Multiconsult

MEMO

PROJECT	**Troll Green Station**	DOCUMENT CODE	713055-2-RIEn-NOT-01
SUBJECT	Integration of a Solar Powered Fuel Saver at Troll Station, Antarctica	ACCESSIBILITY	Restricted
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SUMMARY

This memo is an executive summary in English of the results from the initial feasibility study in Norwegian (Ref.: 713055-RIEn-RAP-01, November 2015) commissioned by the Norwegian Polar Institute (NPI) to Multiconsult.

The ambition of NPI is to replace most of the current energy production with renewable energy at Troll Station (Norwegian research station in Antarctica). The purpose of the work was to study the feasibility of a functional “fuel saver” solar power system (with electricity storage), i.e. to increase the station’s energy autonomy and reduce the need for fuel logistics. Indeed, the station’s location makes diesel supply highly demanding in terms of logistics as well as very expensive.

Considering the latitude, Troll Station’s location benefit of a high solar energy yield, due to favorable solar resources in combination with low temperatures and high albedo (reflected light). Simulation results show that a system combining solar power (app. 762.5 kWp) and electricity storage (app. 3,840 kWh) would thus cover more than 50% of the annual energy consumption at Troll Station. Even though the investment costs of such a system will be very high (approximately 76.25 million NOK at 2015 level), it will represent significant fuel savings (app. 12.50 million NOK per year). The estimated cost of electricity of the renewable energy system over its lifetime is 7.40 NOK/kWh, which corresponds to half of today’s energy cost for diesel generation (15 NOK/kWh). In addition to making Troll Station cleaner and greener, solar power is also highly competitive and profitable.

Harsh climatic conditions in Antarctica, like wind load, sandblasting and snow accumulation, can present physical and mechanical challenges for the operation of a solar power plant. After considering different solutions, existing roofs are likely to be the option with the lowest climatic stress. However, the available roof area at Troll is not large enough to install the needed solar power plant in order to reach 50% of the annual energy consumption. An alternative is to use areas naturally shielded by terrain, a possible location has been identified 5 km northeast of the station.

The existing diesel generator system is over-dimensioned, including periods of the year when contribution from solar energy would be non-existent. It is therefore recommended to consider another generator configuration in order to achieve a more energy efficient operation.

Late 2015, NPI mounted a 7.56 kWp pilot project in order to collect data during the southern winter 2016.

To be further investigated:

- Step 1: Operation and evaluation of the pilot project through the southern winter 2016 will give NPI useful data about both PV production and climate adaptation. This information will be valuable in assessing in detail the potential for implementation of a larger PV capacity with storage.
- Step 2: Evaluation of a configuration combining diesel and solar power production with electricity storage.
- Step 3: The long-term aim for Troll Station is to become completely independent from diesel for electricity production. This would imply storing solar energy from the summer through the long Antarctic winter. This could be achieved by water electrolysis, combined with hydrogen storage and fuel cells, for example.

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Contents

Abbreviations

AC	Alternating Current
AM	Air Mass
BIPV	Building Integrated Photovoltaic
DC	Direct Current
GHI	Global Horizontal Irradiation
IAM	Incidence Angle Modifier
kWh	Kilo-watt Hour
kWp	Kilo-watt Peak
LCOE	Levelized Cost Of Electricity
LID	Light Induced Degradation
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
NOCT	Nominal Operating Cell Temperature
NOK	Norwegian Krone
PR	Performance Ratio
PV	Photovoltaic
STC	Standard Test Conditions

Key Concepts Definition - PV

- **STC (Standard Test Conditions):**

Irradiance of 1,000 W/m², cell temperature 25°C and AM of 1.5. These are the international Standard Test Conditions for PV modules. The measured power under these conditions is given in “Wp” or “kWp” (see below).

- **Rated Power [kWp]:**

Since energy production of a PV cell varies with irradiance, temperature and radiation spectrum, a standard method has been defined to measure the rated power. A “Wp” or “kWp” is thus a measure of the PV module’s performance under STC. A PV system that supplies 20 kW under STC has an installed capacity of 20 kWp.

- **Specific Yield, [kWh/kWp.year]:**

The specific yield shows annual electricity generation [kWh] regardless of the rated power of the installation. In Norway, the specific yield values vary approximately between 700 and 950 kWh/kWp.year, depending on location, technology and design. The specific yield is analogous to the term “operating hours” used in other energy production branches such as wind power or hydropower.

1 Introduction

Figure 1: Troll Station, location. Source: Google Earth.

Troll is the Norwegian research station in Antarctica. The station is built on rock 1,270 meters above sea level and 235 km from the coastline (coordinates 72°01' S, 2°32' E). Most other research stations in Antarctica are usually built on snow / glaciers

The Norwegian Polar Institute[1] (NPI) operates the station all-year round. The energy supply is currently based on diesel generators with heat recovery from exhaust gas and cooling water. In addition to the station's own use, the energy system also delivers electricity for the operation of an antenna system owned by KSAT[2].

The ambition of NPI is to replace most of the current energy production with renewable energy. Measurements have shown that wind will not be a suitable alternative source of energy (wind gusts of up to 60 m/s). However, the station's high latitude, in combination with a dry and stable inland climate with good solar irradiation make PV an attractive energy source.

The purpose of the work is to pre-design a functional "fuel saver" PV system (with electricity storage) for Troll Station, i.e. to increase the station's energy autonomy and reduce the need for fuel logistics. The station's location makes diesel supply highly demanding in terms of logistics as well as extremely expensive.

Multiconsult[3] delivered a feasibility study to NPI in November 2015 that included the evaluation of the existing system (efficiency, generation, consumption and load profiles) and the design and simulation of two cases for implementation of solar energy:

- Case 1: integration of the highest PV power (without storage) limited to optimal operation of the diesel generators.
- Case 2: optimized energy system combining PV, electricity storage and diesel generators maximizing fuel saving.

Figure 2: Troll Station, picture. Source: NPI.

This memo is an executive summary in English of the results from the initial feasibility study in Norwegian (Ref.: 713055-RIEn-RAP-01, November 2015).

