Photovoltaic production for a fixed tilt plane, with different surface azimuth angles. Analyzing system operating conditions and time of day production.

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Abstract

Photovoltaic systems for residential household may be a large part of energy production in the future. The electric grid is facing challenges, and photovoltaic systems can contribute in the reduction of electric grid load by adjusting the orientation of the photovoltaic panels. This report investigates the effects orientation has on a photovoltaic system, considering; time of day production, operating conditions and geographical location. Several simulations have been done where these factors were exanimated. The results presented in this report were induced by the use of a simulation tool called PVsyst. In this program, a photovoltaic system has been designed in order to investigate different orientations of Photovoltaic systems, and the consequence of moving the orientating from directly south into east and west orientation. The result presented in the report discovered that geographically, a more southern locating gives a higher year-round production. However, during the summer, a northern location can have higher production on clear days. East and west oriented system results in a wider production graph during the day, avoiding large production peaks. As the results of this report presents, this does not make up for the lacking production compared to a south oriented system, and with the current energy prices, the recommended orientation is south. However, a changing energy price may lead to a disadvantage to a south oriented system, making it less profitable in the future, in which case this recommendation of the system orientation should be re-evaluated.

Preface

Over the course of my education, which has been focused on energy technology and renewable energy, I have worked up an interstress in clean energy and the utilization of the sun. This motivated me to write my thesis on the application of solar cells. The target group is for people with an interest in energy production using solar cells, and people who are considering installing a PV system on their home roofs. I would like to thank Mohan Lal Khole for supervising this project, and Solcellekraft AS for good insight and necessary data for the PV system.

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Nomenclature

Abbreviations

PV	Photovoltaic
UIA	University of Agder
AMS	Advanced measuring system
kWh	Kilowatt hour
Wp	Watt peak
Kr	Norwegian kroner
NVE	Norges Vassdrag- og enregidirektorat
LCOE	Levelized cost of electricity
TLCC	Total life cycle cost
PVsysts	Photovoltaic software
MPPT	Maximum power point tracking

Symbol

h	Planck's constant
v	Frequency
Isc	Solar constant
Hg	Daily radiation on horizontal surface
Ho	Daily radiation
n	Day of the year (starting at 1 01.01)
rb	Beam tilt factor
rd	Diffuse tilt factor
rr	Reflected tilt factor
It	Total irradiated flux
Qn	Annual energy output
d	Discount rate
N	Expected lifetime
Cn	Annual cost
X	Efficiency loss

1 Introduction

1.1 Background

Photovoltaic or PV installations in the northern part of Europe are less popular than in the more southern parts of Europe [1]. The lack of irradiation in the north may cause a belief that countries in the northern latitudes does not have enough irradiation to make a PV system commercially viable. Although it is true that southern countries such as Spain, France and Italy have far better irradiation, the northern countries have advantageous temperatures. When the temperature in the solar cell decrease, the efficiency increases. This increase in efficiency, may make up for some of the lacking irradiation.

The production of a PV system is dependent on how the system is set up. Tilt of the panel, orientation and location are deciding factors that determines how much energy a system will produce throughout a year. This report investigates a system with a fixed tilt plane at a predetermined location, where the orientation of the system is changed. It is expected that a south oriented system will have the highest production because the sun moves from east to west. This gives a south oriented system the best irradiation exposure for solar production. The impact of the orientation on the PV production will be investigated, and this report aims to evaluate whether there are cases where other orientations can compete with directly south facing PV systems.

Scientists generally agree that the environment is changing, and that the world must change with it. Meeting the worlds energy demand using oil, coal and gas, is no longer a viable option. Other sustainable energy sources must replace the “dirty energy”, that the world is dependent on today. The need for energy is increasing, and every year a noticeable rise in consumption is recorded. During the last 20 years, energy consumption has increased by 40%, and there is no indications of a reduction in energy consumptions in the near future. [2]. Figure 1 presents an overview of the increase in global energy consumption throughout the last centuries.

