
REPORT

Opportunities for Solar Power in Ny-Ålesund

CLIENT

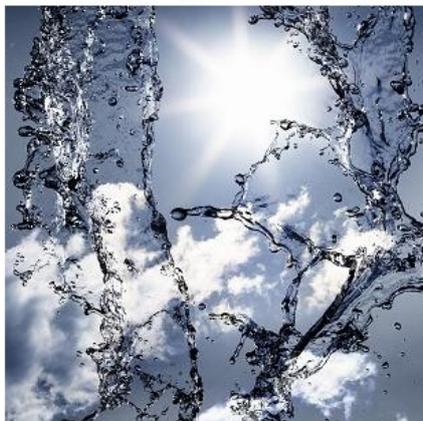
Kings Bay AS

SUBJECT

Integration of solar power in conjunction with existing diesel generators

DATE: / REVISION: December 17, 2018 /

DOCUMENT CODE: 128608-RIEn-RAP-01



Multiconsult

This report has been prepared by Multiconsult on behalf of Multiconsult or its client. The client's rights to the report are provided for in the relevant assignment agreement. Third parties have no right to use the report (or any part thereof) without advance written approval from Multiconsult.

Any use of the report (or any part thereof) for other purposes, in other ways or by other persons or entities than those agreed or approved in writing by Multiconsult is prohibited, and Multiconsult accepts no liability for any such use. Parts of the report are protected by intellectual property rights and/or proprietary rights. Copying, distributing, amending, processing or other use of the report is not permitted without the prior written consent from Multiconsult or other holder of such rights.

REPORT

PROJECT	Solar Power in Ny-Ålesund	DOCUMENT CODE	128608-RIEn-RAP-01
SUBJECT		ACCESSIBILITY	Open
CLIENT	Kings Bay AS	PROJECT MANAGER	Stanislas Merlet
CONTACT	Åsne Dolve Meyer	PREPARED BY	Leif Skorge
		RESPONSIBLE UNIT	1065 Oslo Energibruk og bygningsfysikk

SUMMARY

The following report analyses the potential to reduce fuel use with various levels of solar installations based on received information about existing energy system and needs. The main findings are as follows:

Case A – Rooftop Solar

- 474 kWp
- 590 kWh/kWp yield
- 6% fuel saving
- 2.5% overall electricity cost saving
- There is uncertainty in the cost reduction from installing at volume on many smaller roofs. Roof strength is also a potential concern considering buildings were constructed with outdated snow load requirements

Case B – Ground Mounted solar and Battery Storage

- 913 kWh/kWp yield with single axis tracker
- 25% fuel saving in optimal base cost case
- 19% overall electricity cost saving in optimal base cost case
- 1.9 MWp solar, 1.8 MWh storage in optimal base cost case
- Uncertainty in site ground conditions and cost levels for ground mounted systems at the particular site
- Remaining generator use waste heat might not cover thermal load in summer months

Case C – High Solar Penetration

- Same as Case B with increased size
- 6.7 MWp, 8.4 MWh
- 44% fuel saving with several months of solar only electricity
- Overall electricity costs similar to today
- Would not cover thermal demand
- Further fuel reductions only possible with immature long-term energy storage technology

00	10.12.18		LEIFS Skorge	Klas Ljungberg	Klas Ljungberg
REV.	DATE	DESCRIPTION	PREPARED BY	CHECKED BY	APPROVED BY

TABLE OF CONTENTS

1	Introduction.....	5
2	Modelled Scenarios	5
3	Existing Power System	5
3.1	Generators.....	5
3.2	Fuel use.....	6
3.3	Electricity demand	6
3.4	Heating demand	7
4	Available Solar Resource.....	8
4.1	Insolation	8
4.2	Temperature	9
4.3	Soiling	10
4.4	Horizon	11
4.5	Roof area and orientation.....	11
4.6	Ground mounting	12
5	Solar and Energy System Modelling	13
5.1	Solar – PVSyst	13
5.2	Energy System - Homer Energy.....	15
6	Results.....	16
6.1	Base Case	16
6.2	Case A	16
6.3	Case B	17
6.4	Case C	20
7	Environmental Benefits	20
8	Appendix	21
8.1	Meteonorm Weather Data Ny Ålesund	21
8.2	Solar Yield Simulation Reports.....	21
8.2.1	VC0: Rooftop PV 424 kWp	21
8.2.2	VC2: One Axis Tracker 1 MWp	21

1 Introduction

Ny-Ålesund is home to an international arctic centre for environmental monitoring and research. It is located at 78.55°N, 11.55°E on the island of Spitsbergen, in Svalbard, Norway.

Kings Bay AS¹ provides the services and infrastructure to facilitate research in Ny-Ålesund.

Electricity and heating demand are currently supplied using diesel generators. The goal of this project is to evaluate the potential to reduce local emissions from the generators and the significant carbon footprint from the transport of fuel to the station. Reducing airborne emissions will in addition potentially improve some of the research and monitoring undertaken in the area. A realised solar installation would potentially save a substantial portion of the high costs associated with transporting fuel. The findings of this project related to solar energy generation, operation and maintenance can be applied elsewhere in Svalbard and the wider polar research community.

Local environmental impact is an important factor in Svalbard and the Svalbard Environmental Protection Fund² was set up to fund projects that preserve the distinctive wilderness and cultural heritage of the area. It is mostly funded by a surcharge of 150 NOK to visit Svalbard.

2 Modelled Scenarios

The study will explore three different cases based on existing demand and energy system. The installed capacity of the system will vary from a smaller rooftop installation to offset a portion of diesel use while still needing continual fossil fuel generation, to a larger scale ground mounted system with battery storage to cover demand independent of the use of generators for longer periods of time. Costs and fuel use will be compared with the existing system to determine energy cost and environmental implications.

- A. Low solar utilisation – Existing diesel generators run continuously as today, but with lower load and fuel use
- B. Medium solar utilisation – Battery storage to allow powering off generators during periods of high solar insolation
- C. High solar utilisation – PV + storage have the capacity to cover energy demand over longer periods (days or weeks) of favourable weather

3 Existing Power System

Kings Bay AS is responsible for providing the necessary energy needs of the various activities in Ny-Ålesund throughout the year. It is fuelled using diesel engines connected to generators for producing electricity. The majority of heat demand is provided by a high temperature district heating system that utilises the waste heat from cooling and exhaust from the engines.