[1] Norwegian Polar Institute (NPI): http://www.npolar.no/en
[2] Kongsberg Satellite Services AS (KSAT): http://www.ksat.no
[3] Multiconsult ASA: http://www.multiconsultgroup.com

2 Existing System

Power consumption analysis is based on on-site measurements. Multiconsult had access to monthly values from 2014 and one-minute data from 05/09/2015 7:28 pm to 07/09/2015 9:48 am.

The load profile for 2014 is relatively flat with an annual average of 119 kW. One-minute samples from September 2015 show an average power of 130 kW. The maximum power registered on a one-minute basis is 185 kW.

The station's existing power system consists of two diesel generator sets:

- 2 x 80 kVA, installed in 2005 + 1 x 80 kVA, installed in 2012
- 2 x 280 kVA, installed in 2007

The set installed in 2005 / 2012 acts as backup for the one from 2007 and the three generators must operate together. The two generators from 2007 operate singularly with a cycle time of approximately two weeks. Each one consists of a diesel engine of 280 kW and an alternator of 670 kVA.

The 2014 load average of 119 kW is used in the calculations. It corresponds to 18% of the generator's capacity (670 kVA). Figure 3 below shows that the generator operates with an efficiency of approximately 94% at 18% of load (orange point).

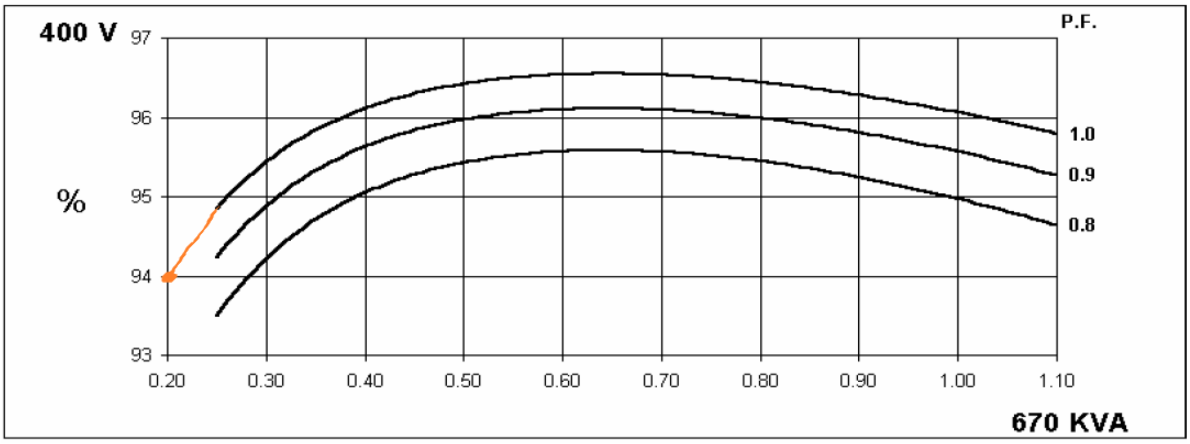
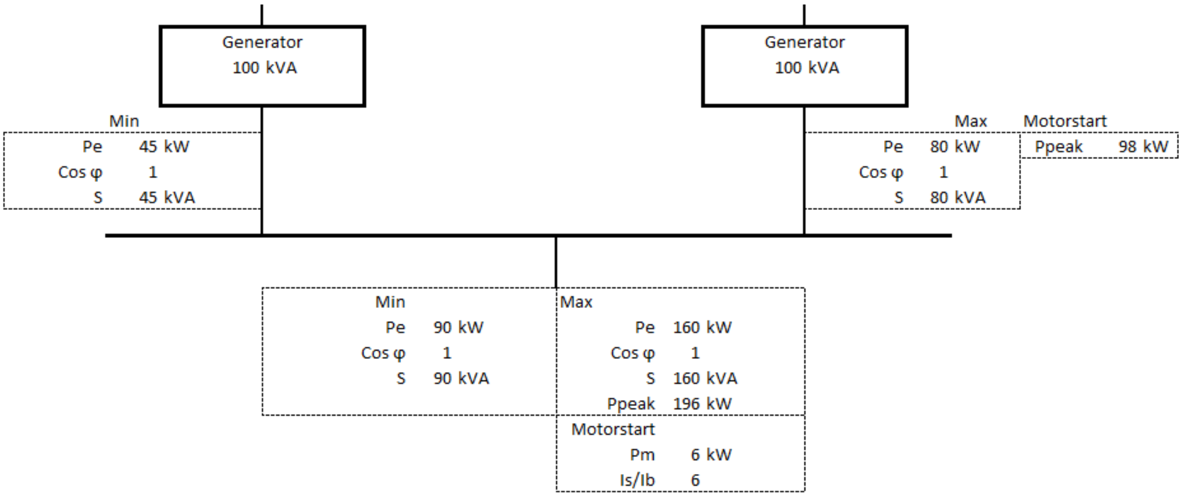


Figure 3: Generator's efficiency according to the load.

An efficiency of 94% means that the generator delivers 263 kW (280 x 0.94). Comparing this value with the average load of 119 kW, we conclude that the generator operates between 40% and 50% of its nominal capacity.

The generators should not operate under low load, which could cause exhaust manifold slobber and wet stacking. In order to avoid this, the diesel engine should run in continuous operation above 30% of the rated power, the optimal charge load being between 70% and 80%. Operating now at approximately 40%, the existing system is generally considered over-dimensioned. This leads to lower efficiency and limited opportunities to add renewable energy production without the flexibility given by storage.

An alternative design could consist of two generators of 100 kVA, which would give a load charge between 45% and 80%.



To increase supply security in case of breakdown and make operation and maintenance easier, a system with four generators of 100 kVA operating singularly would be recommended.

The thermal load power is on average 32 kW while approximately 85 kW is discarded. It is recommended to assess to which extent available thermal energy can be used in the station's system.

An advanced analysis of the load, both electrical and thermal, would be required for the detailed design of a new energy system.

3 Climate

Energy generation of a PV system is highly dependent on local solar irradiance and installation parameters such as orientation and tilt. However, temperature and wind also have an important impact on the plant's performance. Low temperatures gives higher efficiency and wind can add a combined cooling effect.