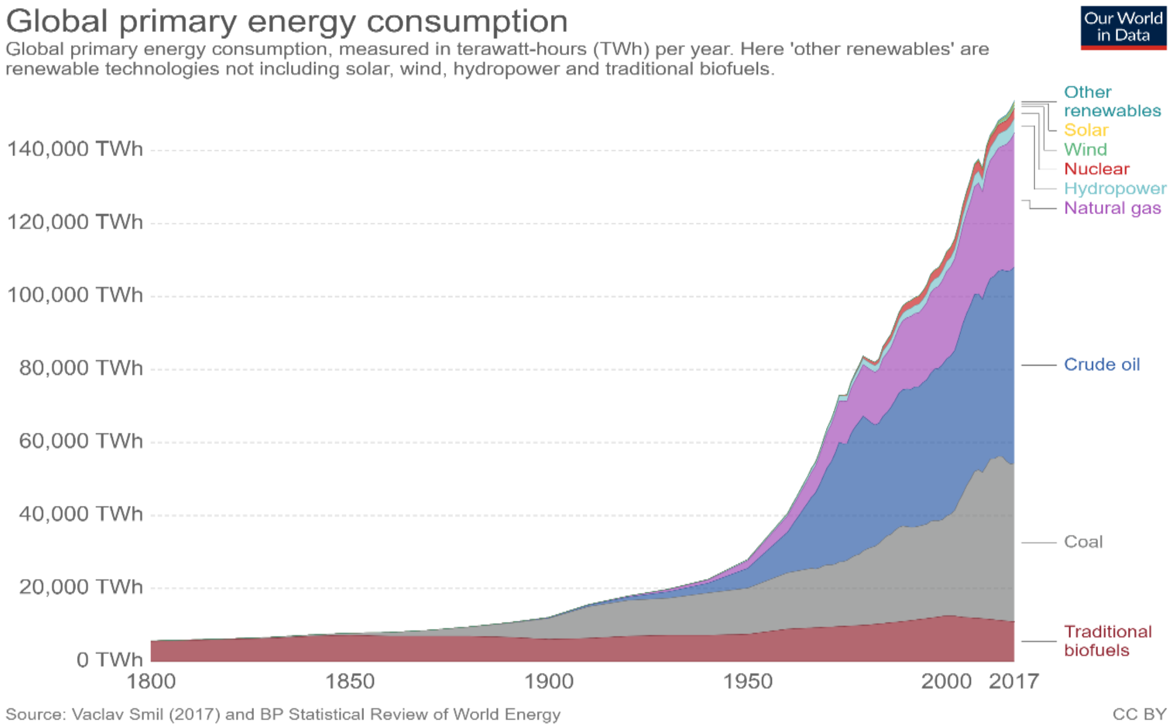


Figure 1 An overview of the increasing energy consumption, including the energy source in the period: 1800-2017 [2].

Renewable energy sources such a PV and wind are somewhat unpredictable. Unlike hydro- or coal power plants, the energy production from PV systems or wind turbines cannot be controlled by demand. This downside can lead to unwanted energy production at unfavourable times. There are several recorded cases where the energy price in Denmark has been negative, meaning the consumer got paid to use energy due to a peak in wind velocity. On the night of 17 march in 2018, the energy price in Denmark was negative for 7 straight hours [3]. This is a good argument for adjusting the time of day production if possible, which can be as simple as adjusting the PV panels in a more east and west direction as opposed to directly south.

In the last decades, an increase in the global economy and population has led to a boost in urbanization. This has caused a significant change in energy demand, which must be dealt with accordingly. A higher energy demand, at a more focused area, also causes issues of city pollution. Energy consumed in buildings by heat, ventilation and other electrical appliances account for approximately 32% of final global energy use, 19% of energy related greenhouse gas emissions, and 51% of global energy consumption [4]. Utilizing rooftops to extract a portion of the energy irradiated from the sun, will assist other energy sources to meet the demand for energy in buildings.