3.1 Generators

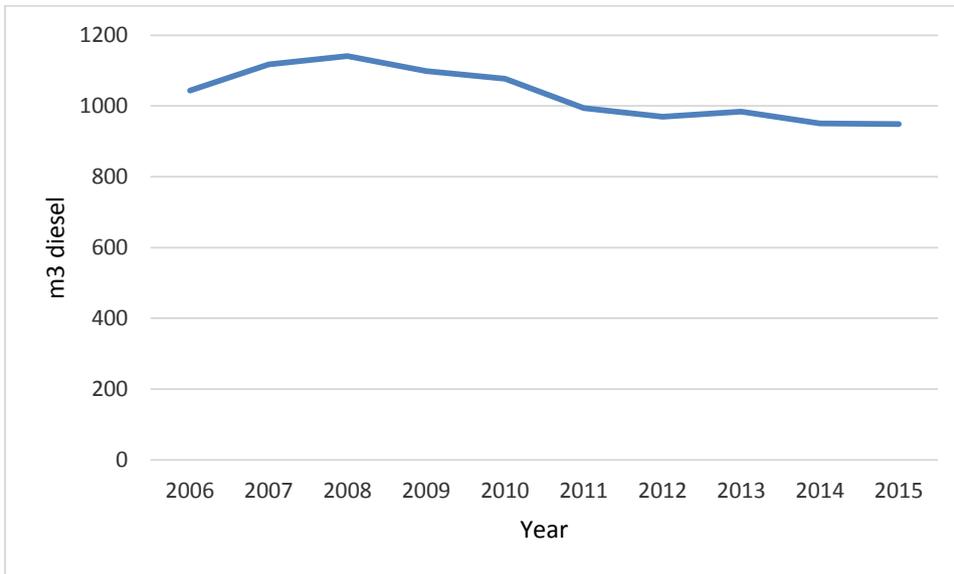
There are three identical Mitsubishi engines connected to Stamford generators that operate depending on load. They are rated at 560 kVA and operate at a maximum load of 470 kW.

¹ Kingsbay.no

² <http://www.sysselmannen.no/en/Svalbard-environmental-protection-fund/>

3.2 Fuel use

As shown below, fuel use is relatively stable with a long-term variation of around +/- 10% from the long-term average for any given year. This is however dependant on future use of the area’s facilities.



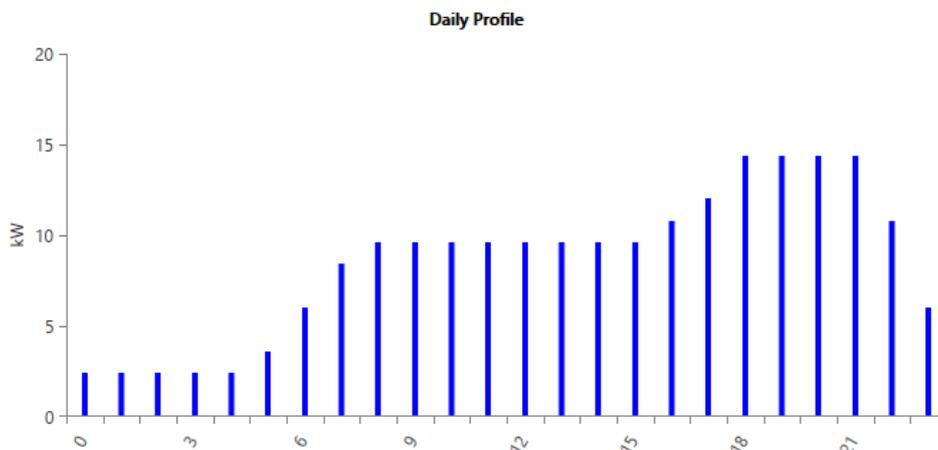
Internal logs from Kings Bay show an average electrical efficiency of 41.7% which is typical of generators of this size provided they operate at efficient load levels. Accounting for waste heat usage overall thermal and electrical efficiency is 76%.

3.3 Electricity demand

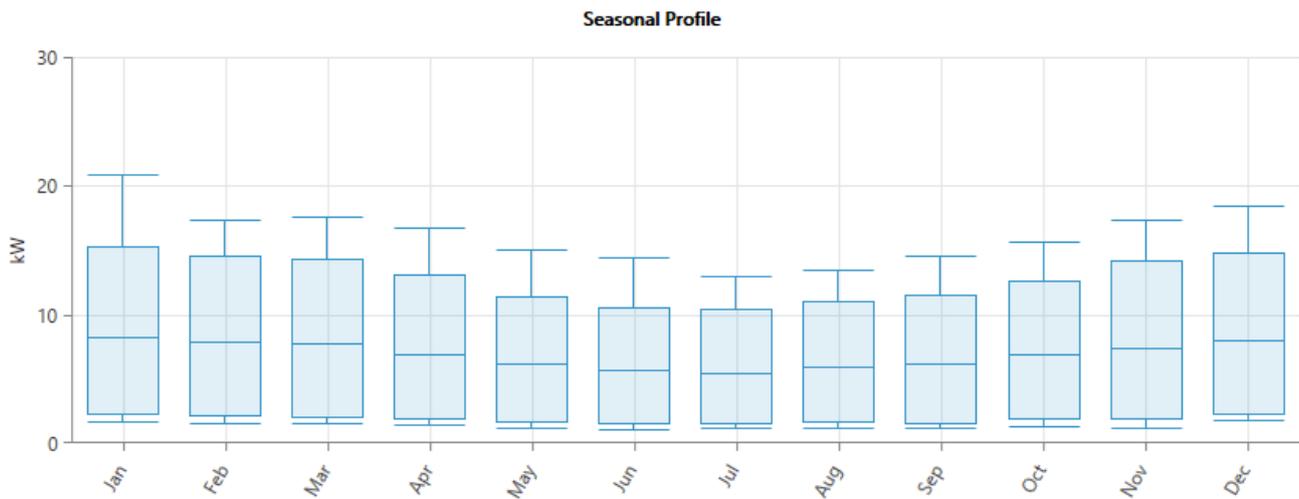
Since solar energy is an intermittent power resource an hourly breakdown of energy use is required to determine its ability to displace diesel generation when the energy is needed if it cannot be stored.

A value of 4.15 kWh/L from the logged data was used to give a yearly electricity demand of 3783 MWh.

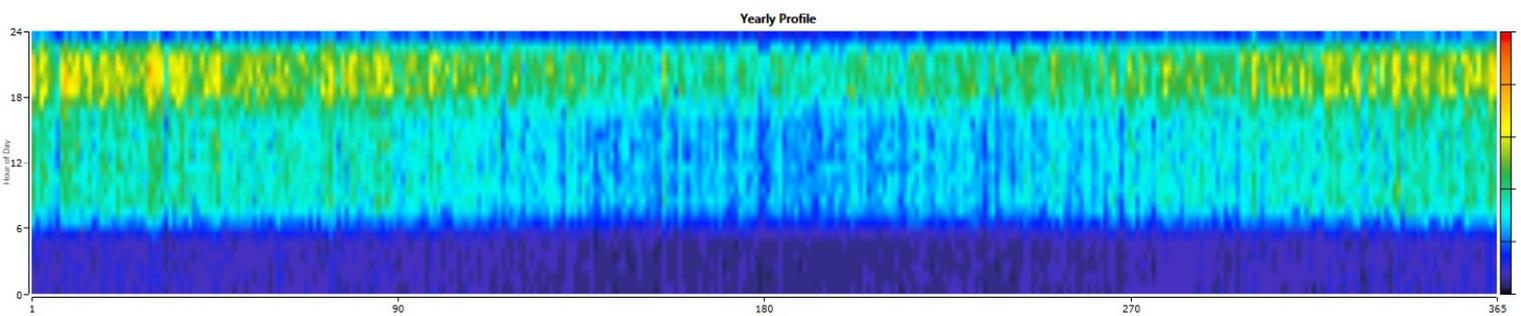
Due to lack of hourly distributed load profile a “community” load profile was used for a similar climate in the open EI database available in Homer Energy.