3.1 Solar Resources

Quality assurance of data measured on site has not been possible because of calibration issues with the equipment. Two climate sources have thus been studied for the station's location:

- Meteonorm 7.1[4]: dataset generated by interpolation between the closest weather stations, complemented by satellite data.
- Nasa-SSE[5]: dataset generated by satellite data.

[4] Meteonorm: http://www.meteonorm.com
[5] Nasa-SSE: https://eosweb.larc.nasa.gov/sse

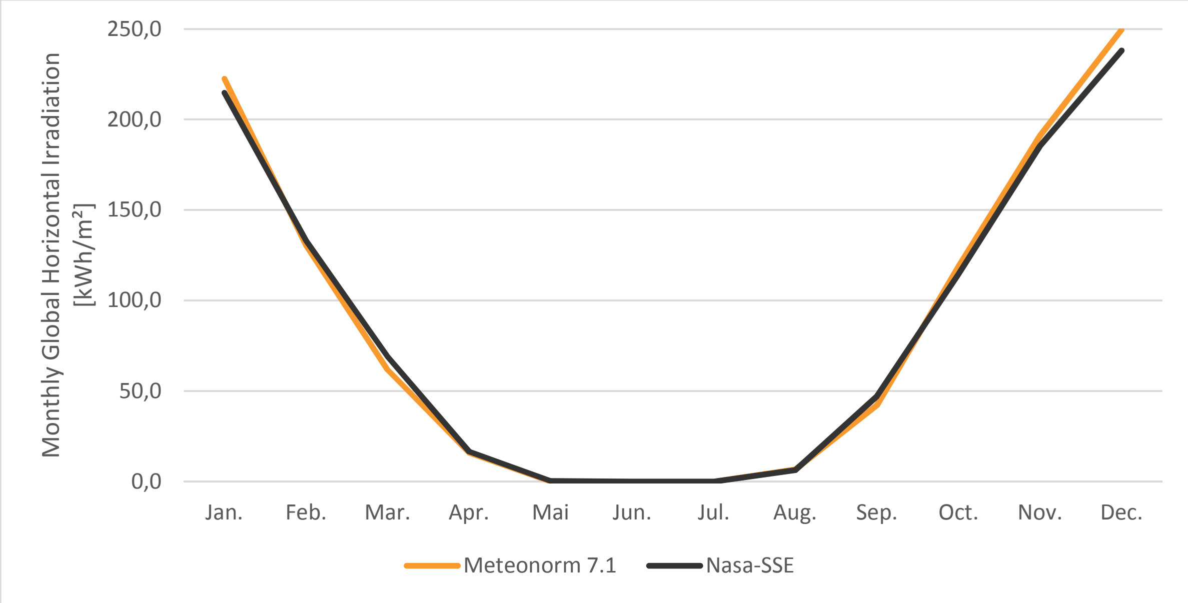


Figure 4: Monthly Global Horizontal Irradiation (GHI) at Troll.

In Figure 4, we observe that the data collected from the two sources are very similar. The annual GHI[6] (combining direct and diffuse irradiation) from Meteonorm 7.1 is 1,038.3 kWh/m² while Nasa-SSE gives 1,024.6 kWh/m².

The months of May, June and July, during the Antarctic winter, are completely dark.

3.2 Temperature

We can emphasize that, although irradiation from the two sources are relatively similar, temperatures are significantly higher in the dataset from Meteonorm 7.1 than the one from Nasa-SSE. The yearly average temperature from Meteonorm 7.1 is -19.3°C while Nasa-SSE gives -26.3°C.

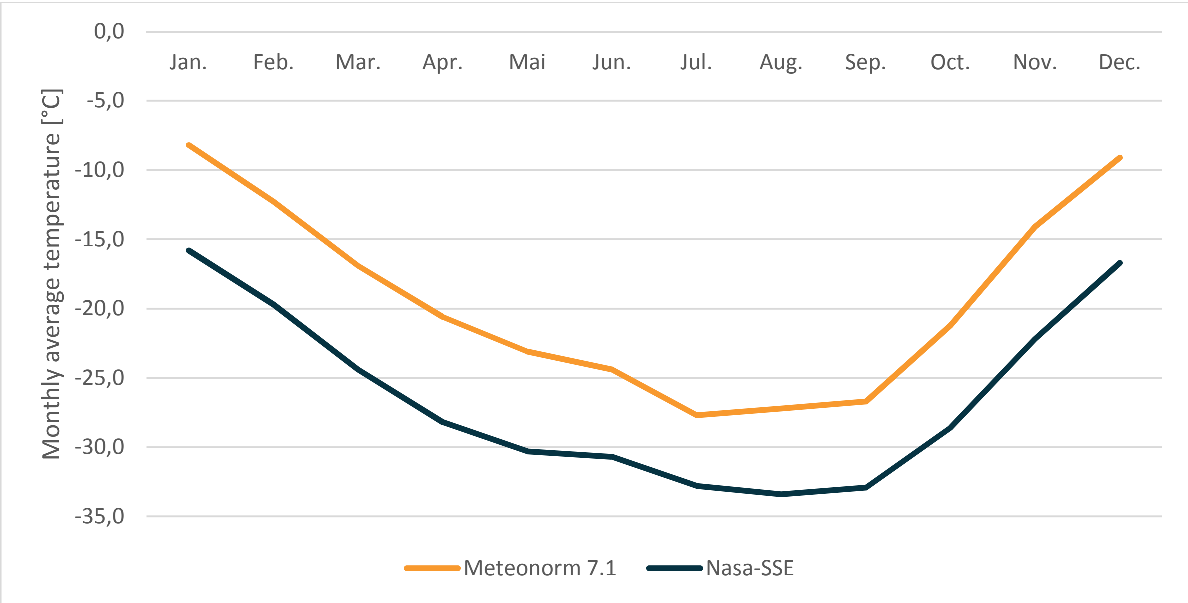


Figure 5: Monthly average temperature at Troll.

[6] GHI: Global Horizontal Irradiation [kWh/m²]

Multiconsult chose to use data from Meteonorm 7.1 for the simulations in this study. The dataset (both irradiation and temperature) is based on interpolation between Novolazarevskaya (Russian research station - 367 km), Neumayer III (German research station - 401 km) and Syowa (Japanese research station - 1400 km). Being based on measured data and completed by satellite information, it is considered more precise than Nasa-SSE, which rely on satellite data only.