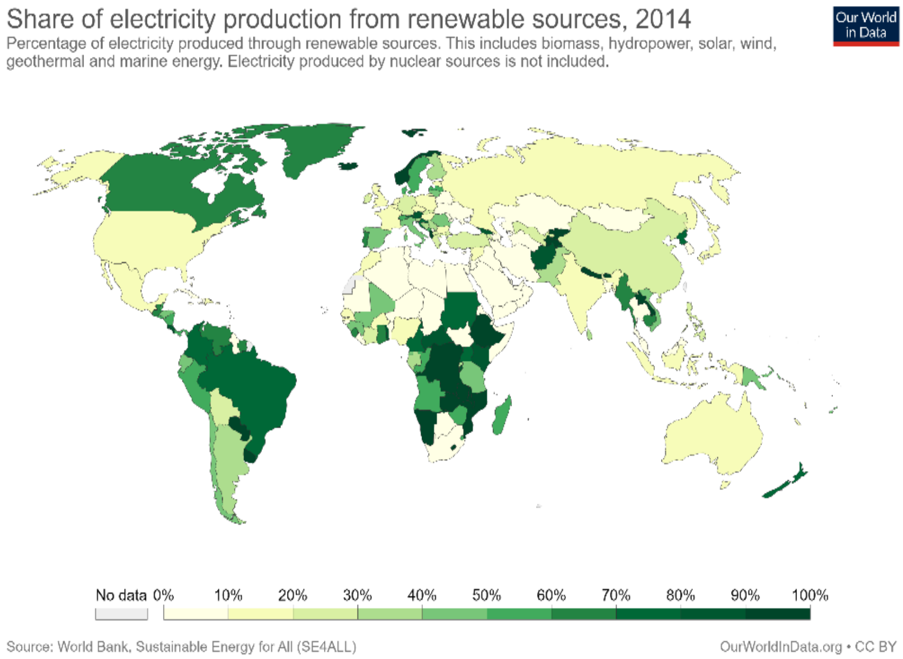


Figure 2 Share of electricity produced from renewable energy sources, as shown above, Norway is at 100% using mostly hydro power [2].

This report investigates the correlation between PV production and the orientation of solar panels in Norway, a country which can mostly supply its entire population with renewable clean energy from water reservoirs. However, this is not always the case. Hydro power plants in Norway are run like any other business, where power companies sell a large portion of the power produced when the price of energy is high, resulting in higher profits. This leads to a massive export of clean energy to other parts of Europe. The consumer in this case, is left buying energy which may origin from coal, gas or other "dirty" sources. Thus, a country like Norway cannot be satisfied with the high amount of "clean energy" it produces, when the origin of consumed energy is not necessarily environmentally friendly. Norway needs to explore, develop and exploit other renewable energy sources, so that one day, the world may exclusively rely on clean and renewable energy [5].

The initial cost of a PV system has drastically decreased over the past decades. In combination with a higher focus on environmental related challenges, the PV industry is experiencing a small scale revolution. Just in the new millennium, the PV installed capacity in the world has increased from a small and negligible production in the year 2000, into an impactive production of 404,5 GW in 2017. As of yet, Norway is currently lagging behind, and has not yet taken part in the revolution. According to an article by muliconsult (2018), the combined production of installed PV power in Norway is 68 MWp [6], a small percentage of the global total. However, new research shows that the popularity of PV systems in Norway is increasing. In the period of 2017 to 2018, the intalled PV power increased by 29%. Enova recorded 837 new PV installations in 2018, which is an significant increase in comparison to the 145 recorded installations in 2016 [7].

Figure 3 and 4 indicates the boost in PV installed power over last decade. This developent show no indication of slowing down, and the future of PV systems is looking promising. Due to lower price per Watt intalled, and an larger consern with regard to the enviorment, PV power production may have a bigger impact in the future of energy supply.