The peak demand in the late afternoon is common and limits the possible deployment of solar without some form of storage. The load is adjusted for seasonality as shown below.

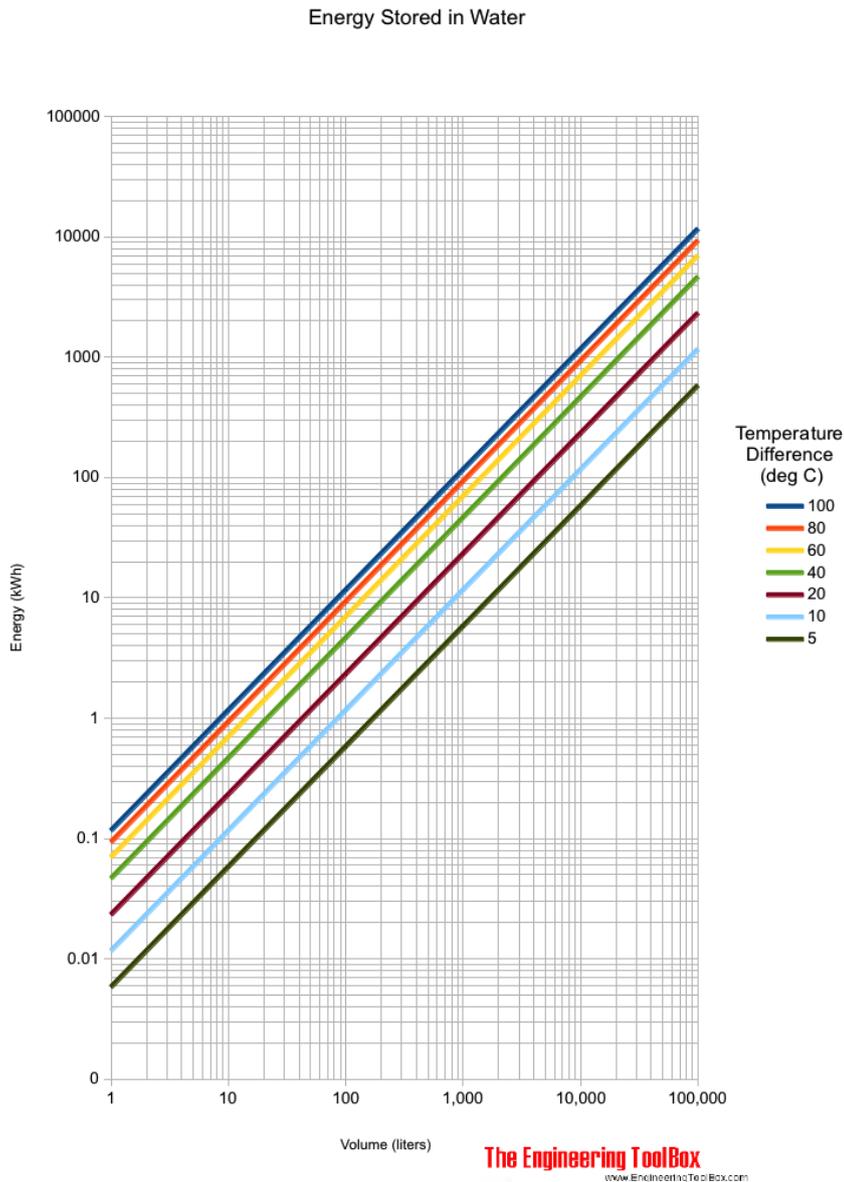


Finally a normally distributed variability of 10% day to day and every hour is applied to better reflect a typical aggregated load and ensure the technical solution can adapt to real life conditions. The final hourly load profile scaled to monthly fuel use for further analysis is shown below.



3.4 Heating demand

From the data logs it is stated that waste heat from the generators supplies approximately 73% of district heating demand on average. In addition, there is electrical water heater with power capacity from 15 kW to 225 kW and used to regulate excess electrical power when using two generators at lower load demand than optimal for generators. It is assumed the planned upgrade from 1600 L water tank from 800 L is installed. There is an average of 20-degree temperature difference from outgoing to incoming heating water, giving an approximate thermal storage capacity of over 100 kWh that can potentially be used to store excess solar production.

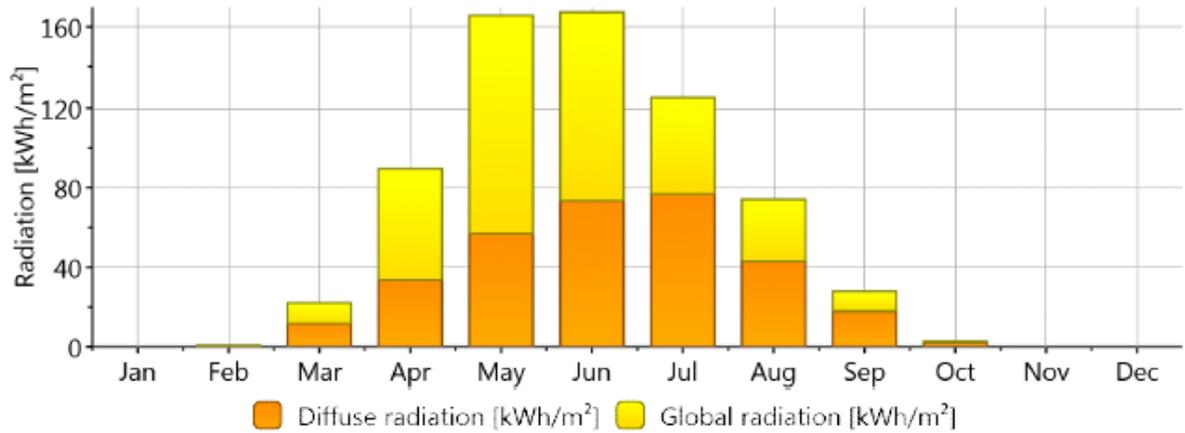


4 Available Solar Resource

4.1 Insolation

Solar irradiation data is from Meeonorm using the nearby climate monitoring station, which greatly reduces the uncertainty of the measurements. The data is a long-term average over several years which is then used to generate hourly irradiation in PVSyst taking into account weather patterns.