If it should turn out that the actual temperatures are lower than the ones used as input for our simulations, the main consequence would be a higher production (increased efficiency of solar cells at low temperature). Multiconsult therefore consider this choice a conservative one.

3.3 Wind

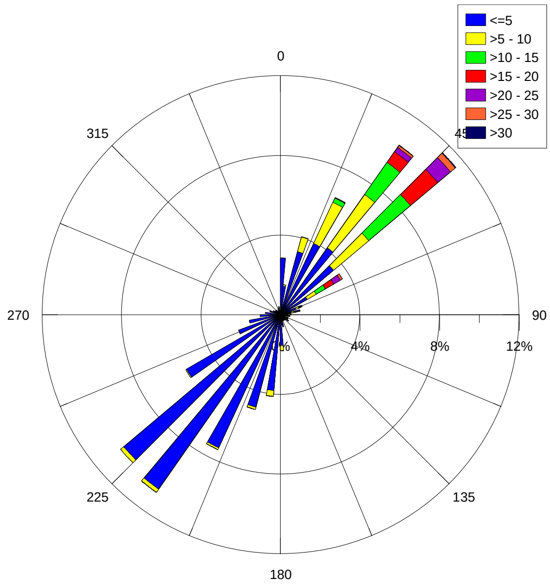


Figure 6: Wind rose at Troll.

Wind direction and speed are measured at an on-site 10 m high meteorological mast. Due to the relatively short period (9 years) of measurements, the 50-year return period is not calculated. However, the maximum 10 minute mean wind velocity was measured at 54 m/s. Wind data have also been completed and crosschecked with values from the database eKlima[7] operated by the Norwegian Meteorological Institute[8] (MET).

With an estimated gust factor of 1.1 applied to 54 m/s, we can consider wind gusts of about 60 m/s. Figure 6 below shows bidirectional wind directions (northeast / southwest) and uniform high wind speeds from the northeast.

4 PV System Simulations

The software solutions PVsyst (version 6.39) and Polysun (version 8.1) have been used for simulation of the solar power production.

PVSyst is developed by the University of Geneva and is among the most used PV simulation tools worldwide, for both system design and technical review. PVsyst has advanced features for the simulation of losses that might occur in a solar power plant, including a 3D tool for shading simulations.

Polysun is developed by the company Vela Solaris and provides the ability to combine several renewable energy sources. Polysun offers advanced features for simulation of stand-alone solar power plants with programmable controllers.

Simulations have been made with two PV modules: REC 260PE (polycrystalline silicon), and LG Neon^2 305 by LG Electronics (monocrystalline silicon). These two modules are chosen to illustrate the difference between a "standard" good product and a product with higher efficiency. The modules from REC have an efficiency of 15.8%, while modules from LG Electronics have an efficiency of 18.6%. The best efficiency on the market today is approximately 22%. Only a few suppliers produce modules with such high efficiency, which leads to limited availability and higher cost. Simulations have been

[7] eKlima: http://eklima.met.no

[8] Norwegian Meteorological Institute (MET): http://met.no/english

done with inverters from the German producer SMA (one of the world's leading producers) as an example.

Two systems are considered: integration of the highest PV power (without storage) limited to optimal operation of the diesel generators, and an optimized energy system combining PV, electricity storage and diesel generators maximizing fuel saving.

4.1 PV Without Storage

As mentioned in Chapter 2, diesel generators should not operate below 30% of their rated power. The contribution of solar power without storage is thus limited by the already low generator operation window (40 - 50%).

Taking into account that 95 kW is the lowest measured load (on a minute average) and that the diesel generator with a total rated power of 263 kW would operate at 30%, the PV capacity is then limited to:

95 kW - 263 kW * 30% = 16 kW

An installation of this size can fit on the station's roofs. The results of the simulation are shown in Table 1.

Table 1: Key figures simulation PV without storage.

Model PV module	REC 260 PE
Type of PV cell	poly-Si
Rated power PV module [Wp]	260
Dimensions PV modules [mm]	1,665 x 991
Area PV module [m²]	1.65
Efficiency PV module [Wp/m²]	157,6
Azimuth [°/North]	-20
Tilt [°]	20
Number of PV modules	60
Installed capacity [kWp]	**15.60**
Area PV array [m²]	99
Model inverter	SMA STP 20000TLEE-10
Number of inverters	1
Performance Ratio (PR) [%]	94
Specific yield [kWh/kWp.year]	1,207
Energy production [kWh/year]	**18,826**

The annual maximum power (in summer) is 15.36 kW and thus never exceeds the required 16 kW limit. A 15.6 kWp PV plant will produce approximately 18.3 MWh/year, which corresponds to approximately 5,000 litres of diesel per year.

4.2 PV With Storage

It is assumed in this case that PV will cover most of the energy consumption in the summer. A battery pack is used in addition as a buffer for temporary storage (increase the match with the load profile by reducing weather-dependence) and an optimal operation of the diesel generators.

Although the sun shines all day during summer in Antarctica, the radiation at "night" is not high enough to meet the energy requirements of the station and the battery pack must be designed accordingly.

The station's load profile is assumed to be flat throughout the day with a load of approximately 130 kW (energy consumption of approximately 3,120 kWh per day). Diesel generators will stop when PV and/or the batteries cover 100% of the electricity demand, the system must then also cover the thermal demand. An additional 35 kW is therefore included, increasing the total load power to 165 kW (3,960 kWh/day). An electric boiler could cover the thermal demand. Thermal storage (tanks) could also be considered in the final design, as it is considerably cheaper and easier to store heat than electricity.

For the days with insufficient solar energy to cover daily needs, the battery pack will provide the additional energy until the charge level of the battery eventually drops down to a minimum. Then the generator will start up, but as it should always operate on optimal load, any surplus will be used to charge the battery.

The results of the simulation are shown in Table 2.

Table 2: Key figures simulation PV with storage.