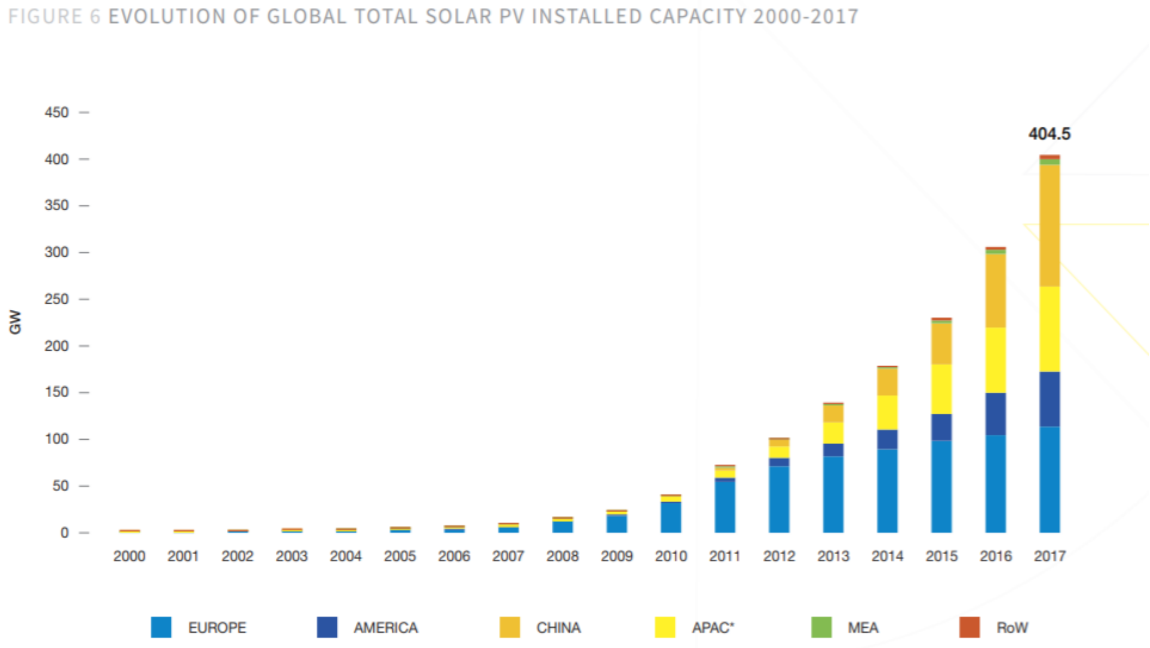


Figure 3 The graph above shows how the PV installed power has improved in the twenty-first century [8]

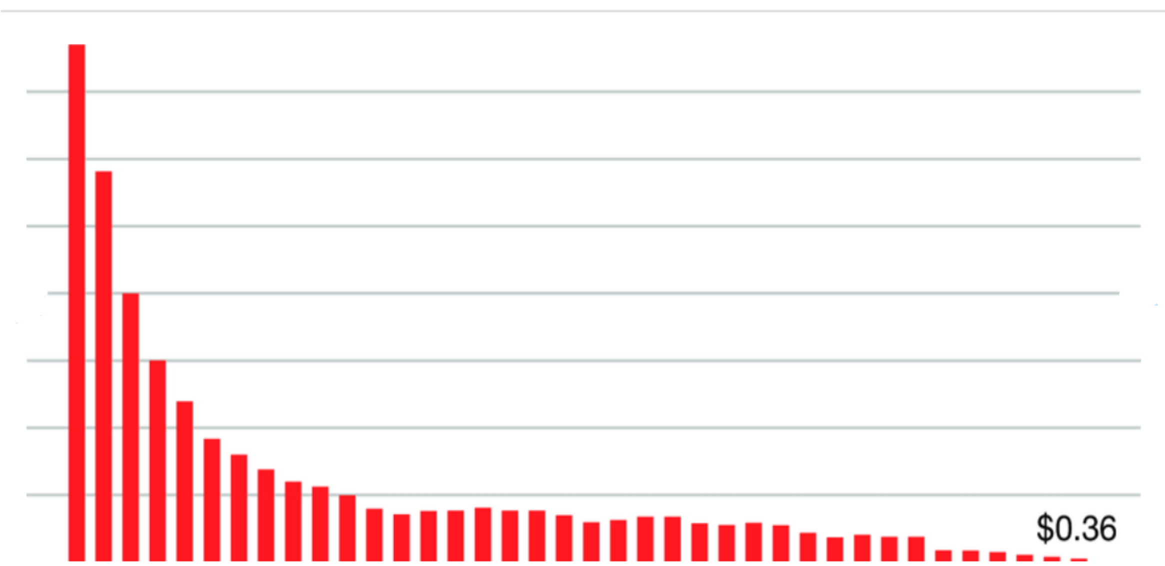


Figure 4 The graph above demonstrates how the prices for PV power has decreases over the last 37 years, from about 100$ per watt in 1977, until 0.36$ per watt in 2014 [9].