Monthly radiation



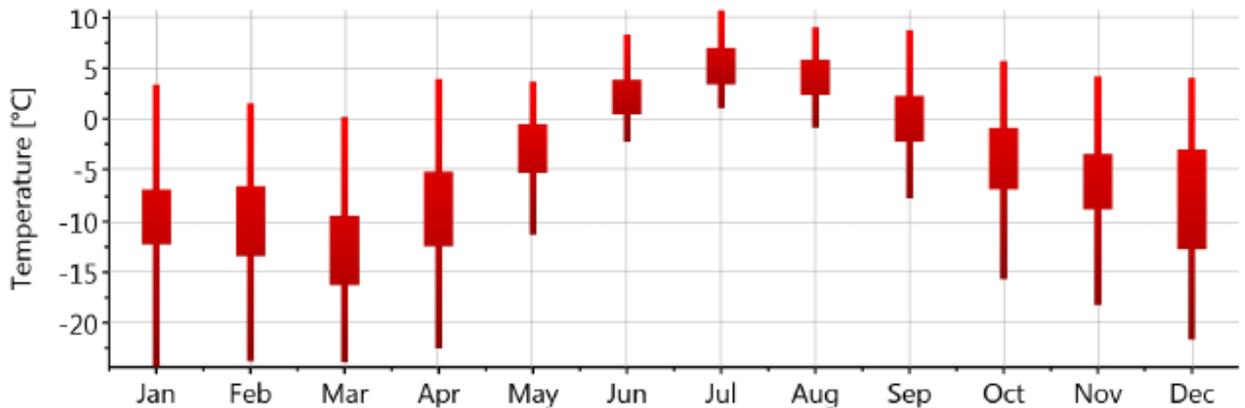
Daily global radiation



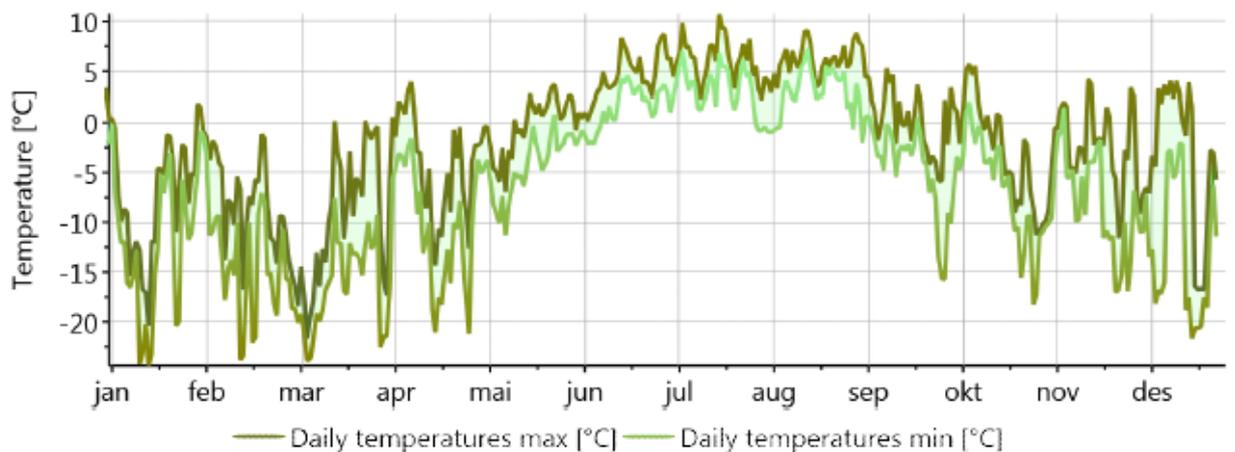
4.2 Temperature

Average temperatures throughout the year are from the same local weather station. Higher solar cell temperatures reduce efficiency. In colder regions and especially Svalbard a solar cell can in fact expect a temperature associated gain in efficiency compared to standard testing conditions under which a modules power output is rated. Hourly temperature used in solar yield simulations is calculated in the same manner as for irradiance.

Monthly temperature



Daily temperature



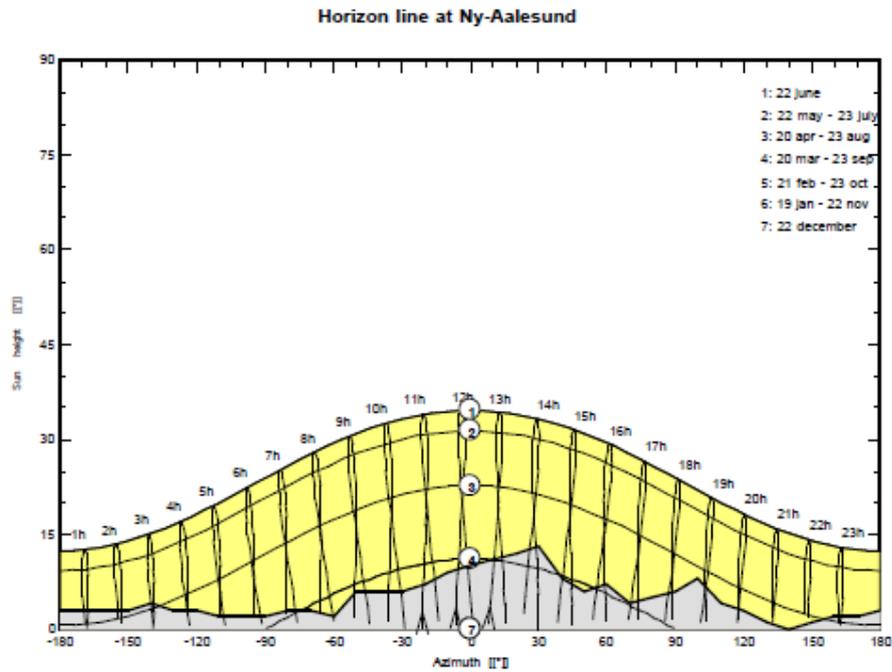
4.3 Soiling

Dust and dirt accumulation on solar modules reduce the light available on the solar cells. In addition, there is considerable snowfall in Ny-Ålesund. Based on industry standards for average soiling as well as snow ground coverage observations at the site and accounting for melting and sliding of snow on tilted modules the following soiling values are assumed. Snow on the ground will however increase the diffuse irradiation on the modules. Fresh snow has an albedo (reflectivity) of 80% compared to typical soil which has albedo of 20%.

%	Jan	Feb	Mar	Apr	May	Jun
Rooftop (30 degrees)	25	25	25	25	20	10
Ground Mount (Tracking)	15	15	15	15	10	2
%	Jul	Aug	Sep	Oct	Nov	Dec
Rooftop (30 degrees)	2	2	2	10	10	15
Ground Mount (Tracking)	2	2	2	20	20	25