Model PV module	LG305N1C-G4
Type of PV cell	mono-Si
Rated power PV module [Wp]	305
Dimensions PV modules [mm]	1,640 x 1,000
Area PV module [m²]	1.64
Efficiency PV module [Wp/m²]	186
Azimuth [°/North]	0
Tilt [°]	20
Number of PV modules	2,500
Installed capacity [kWp]	**762.5**
Area PV array [m²]	4,100
Model inverter	SMA FLX PRO 17
Number of inverters	42
Storage capacity [kWh]	**3,840**
Specific yield [kWh/kWp.year]	1,100
Energy production [kWh/year]	**838 455**

An example of the electrical behavior of the system is shown in Figure 7 below.

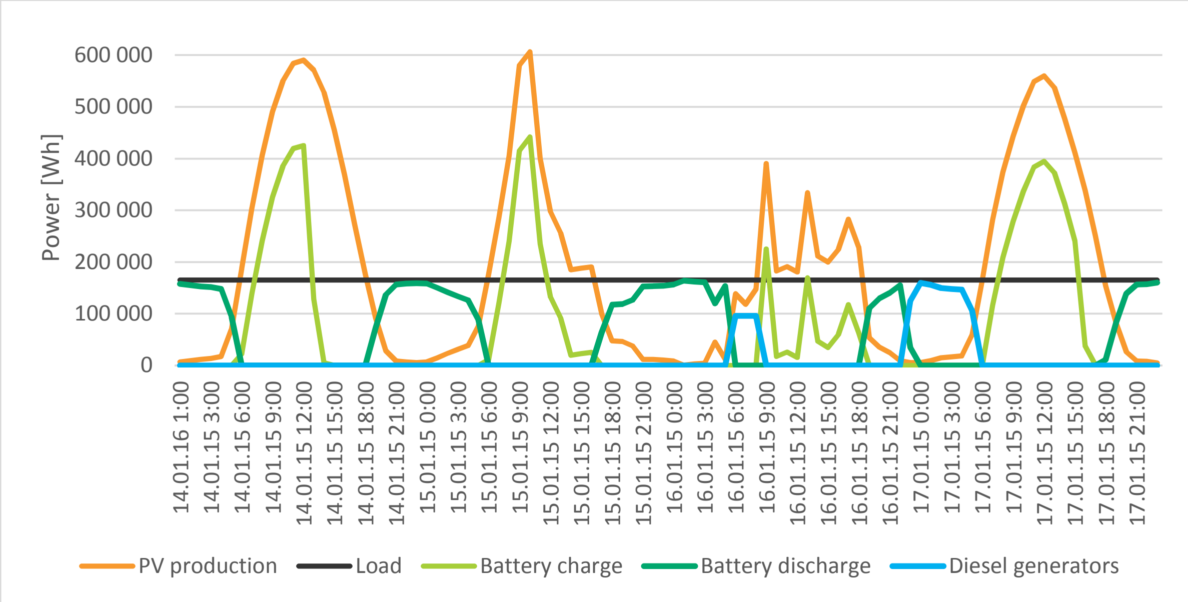


Figure 7: Example (four days) electrical behavior with storage (hourly values).

The example above is based on a sample of four days during summer (January). While on Day 1 (a sunny day) PV manages to supply 100% of the energy demand, Day 2 and Day 3 experience inclement weather and limited solar irradiation, diesel generators must then compensate energy production.

Figure 8 below shows daily values simulated for a year. Batteries provide short-term storage and cannot compensate the winter darkness. Most of the energy production during April, May, June, July and August comes from the diesel generators, as shown in Figure 9.

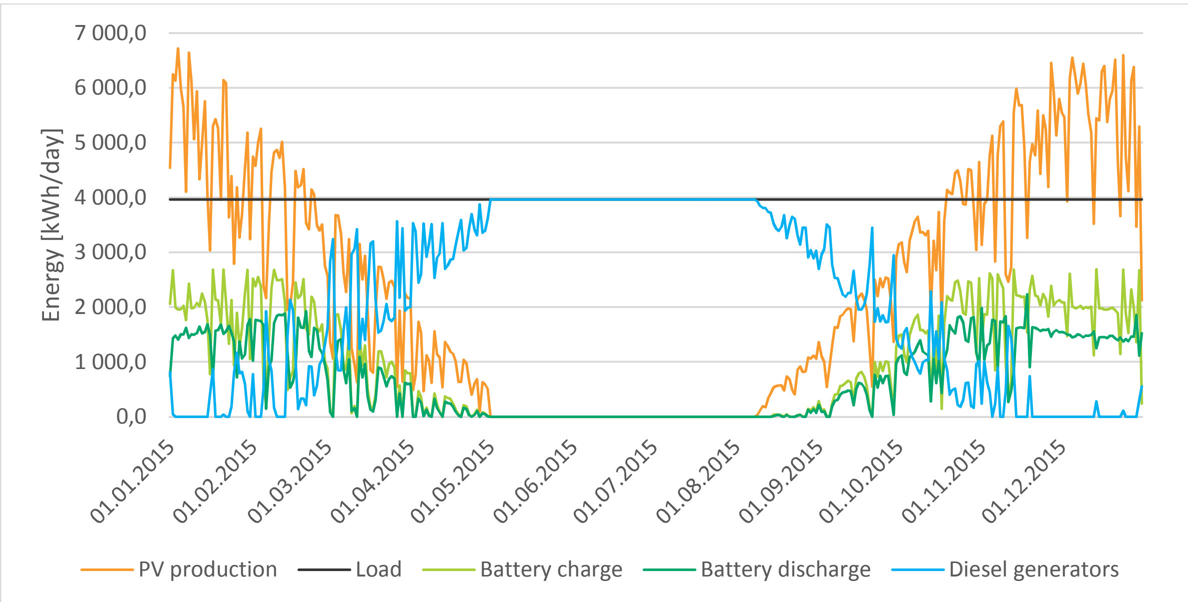


Figure 8: Energy overview with storage (daily values).

