
	1200	29.1%	36.6%	40.4%	43.5%	46.3%		1200	54.6%	65.3%	68.8%	71.5%	73.7%
	1300	29.8%	37.6%	41.6%	45.0%	47.9%		1300	55.1%	65.8%	69.4%	72.3%	74.5%
	1400	30.5%	38.4%	42.6%	46.3%	49.4%		1400	55.5%	66.3%	69.9%	72.9%	75.2%
	1500	31.1%	39.2%	43.5%	47.4%	50.7%		1500	55.9%	66.7%	70.4%	73.4%	75.9%
	1600	31.7%	39.9%	44.3%	48.3%	52.0%		1600	56.3%	67.0%	70.8%	73.9%	76.4%
	1700	32.2%	40.5%	45.1%	49.2%	53.0%		1700	56.6%	67.4%	71.2%	74.4%	76.9%
	1800	32.7%	41.1%	45.8%	50.1%	54.0%		1800	56.9%	67.7%	71.6%	74.8%	77.4%
	1900	33.1%	41.6%	46.5%	50.8%	54.8%		1900	57.2%	67.9%	71.9%	75.2%	77.8%
	2000	33.5%	42.1%	47.1%	51.6%	55.6%		2000	57.4%	68.2%	72.3%	75.6%	78.1%

Table 4-3 Coral Harbour Excess Generation

Excluding Wind							Including Wind						
Excess Generation (MWh)		BESS System Size (kWh)					Excess Generation (MWh)		BESS System Size (kWh)				
		0	1000	2000	3000	4000			0	1000	2000	3000	4000
Solar System Size (kW AC)	0	0	0	0	0	0	Solar System Size (kW AC)	0	655	354	301	260	228
	100	1	0	0	0	0		100	706	390	336	294	261
	200	31	0	0	0	0		200	784	432	376	333	298
	300	118	0	0	0	0		300	887	481	423	378	341
	400	211	0	0	0	0		400	985	540	478	431	391
	500	215	0	0	0	0		500	1,042	608	540	490	447
	600	262	17	0	0	0		600	1,136	696	611	555	510
	700	357	85	12	0	0		700	1,258	812	701	633	585
	800	466	180	74	10	0		800	1,390	944	818	727	669
	900	586	290	164	68	10		900	1,529	1,084	950	847	771
	1000	719	408	269	154	64		1000	1,675	1,230	1,089	978	892
	1100	850	537	383	256	148		1100	1,824	1,382	1,234	1,118	1,025
	1200	990	672	505	367	246		1200	1,980	1,537	1,383	1,262	1,166
	1300	1,139	812	636	485	355		1300	2,139	1,694	1,537	1,409	1,310
	1400	1,291	956	772	609	471		1400	2,302	1,854	1,693	1,560	1,457
	1500	1,443	1,102	912	741	591		1500	2,463	2,014	1,851	1,716	1,608
	1600	1,598	1,251	1,056	878	717		1600	2,625	2,177	2,010	1,873	1,763
	1700	1,755	1,404	1,201	1,018	850		1700	2,792	2,342	2,171	2,032	1,920
	1800	1,914	1,558	1,349	1,162	989		1800	2,956	2,507	2,333	2,192	2,078
	1900	2,075	1,714	1,499	1,307	1,131		1900	3,123	2,674	2,497	2,353	2,239
	2000	2,237	1,872	1,651	1,454	1,277		2000	3,293	2,841	2,661	2,516	2,402

5. LOWEST COST OF ENERGY

Capital Expenditure (CAPEX) costs for each respective system configurations and annual “Demand Met” figures from **Table 4-1** above were utilized to provide a normalized dataset highlighting cost competitiveness (per useful unit of energy generated) of each configuration.¹¹

Table 5-1, on the following page, presents the normalized comparative costs of each configuration. The percentages are cost/MWh divided by the average of the maximum and minimum costs/MWh across the whole table. The lowest percentage represents the most cost-effective system and the highest percentage represents the least cost-effective project.¹²

¹¹ CAPEX cost included known and foreseeable hard and soft development costs, site specific variances and QEC requirements have the potential to influence assessment findings.

¹² \$CAD/MWh, based on year 1 generation, as such findings do not represent a formal LCOE.