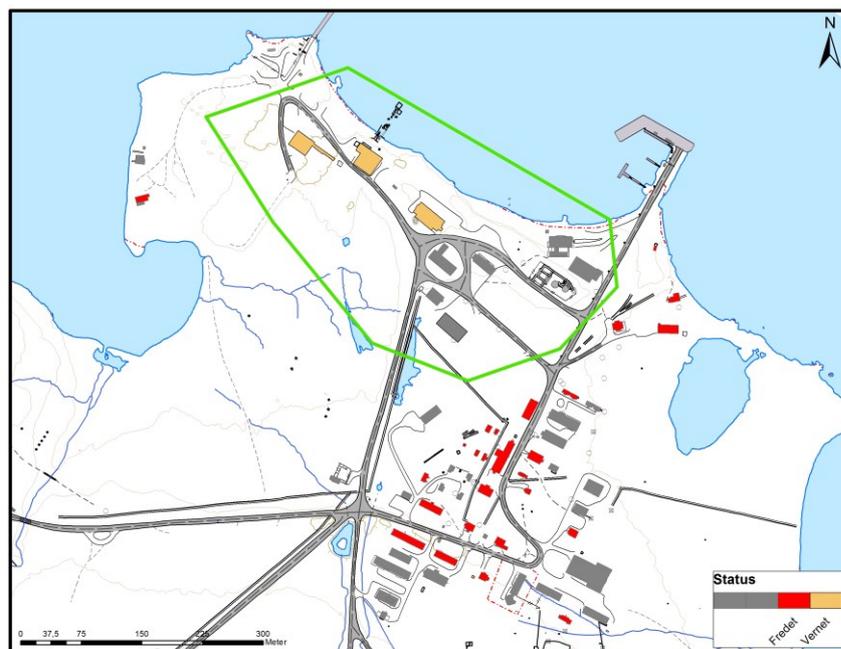
4.4 Horizon

The terrain is a significant loss factor for solar installations. The horizon from the meteorological station is shown below in grey. Sun paths throughout the year are overlaid. There is up to a 15-degree horizon to the south west and with the low sun and due to the far northern latitude there is barely any direct sunlight before the end of March and after the end of September.



4.5 Roof area and orientation

The below map shows the buildings in New-Ålesund.



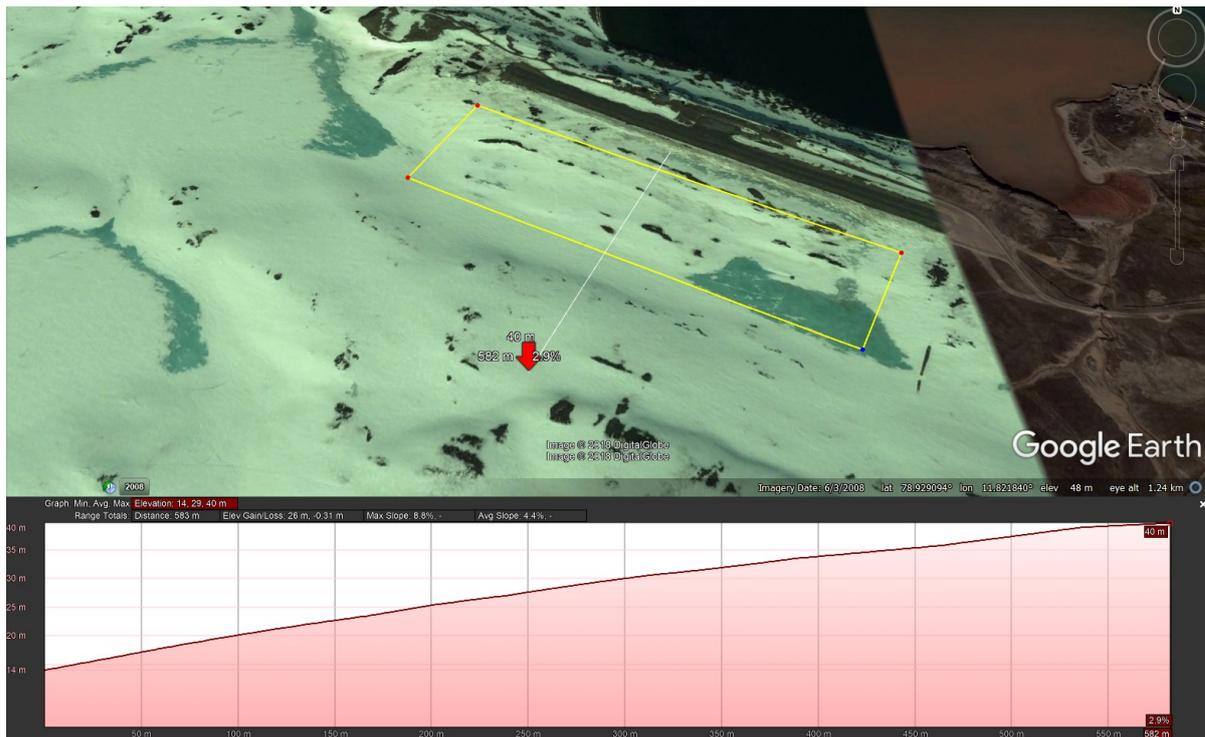
Buildings that have a suitable area, lack of shading, and favourable azimuth (degrees from due south) have been considered. The table below shows the total area and angles used to evaluate the rooftop potential, excluding protected buildings. It is assumed that the roofs have a typical average slope of

30 degrees and that there is a suitable low voltage distribution network to distribute the solar output to loads. It is estimated that 90% of the available area is suitable for installation, taking into account distance to edges and other obstructions.

Azimuth degree (-East,+West)	Available roof area (m2)
-65	149
-35	127
0	178
25	1482
30	252
40	483
115	353
Total	3025

4.6 Ground mounting

The below area adjacent to the airstrip 1 km from power station is used to represent a potentially suitable low slope site for a ground mounted solar park. The marked area is 20 hectares which is enough space for a 10+ MW widely spaced tracking plant or 20+ MW fixed tilt. The likely optimum sizing would require significantly smaller area, ideally closer to the power station and loads to reduce costs and losses.



It is understood that much of the land is protected in the area so further exploration into optimum site is not undertaken. The cost associated with foundations for substructures of the solar system is a significant portion of overall cost and dependant on local soil conditions, which will also be complicated by presence of permafrost. Depending on the depth of bedrock, predrilling may be required rather than directly piling supports, which can add to costs.

There may be concerns from aviation authorities regarding glint and glare from a solar installation visible by planes in the air. This can be mitigated by modelling any interference and further reducing reflection from panels with careful placement of the array or light scattering coatings. Solar modules however inherently have low reflectivity and have been installed at many airports previously.

5 Solar and Energy System Modelling

5.1 Solar – PVSyst

PVSyst is a solar simulation software developed by Geneva University and is a market leading tool in calculated expected energy output from solar energy systems. It includes a database of available products with manufacturer provided efficiencies. The software applies electrical and thermal losses on the system with intensity and sun angle for every hour of the year under expected weather conditions to provide an average yearly yield and typical production profile on an hourly basis.

Industry best practice inputs which have been proven to provide accurate results compared to real world experience of installed systems are used. See appendices for detailed loss assumptions for each system.

Typical multicrystalline 60 cell modules with efficiency of 15.8% have been modelled. It may be beneficial to consider higher efficiency or even monocrystalline modules of up to 20% efficiency, which will be more expensive per watt but may reduce overall cost when considering logistics and balance of system costs which account for 60-70% of total system costs, as well as allowing higher production on limited installation areas. The below image shows a rooftop solar installation in

Boston. All black modules are available at a slight cost premium and slightly lower efficiency compared to a white backsheet (space between cells).