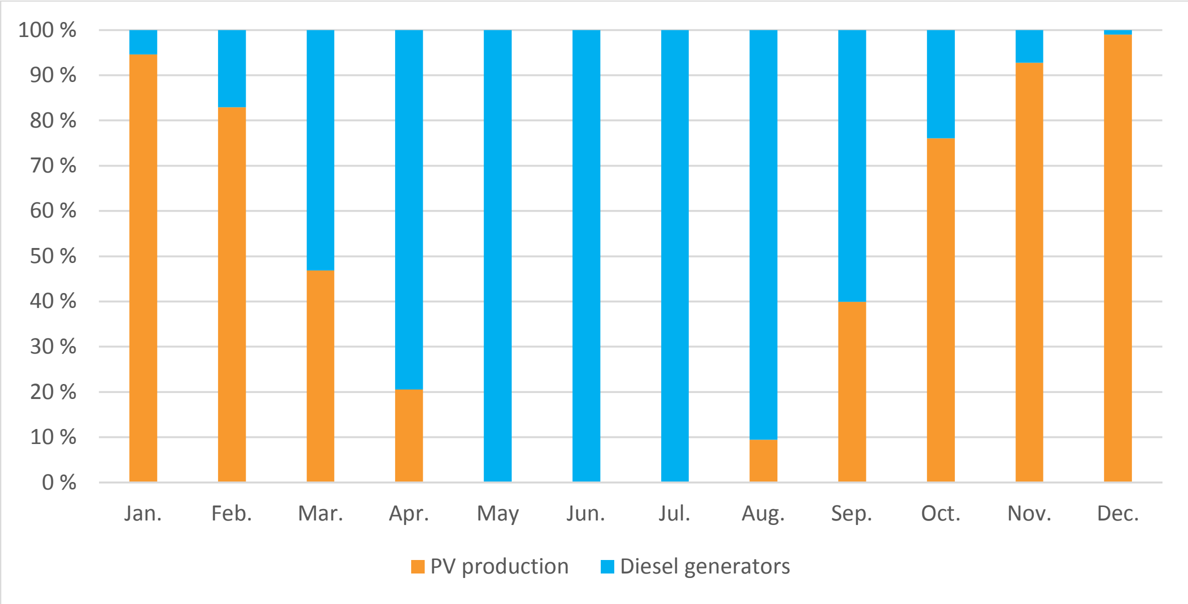


Figure 9: Balance PV/diesel per month.

The optimal solution would be to mount the PV plant on available roof areas. This results in limited wind loads and would make operation, maintenance and monitoring easier. However, there is not enough space on the station's roofs to install the required capacity of 762.4 kWp (app. 4,100 m²). A ground-mounted PV plant is considered, with an optimal location approximately 5 km northeast of the station (as shown in Figure 10, details in Chapter 0). The inverters should be installed on site in an insulated container in order to operate power transmission in alternating current (400V AC), which means lower losses and reduced amount of cables.

Figure 10: Possible location of the PV plant. 5 km north-east of the station.

5 Climate Adaptation Measures

Due to high wind velocity, low air temperature and snow loads, climate adaptation measures and winterization are necessary. Wind gusts of 60 m/s have been observed, and rocks, sand and ice particles can be blown. Abrasive blasting of surfaces due to high wind speed is a concern at the station. Moreover, the snow cover of the site does not melt during summer. This makes the snow accumulation around the installation increasingly important. A ground-mounted PV plant should not accumulate snow inside the installation (between rows of PV modules), where it might be difficult to remove it.

5.1 Wind

Wind speed varies widely at the station. If the PV plant will be ground-mounted, it should be placed in an area that is partially shielded by topography. Using numerical simulations, the terrain effect on airflow has been calculated for 16 different wind directions. The results are further weighted with wind data from the measuring station. This method, called Computational Fluid Dynamics (CFD), is documented by Berg (2011) and Bechmann (2011)[9]. A three-dimensional CAD model of the terrain has been implemented in the CFD model. The analyzed area is divided into small volume cells where pressure, wind speed vector and turbulence are calculated for each cell. The program used for this study is OpenFOAM version 2.4.

Figure 11 shows the probability of high wind speed at the station and surroundings.

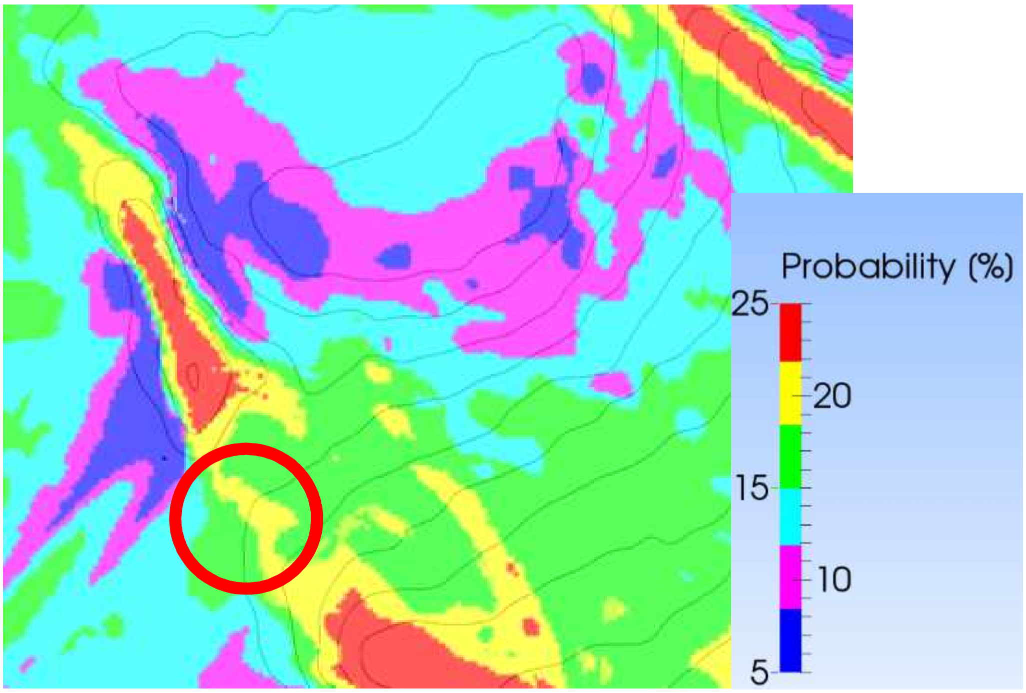


Figure 11: Probability of wind speed > 10 m/s. Station's location in red circle.