Table 5-1 Coral Harbour Normalized Comparative Cost

Excluding Wind							Including Wind						
Normalised Cost/MWh of Demand Met	BESS System Size (kWh)						Normalised Cost/MWh of Demand Met	BESS System Size (kWh)					
	0	1000	2000	3000	4000			0	1000	2000	3000	4000	
Solar System Size (kW AC)	0	-	-	-	-	-	Solar System Size (kW AC)	0	25.6%	25.4%	28.3%	30.6%	32.4%
	100	51.1%	91.6%	124.8%	152.9%	175.9%		100	26.3%	25.8%	28.4%	30.5%	32.2%
	200	39.8%	56.8%	73.4%	87.4%	98.9%		200	26.4%	25.4%	27.8%	29.8%	31.4%
	300	38.7%	43.8%	54.8%	64.2%	71.8%		300	26.4%	24.9%	27.1%	28.9%	30.4%
	400	37.4%	36.5%	44.8%	51.9%	57.6%		400	26.5%	24.5%	26.6%	28.3%	29.6%
	500	31.3%	32.0%	38.7%	44.3%	48.9%		500	25.8%	24.2%	26.1%	27.7%	29.0%
	600	29.2%	29.6%	34.8%	39.5%	43.4%		600	25.7%	24.1%	25.8%	27.3%	28.5%
	700	29.0%	28.8%	32.1%	36.0%	39.3%		700	25.9%	24.3%	25.7%	27.0%	28.2%
	800	29.1%	28.6%	31.1%	33.4%	36.2%		800	26.1%	24.5%	25.8%	26.9%	27.9%
	900	29.3%	28.7%	30.6%	32.2%	33.8%		900	26.3%	24.8%	25.9%	26.9%	27.7%
	1000	29.8%	28.7%	30.4%	31.6%	32.5%		1000	26.6%	25.0%	26.0%	26.9%	27.6%
	1100	30.2%	29.1%	30.4%	31.3%	32.0%		1100	27.0%	25.4%	26.4%	27.2%	27.8%
	1200	30.8%	29.5%	30.5%	31.3%	31.7%		1200	27.4%	25.8%	26.7%	27.4%	28.0%
	1300	31.6%	30.0%	30.7%	31.3%	31.5%		1300	27.9%	26.2%	27.0%	27.7%	28.3%
	1400	32.3%	30.5%	31.0%	31.3%	31.4%		1400	28.4%	26.6%	27.4%	28.0%	28.5%
	1500	33.0%	30.9%	31.3%	31.5%	31.4%		1500	28.9%	27.0%	27.7%	28.3%	28.7%
	1600	33.7%	31.4%	31.7%	31.7%	31.5%		1600	29.3%	27.3%	28.0%	28.6%	29.0%
	1700	34.3%	31.9%	32.0%	31.9%	31.6%		1700	29.7%	27.7%	28.3%	28.8%	29.2%
	1800	34.9%	32.3%	32.3%	32.1%	31.7%		1800	30.1%	28.0%	28.6%	29.1%	29.5%
	1900	35.6%	32.8%	32.6%	32.3%	31.9%		1900	30.5%	28.4%	28.9%	29.3%	29.7%
	2000	36.2%	33.2%	32.9%	32.5%	32.0%		2000	30.9%	28.7%	29.1%	29.6%	29.9%

Utilizing the findings above, **Table 5-1** indicates that:

1. A 1000 kW wind project is, conceptually, more cost competitive (\$/MWh) than any solar solution.
2. A 800 kW solar project combined with 1MWh battery is predicted to be the most cost-effective scale (\$/MWh) for solar only generation.
3. The most cost competitive project (\$/MWh) appears to be 1000 kW of wind energy plus 600 kW of solar energy with a 1000 kWh battery.

It should be noted that it is expected that a battery will be required to maintain grid stability, while reaching a high level of renewable energy penetration.

6. CONCLUSIONS & RECCOMENDATIONS

Detailed 10 second generation data was not available from QEC for Coral Harbour. Therefore, the data that was available for Coral Harbour was correlated with the data that was available for the Naujaat community. This process confirmed the validity of scaling the Naujaat 10 second generation data as representative of the Coral Harbour community.

The detailed 10 second generation data provided for the community of Naujaat have been processed into a years' worth of demand data and scaled to the 2025 forecast demand for Coral Harbour. This has been directly compared with an hourly wind and solar power output time series produced for the Coral Harbour site specifically. The interaction between the demand, renewable generation and a BESS has been modelled for a range of wind, solar 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. Due to higher levels of uncertainty in the wind power time series data, systems that include wind power are less certain than solar systems. 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. This study could be refined based on site specific, high resolution demand data – the current study is based on demand data for Naujaat scaled to match the annual demand for Coral Harbour.
6. Modelling outcomes indicate that the most-cost effective (\$/MWh) single technology project is a 1000 kW wind project. The addition of a battery to the wind project decreases the cost per MWh of demand met slightly. It should be noted that it is expected that a battery will be required to maintain grid stability. A 800 kW solar project, with a 1 MWh battery, is predicted to be the most

cost-effective scale (\$/MWh) for solar only. The most cost competitive project overall (\$/MWh) appears to be 1000 kW of wind energy plus 600 kW of solar energy with a 1000 kWh battery. 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 EWT 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 – As the site consists of a single turbine without any neighbouring third party turbines, wake losses have not been included here.

3 Turbine performance – It is assumed that the turbine will perform according to the sales power curve data provided by EWT. 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:

- Aerodynamic degradation not due to Icing – Assumed 0.5% over a typical 10 year financing period.
- 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 following reference [1], 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. This is a conservative treatment in this case as 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 EWT's icing packages.

- Temperature threshold – It is understood that EWT turbines 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. 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%.
- 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).
- 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:

- Wind sector management – Assumed none required – this is usually only applicable to larger developments that also have issues with turbine spacing.
- Grid & offtaker curtailment – These are modelled in time series depending on the scenario modelled.
- 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.

Table AA-0-1 – 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 on 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.
		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

Category Number	Category Name	Sub Category Number	Sub Category Name	Definition
				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,