String inverters are used due to flexibility in scaling the system. Inverter sizing varies from 8 to 30 kW depending on installed area for the distributed rooftop system and 80 kW units for the ground mounted system. Depending on distance to power station it will likely be beneficial to transmit power from a larger ground mounted plant at medium voltage to reduce losses and cable diameter. The included cost and losses should account for the added transformers and cables.

For the ground mounted system, a 1000 kWp one axis tracking system is modelled which will then scaled in size for optimum savings. A one axis tracking system rotates to follow the sun from morning to evening. For higher latitudes tracking systems allow significant increases in irradiation on the modules, and is used on most large scale solar parks since the yield gain significantly offsets slightly higher system costs. The image below shows a 2.7 MWp tracking system in Minnesota.



5.2 Energy System - Homer Energy

Homer Energy is an optimisation software. It simulates technical and commercial parameters of potential energy system and sizes the system such that energy needs are met on an hourly basis with lowest overall cost over the system lifetime. System components are in this case: Solar output from PVSyst, existing generators, and batteries to meet variable load outlined in 3.3. The main modelling assumptions are as follows.

Financial:

- Project lifetime: 20 years
- Discount rate: 4%
- Inflation: 2%

Generators:

- Replacement cost: 1 MNOK per generator
- Minimum load: 25%
- Operating cost: 50 NOK/operating hour (typical assumption of generators of this size)
- Lifetime: 50 000 operating hours (Typically between 20-80000 for continuously running low RPM generators, as little as 15 000 for variable and intermittent use generators)
- Fuel Cost: 15 NOK/L assumed (Sensitivity with 12 and 18 NOK/L also modelled to account for subsidised fuel at the low and added logistics for the high case)

Solar:

- Hourly Production profile for rooftop and ground mounted tracking system from PVSyst
- Rooftop cost: 12 NOK/W (Sensitivity of -20%/+20% also modelled)
- Ground mounted cost: 10 NOK/W (Sensitivity of -20%, +20% also modelled)
- Operations and Maintenance costs: 0.05% of capital cost per year
- Required operating reserve: 70% (To account for fast cloud cover that can reduce most of solar output in the space of minutes)

Battery Storage:

- Typical Lithium-ion system
- C rate: 0.25 (4h of storage, e.g. 250 kW, 1000 kWh)
- Efficiency: 88% Round trip efficiency (charging and discharging AC-DC-AC losses)
- Cost: 3500 NOK/kWh (Sensitivity -20%, +20%)
- Operation and Maintenance: 2.5% of capital cost per year
 - This accounts for both routine and maintenance as well as capacity augmentation whereby the system is both oversized and added to over time to account for degradation so that the fuel savings can remain constant over the lifetime of the project

6 Results

6.1 Base Case

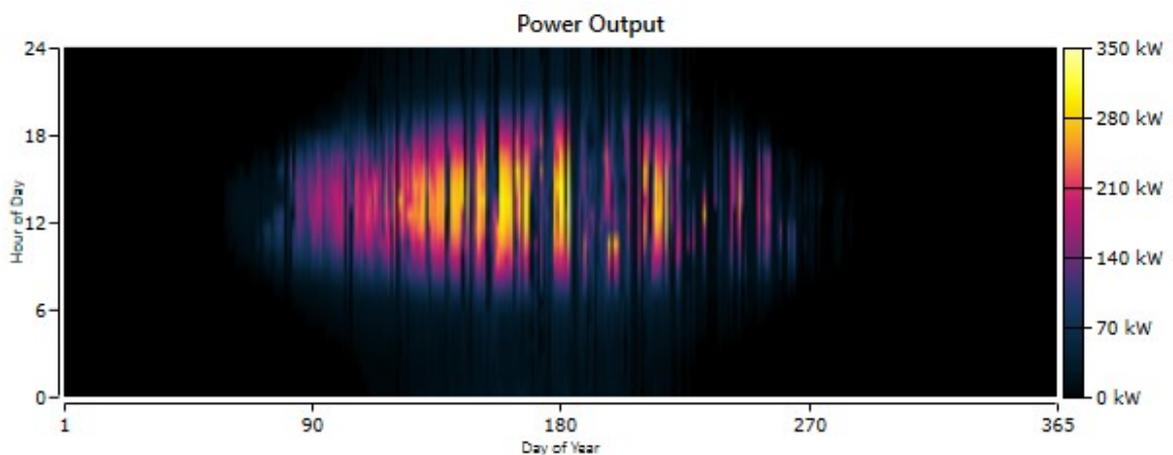
The base case of existing generators with assumptions of fuel cost, replacement O&M and efficiency outlined previously give a levelized cost of (electrical) energy over 20 years as follows:

- 12 NOK/L: 3.29 NOK/kWh
- 15 NOK/L: 4.06 NOK/kWh (Base Case)
- 18 NOK/L: 4.84 NOK/kWh

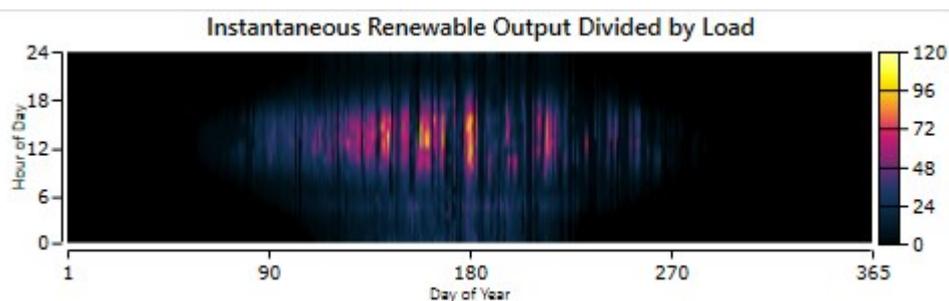
Levelized cost is the sum of all costs over the system lifetime discounted to present value and is a typical method of comparing generation costs between technologies. This means that costs in the future (fuel and replacement) have less of a financial impact than initial capital expenditure (solar, storage).