Wind loads on solar panels are calculated using the standard EN 1991-1-4: 2005. This must be differentiated for each location, based on roof geometry and orientation. There are also rules for freestanding panels in Section 7.3 of the standard. Generally, wind loads are significantly greater for a freestanding panel than a panel mounted in a protected zone of a flat roof, given the same wind conditions.

[9] Berg, J., J. Mann, A. Bechmann, M. Courtney, and H. Jørgensen. 2011. «The Bolund experiment, Part I: Flow over a steep, three-dimensional hill». Boundary-Layer Meteorology, vol. 141, no. 2, p. 219–243. Bechmann, A., Sørensen, N. N., Berg, J., & Réthoré, P-E. M. 2011. «The Bolund Experiment. Part II: Blind Comparison of Microscale Flow Models». Boundary-Layer Meteorology, 141(2), 245-271. 10.1007/s10546-011-9637-x

5.2 Snow

According to NPI, there is very little snowdrift around buildings at Troll. This is likely because the most frequent wind comes from northeast and passes over approximately 1 km of rocky ground snow free. With solar panels mounted on building roofs, snow accumulation is considered to be limited and can be removed by simple maintenance. Snowdrift can however be a relevant problem if the PV plant is placed on the glacier west of the base or on rocky ground northeast of the base.

Sandblasting of equipment is reported as a problem at the station. The reason for this is that sand and stones are picked up by the wind and hit the buildings. This is particularly prevalent with high wind speeds from the northeast when air passes over the graveled area. The phenomenon decreases west of the buildings. This sandblasting problem is considered smaller northeast of the base.

Considering the glacier northeast of the station as the location for the PV plant, snowdrift can accumulate because of the air flow under the PV modules and the snow particles the air can carry. Snow particles move when the threshold friction velocity (for a defined type of snow), u_{*t}, is higher than the air friction velocity u_* over the surface. The snow threshold friction velocity describes how volatile snow particles are, and varies from 0.05 m/s for fresh snow to 1 m/s for packed snow/ice.

Snow accumulation under the PV modules can be prevented by an adequate elevation of the panels from the ground. This is studied by CFD simulations with an example of 16 rows of panels. The panels are 1 m wide and tilted 15° from horizontal, with 1 m between rows.

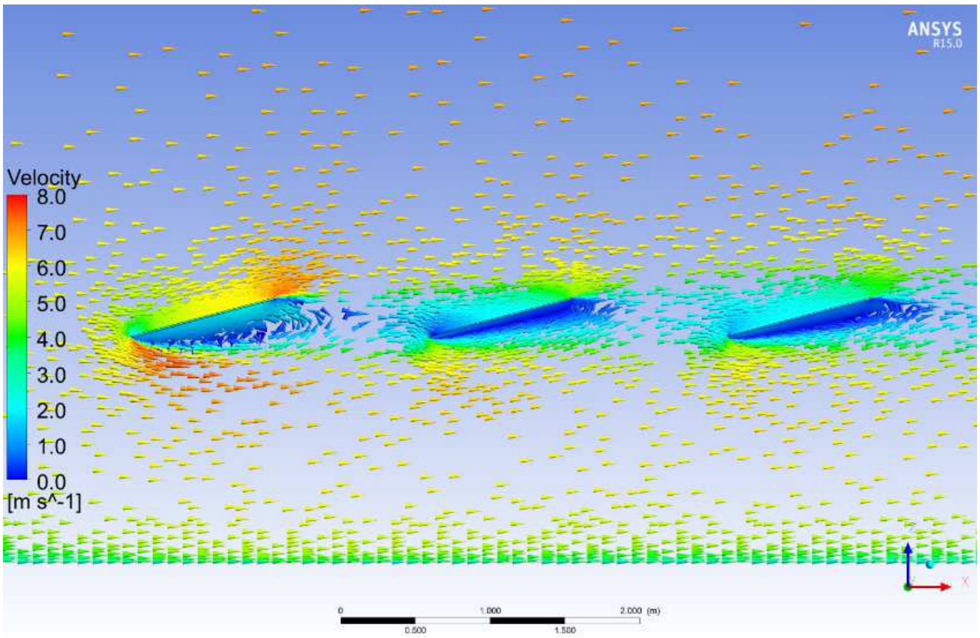


Figure 12: Wind simulation under PV modules.

Figure 12 above shows a section of the wind pattern around 3 of the 16 simulated rows of PV modules. The wind speed is set at 8 m/s (at 10 m elevation).

Figure 13 shows the variation of relative friction velocity along the rows of PV modules for different distances between ground and modules (h), i.e. 0.5 m, 1.0 m and 1. 5 m. Snow threshold friction velocity (u_{*t}) is set at 0.4 m/s (corresponding to snow at a wind-hardened surface). Values of relative friction velocity (u_*/u_{*t}) lower than 1 m/s indicate snow accumulation. Values higher than 1 indicate snow erosion.

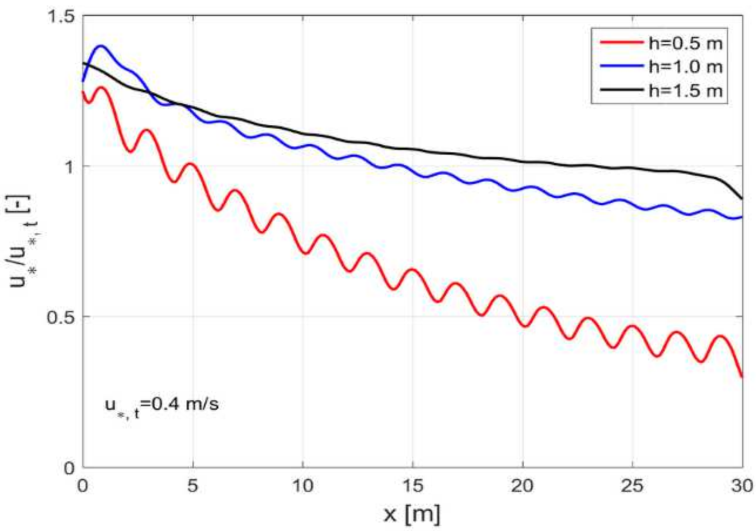


Figure 13: Relative friction velocity under 16 rows of PV modules with variable distance between ground and modules.