1.2 Solcellekraft AS

This report is carried out by the initiative of Solcellekraft As. Which is a company that installs complete PV systems on houses and industrial buildings. Solcellekraft AS receives daily requests from households, interested in the potential of PV power production on their corporate or private roof. The company has its own website and sales team that offer information about products and installations. Over the course of 2018, Solcellekraft AS delivered approximately 40 PV systems distributed throughout Norway, and during first quarter of 2019, Solcellekraft AS installed about 30 system. This is evidence of a significant increase in the popularity of solar systems. Solcellekraft AS offers all the components required for a functioning PV system, including installation and connection of the system to the electric grid. Figure 5 shows one of the many systems installed by Solcellekraft AS in February 2019.

Figure 5 Housed equipped with solar panels supplied from Solcellekraft AS

NVE believes that the power grid in Norway is fragile and is expecting power tariffs in the future. The tariffs will be an added cost for the consumer, adding a fee per kWh consumed. These tariffs will make the production time of day more important than earlier, at least from a financial point of view. Therefore, Solcellekraft AS wants to investigate the potential of power production using different panel orientation, as well as the financial aspect of installing solar panels oriented towards east and west, rather than directly south. This to maximize the production at more favourable times of day, where the price of electricity tends to be higher. Installing panels facing east and west as opposed to directly south, may reduce the overall production during the year. However, the production during morning and evening may increase, resulting in higher value per unit of power. Solcellekraft AS is a countrywide supplier of PV systems, thus the company asked that different geographic locations are considered in the report [10].

1.3 Topics to explore

This report takes a closer look in to the orientation of solar panels, using several case studies with possible tariffs. Because Norway is a long country with greatly varying solar conditions, solar movement and irradiation conditions in the southern, eastern, western and northern part of the country are investigated. The following topics will be addressed in this report:

- How much electricity is produced with PV systems oriented to the south, as opposed to east and west, and how is the energy production distributed with regard to time of day?
- How will potential tariffs from NVE influence the profitability of power production during the morning and evening?
- How does the solar conditions change with geographical differences, and to what degree does it influence the overall power production and time of day production?
- What changes in power production can be expected if the surface azimuth angle (orientation) is adjusted?

1.4 Scope of work and limitations

- The case studies presented in this report are heavily dependent on statistical weather data. Thus, the results have a level of uncertainty with regard to future weather conditions.
- There are several different PV system designs available on the market. This report is written in collaboration with Solcellekraft AS, and the case studies are based on data provided on systems in their portfolio.
- Due to the scope of the thesis, calculations regarding solar radiation and cell technology is covered to a limited degree.
- The case studies presented are also dependent on energy prices, which is constantly changing. This factor limits the accuracy of the energy price utilized throughout the financial analysis in this report.

1.5 Thesis structure

Section1: The introduction gives the reader an insight in the background for this thesis. Why this topic is explored and some basic information about circumstances around the thesis. It also mentions some of the question this thesis is intended to answer.

Section2: Theory review will give the reader more information about the topics of the thesis. This section will give the reader some basic knowledge around the subject.

Section3: Methodology will give the reader insight in how the experiments are done and which assumptions are made. This section includes simulation tool and specifications around this.

Section4: Results and discussion will provide the reader with concrete results from the simulated cases studies. It will also include a discussion, which gives the reader some reflections around these results.

Section5: Conclusion and further work help the reader to sum up the thesis. This chapter also includes a recommendation based on results and discussion.

2 Theoretical review

2.1 PV

Photovoltaic systems are designed to convert photonic energy from the sun into applicable electricity. This is done by using a specialized semiconductor diode with a large barrier which, when exposed to light, can produce a DC current. A PV system for a typical household will contain an inverter that convert the DC current into AC current, which can be used to supply most of the electrical appliances in the household.

PV systems in Norway are not as widespread as many environmentalists would want. High costs and small commercial potential have made PV system less attractive than other energy efficient solutions, such as heat pumps and waterborne heat. However, over the last few years, several firms have started selling complete PV systems for installations on commercial and private rooftops in Norway.