6.2 Case A

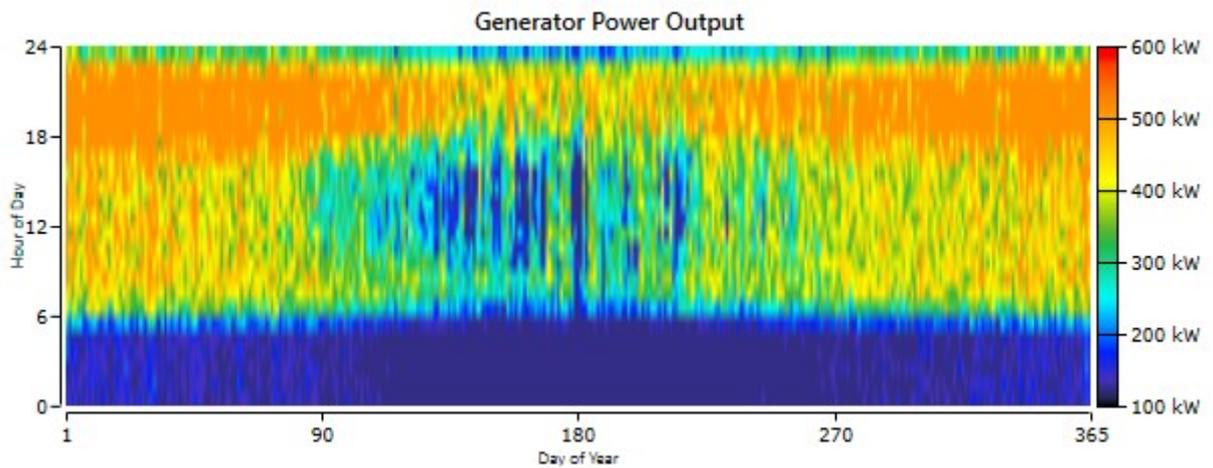
Based on the assumed system and available area the distributed solar potential on the rooftops is **474 kWp**. The average yield of these rooftop areas is **590 kWh/kWp**. This gives a total potential yearly production of **279.3 MWh**. Accounting for minor (1%) curtailment when output exceeds electrical demand, the solar system can cover **6.14%** of total electrical energy demand. Hourly output over the year is shown below where it is shown that output is predominantly in the middle of the day during summer months.



The below figure shows that solar output approaching 100% of electrical demand is limited to a few hours per year with a system of this size.



The next figure shows the output of the main generator, which in this simulation is for baseload power. It is operated towards minimum load at times of high solar output such that it can ramp up to offset a sudden drop in solar output from cloud cover.



Financial viability for the system with sensitivity analysis on solar system costs and diesel price is summarised in the table below.

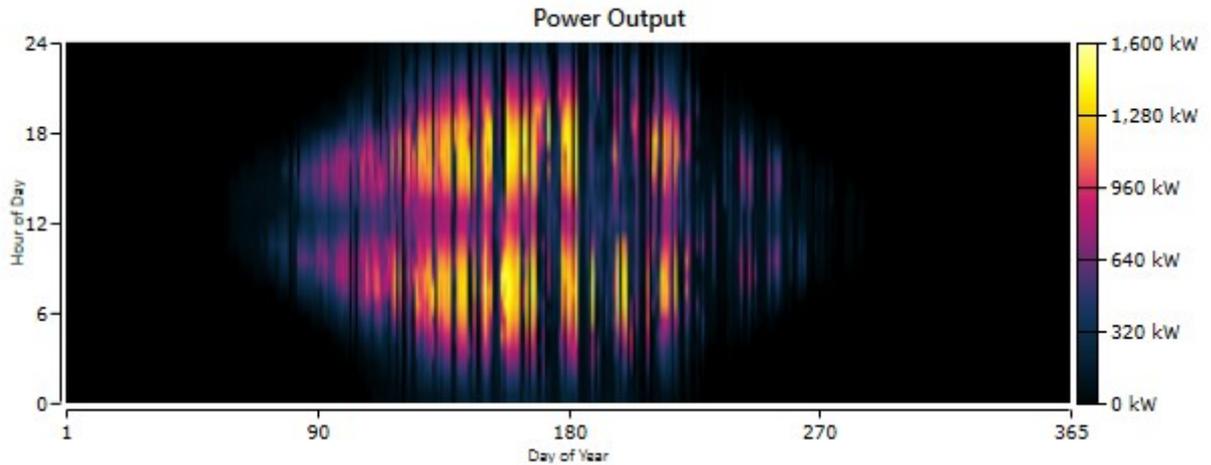
NOK/kWh	-20% Solar Cost	12 NOK/W Solar Cost	+20% Solar Cost	Diesel Only
12 NOK/L Diesel	3.17	3.19	3.21	3.29
15 NOK/L Diesel	3.89	3.91	3.93	4.06
18 NOK/L Diesel	4.62	4.64	4.65	4.84

There is a modest saving in all cases ranging from **2.4%** with high solar costs and low diesel costs, to **4.5%** with lower solar costs and high diesel costs. Note that this is a blended cost of energy where diesel accounts for almost 94% of generation which is why savings are modest when in fact the cost of generation will be significantly lower for solar.

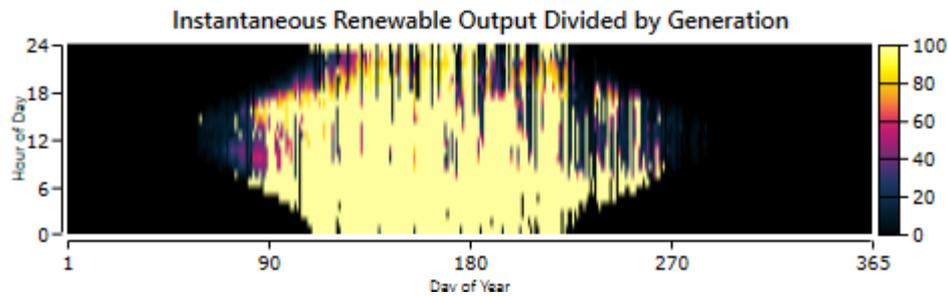
The investment requirement is anticipated to be **5.69 MNOK** with a range between **4.56 MNOK** and **6.8 MNOK**. This is based on mainland market costs and is reliant on cost reduction at scale and that the various roof surfaces are suitable for solar installation. The upper cost range may be higher factoring in location and building conditions.

6.3 Case B

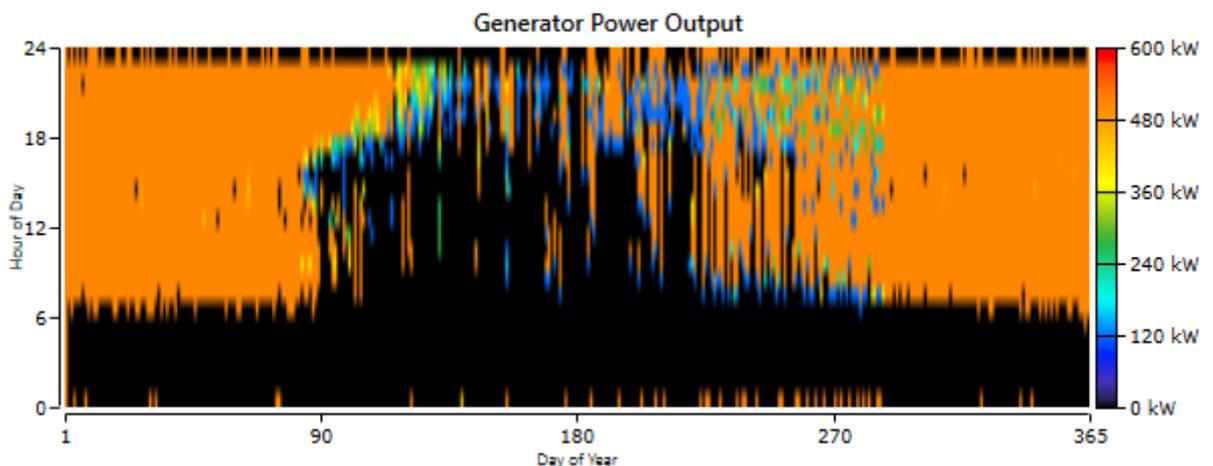
The expected yield of a one axis tracking system is **913 kWh/kWp**. This is comparable to an optimally oriented south facing rooftop system in Oslo. The hourly production profile of this 1 MWp system has been sized with storage to give lowest overall cost of energy with existing generators. The following are detailed results for the base case costs and diesel cost of 15 NOK/L. Compared to the rooftop system, a tracking system has higher production in the morning and afternoon, even producing at night in summer since it can track the sun to the east and west when it will be at a northerly angle.