Based on simulations we can assume that, with a distance between ground and modules of 1.5 m (black curve), 14 rows of PV modules can be mounted without snow accumulation occurring (with wind speed at 8 m/s). With 1 m between ground and modules (blue curve), the number of rows is reduced to 9.

6 Economical Assessment

With increased deployment and new technological advances, the overall cost picture for installed PV is decreasing constantly. The last 3 years, for example, system costs decreased by almost 70%. Costs have more or less come to a stabilized level, but the trend is still downward. In addition, the price of batteries have fallen by around 14% annually from 2007 to 2014 and will probably continue to fall.

Investment costs for this project apply to the report date (winter 2015). A PV plant being built sometime in the future will probably benefit from lower investment costs.

Table 3: Key figures investment costs.

Variant	Pilot Project	Without storage	With storage
Type of PV cell	mono-Si	poly-Si	mono-Si
Efficiency PV module [Wp/m²]	192	158	186
Number of PV modules	24	60	2 500
Installed capacity [kWp]	7.56	15.6	762.5
Area PV array [m²]	39	99	4,100
Specific yield [kWh/kWp.year]	1,040	1,207	1,100
Energy production [kWh/year]	7,862	18,826	838,455
Investment cost [NOK/Wp] (w/o VAT)	33.8	33.8	100
Total investment cost [NOK] (w/o VAT)	255,528	527,300	76,250,000

NPI state that the diesel consumption is around 3.43 kWh/litre. By assuming diesel cost to be approximately 45 NOK/litre[10] and adding 15% for operation and maintenance of the generator set (in order to obtain an equivalent to the levelized cost of electricity), the energy cost is approximately 15 NOK/kWh.

Investment cost of the system without storage is based on the actual offer for the pilot project (33.8 NOK/Wp).

If this project will be realized, it will be the first PV system of this type (size and conditions). There are therefore few references to similar projects, but the investment cost has been assessed to 100 NOK/Wp or lower. Costs include equipment (PV modules, mounting system, inverters, cables, batteries, etc.), transport and installation. Transport to Antarctica is based on 8 containers, at 300,000 NOK per container. For comparison, smaller systems of the same type have been installed in Norway at 60 - 80 NOK/Wp. Larger systems can benefit from economies of scale and be cheaper per installed capacity, but transport to Antarctica will contribute to higher costs.

An LCOE[11] calculation has been made for the system including storage. The levelized cost of electricity is a measure of a power source that attempts to compare different methods of electricity generation on a comparable basis. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime.

Table 4 gives simplified figures to help assessing the economy of the project.

Table 4: Comparison energy costs diesel / PV. LCOE.

	Diesel	PV
Levelized Cost Of Electricity [NOK/kWh]	15	7.40[12]
Savings [MNOK/year]		12.5
Estimated ROI[13] [years]		6.1

[10] NOK: Norwegian Krone (1 USD ≈ 8.36 NOK, July 2016)

[11] LCOE: Levelized Cost Of Electricity

[12] LCOE inputs: lifetime 25 years, linear degradation PV 0.4%, discount rate 4%, incl. 1 change of inverters and batteries.

[13] ROI: Return On Investment

7 Pilot Project

NPI mounted a pilot project in order to collect data about both production and weather resistance during the southern winter 2016. The pilot project consisted of the equipment listed in Table 5 below.

Table 5: Key figures pilot project.

Model PV module	LG315N1C-G4
Type of PV cell	mono-Si
Rated power PV module [Wp]	315
Dimensions PV modules [mm]	1,640 x 1,000
Area PV module [m²]	1.64
Efficiency PV module [Wp/m²]	192
Azimuth [°/North]	20 / -160
Tilt [°]	10
Number of PV modules	24
Installed capacity [kWp]	**7.56**
Area PV array [m²]	39.4
Model inverter	Fronius Symo 3.7-3-M
Number of inverters	2

The pilot project is mounted on top of a set of containers (sleeping modules).

Figure 14: Pictures pilot project. Source: NPI.

8 Conclusion

Considering the latitude, Troll Station's location benefit of a high solar energy yield, due to favorable solar resources in combination with low temperatures and high albedo (reflected light). Simulation results show that a system combining solar power (app. 762.5 kWp) and electricity storage (app. 3,840 kWh) would thus cover more than 50% of the annual energy consumption at Troll Station. Even though the investment costs of such a system will be very high (approximately 76.25 million NOK at 2015 level), it will represent significant fuel savings (app. 12.50 million NOK per year). The estimated cost of electricity of the renewable energy system over its lifetime is 7.40 NOK/kWh, which corresponds to half of today's energy cost for diesel generation (15 NOK/kWh). In addition to making Troll Station cleaner and greener, solar power is also highly competitive and profitable.

It is recommended to design the system with PV modules of high quality, which can withstand harsh climatic conditions, and Lithium-ion batteries, which have a lower self-discharge than conventional batteries, and do not suffer from the "memory effect" and therefore do not need to be fully discharged before recharging.

When looking for the best location for the PV plant at the station, it is important to limit wind load, snow accumulation and sandblasting. Placing PV modules on existing roofs most likely provides the lowest climatic stress. Snowdrift is not a significant problem around the buildings. If the PV plant is ground-mounted, it will be prudent to utilize areas naturally shielded by terrain. A possible location has been identified 5 km northeast of the station. There, problems linked to sandblasting will likely be reduced due to the wind direction. The design must take into account sufficient distance between the ground and the modules in order to avoid snow accumulation.

The existing diesel generator system is over-dimensioned, also for periods of the year when there would be no contribution from solar energy. It is therefore recommended to consider another generator configuration in order to achieve a more energy efficient operation (alternative: 4 x 100 kVA).

Operation of the pilot project through the southern winter 2016 will give NPI useful data about both PV production and climate adaptation. This information will be valuable in assessing in detail the potential for implementation of larger PV capacity with storage.

The long-term aim for Troll Station is to become completely independent from diesel for electricity production. This would imply storing solar energy from the summer through the long Antarctic winter. That could be achieved by water electrolysis combined with hydrogen storage and fuel cells for example.

9 Authors

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