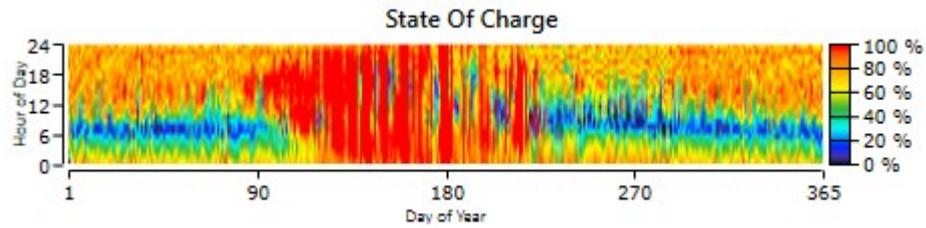
The below figure shows that the solar output covers most of electrical demand in summer months where a certain portion will be stored in the batteries. Note that the optimum sizing allows for approximately 13% curtailment, or excess solar production, as being more cost effective than diesel generation or storing the energy in a larger, more costly battery.



The next figure shows the output of the main generator. With the recommended sizing the generator is at times off for up to 16 hours a day. Further studies must determine whether there would be sufficient waste heat production and thermal storage to cover heating demand in warmer months, or whether it is cost efficient to provide electrical heating from the solar system.



Battery state of charge is shown in the following figure. In the summer period the battery is fully charged with excess solar power every day and the battery also allows more efficient operating loads for the generators throughout the year



Financial viability for the system with sensitivity analysis on solar system costs and diesel price is summarised in the table below.

NOK/kWh	-20% Solar and battery Cost	Base Case Solar and Battery Cost	+20% Solar and Battery Cost	Diesel Only
12 NOK/L Diesel	2.65	2.73	2.81	3.29
15 NOK/L Diesel	3.18	3.28	3.36	4.06
18 NOK/L Diesel	3.69	3.81	3.91	4.84

Optimal solar sizing:

MWp	-20% Solar and battery Cost	Base Case Solar and Battery Cost	+20% Solar and Battery Cost
12 NOK/L Diesel	1.83	1.67	1.67
15 NOK/L Diesel	2.67	1.88	1.8
18 NOK/L Diesel	2.66	2.67	2.32

Optimal Battery Sizing:

MWh	-20% Solar and battery Cost	Base Case Solar and Battery Cost	+20% Solar and Battery Cost
12 NOK/L Diesel	1.89	1.89	1.68
15 NOK/L Diesel	2.52	2.1	1.89
18 NOK/L Diesel	3.36	2.52	2.31

There is a larger saving in all cases ranging from **14.6%** overall energy cost reduction with high solar and battery costs and low diesel costs, to **23.8%** with lower solar and battery costs and high diesel costs. Overall solar penetration ranges from **23.5% to 30.5%** for the lowest and highest saving sizing respectively.

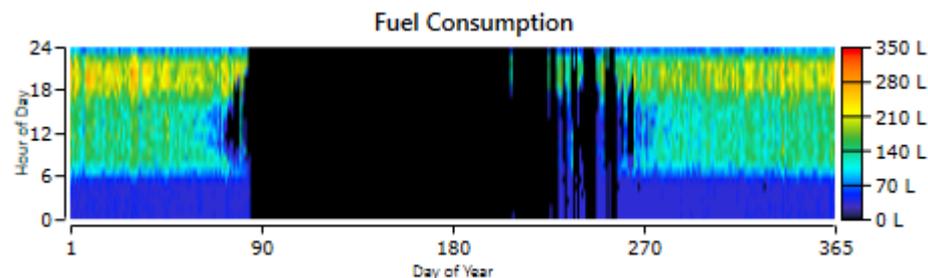
The investment requirement is anticipated to be **26.2MNOK** with a range between **21.3 MNOK** for low solar and battery costs along with low diesel cost that gives smaller system sizing and **37.5 MNOK** with high solar and battery costs along with high diesel cost that gives larger system sizing.

This is based on international market costs with anticipated cost increase for location and an extensive tender process should be the basis of any investment decision. The battery storage and solar park market for large systems is relatively immature in Norway, and there is some uncertainty to the suitability of the site for a ground mounted solar.

This is a large potential investment and likely unfeasible to pay upfront for energy savings over the course of 20 years. A power purchase agreement or lease of equipment from a system installer and operator would be a way to remove upfront costs while still make savings, although there would be costs associated with financing the installation.

6.4 Case C

Since Case B is a cost optimisation for overall electrical energy cost a further increase in solar and storage capacity will lead to increased costs. Further sizing was modelled to determine how much fuel could be replaced for the same cost of energy as existing diesel system. Using the base case fuel cost (15 NOK/L) and base case solar and storage costs **43.7%** of electrical demand can be met with solar energy. Sizing is in this case **6.67 MWp** with **8.4 MWh** of storage. Generator fuel use is shown below and only used once from the end of March to the beginning of August.



Although this system yields comparable costs to the existing system with assumptions used, almost 53% of solar energy is unused. Due to the extremely high latitude almost all solar output is in the summer months and therefore current storage technologies cannot increase the solar penetration beyond 50%. Typical off-grid solar and storage systems on remote sites with fuel logistics challenges closer to the equator can typically achieve penetrations of 90+% at lower cost than diesel. The reduced variation in daylight length is a larger contributing factor to viability than an optimal site with two times the yield as Ny-Ålesund. Longer term seasonal storage with reasonable cost is limited to pumped hydro for the time being, whilst hydrogen production and storage or other technologies may be feasible in the medium-term.

7 Environmental Benefits

The following values are CO₂ emissions from fuel saving without emissions associated with transport of fuel to site. These values are dependant on the specific generator but indicate up to one thousand tonnes of CO₂ emission reduction potential. The CO₂ involved in manufacturing the solar and battery systems is outside of the scope of this report and dependant on country and method of manufacture, logistics, electrical and mechanical balance of system etc. For reference a typical solar system has an embedded energy and CO₂ payback of under three years.

Base case diesel: 2,635,053 kg/yr

Case A: 2,475,165 kg/yr, **-6.1%**

Case B: (Base Case Costs): 1,851,657 kg/yr, **-29.7%**

Case C: 1,479,405 kg/yr, **-43.9%**

8 Appendix

8.1 Meteonorm Weather Data Ny Ålesund

8.2 Solar Yield Simulation Reports

8.2.1 *VC0: Rooftop PV 424 kWp*

8.2.2 *VC2: One Axis Tracker 1 MWp*