2.1.1 PV systems

A household PV system needs two main parts to function, namely a solar panel and an inverter. The systems can furthermore be divided into several other components. The complete packages that exist on the Norwegian market today normally consists of:

- Solar panels
- Inverters, cables and connections
- Mounting kit
- Monitoring system

The solar panels convert the photons in sunlight into DC current. The inverter converts the DC current into AC current at 50 Hz, which is electric grid quality current. The mounting kit is a series of rails and ceiling mounts, which secure the panel to the roof. The monitoring system is a simple wi-fi unit, which is connected to the internet as well as the inverter. This wi-fi unit can record the overall production at any given time and feed the data to a website or a smartphone application. If the PV system is connected to a storage system, the excessive power can be stored for future use. If the PV system does not have a storage system, the excessive power will be fed onto the electric grid, so that other households may absorb it [11].

Figure 6 gives a simplified overview of the components, and how they work together to produce electricity that can be utilized by the consumer.

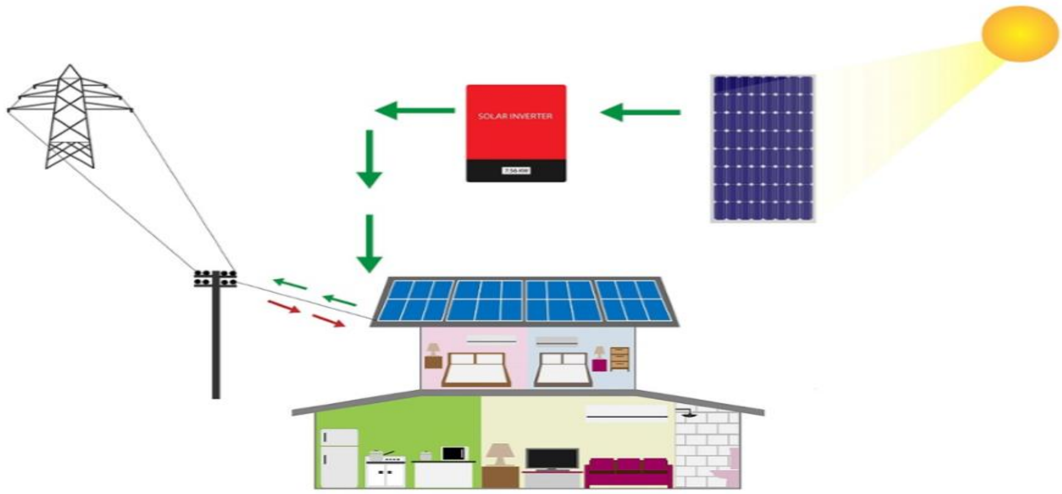


Figure 6 A PV system overview including the essential components to produce electricity. Showing the link: sun-panels-inverter-house grid-electric grid [10].

2.1.2 Solar tracking

PV systems can be equipped with a tracking solution. Solar tracking is a device that orients the solar panel toward the sun. This is to reduce the angle of incidence between the irradiated sunlight and the photovoltaic panel. There are several types of tracking, the most primitive being a "manual tracking system". This type of installation is equipped with a rotational neck which can be rotated by hand to follow the movement of the sun. There are more advanced tracking systems that can follow the motion of the sun by using sensors, and hydraulics to adjust both the tilt and orientation of the panel. This technology is not relevant for this report as it has high investment cost and is mostly suitable for large commercial solar plants [12].

2.1.3 PV Cell technology

Solar cells convert solar energy directly to electric energy, using the photovoltaic effect. The energy can be consumed continuously, stored in batteries, or fed onto the electric grid. During the production of solar cells, usually a semiconductor such as crystalline silicon is used. It is believed that nanotechnology can be used to increase the overall efficiency of the solar cells in the future [14]. The efficiency of a solar cells is a measure of how much of the incoming energy can be converted to electric energy. Typical efficiency data for solar cells today are approximately 16% for polycrystalline silicon and 18% for monocrystalline silicon.

Monocrystalline has the highest efficiency, but at a higher production cost. Polycrystalline is more cost efficient, but at a reduced efficiency per area compared to monocrystalline panels. This makes polycrystalline panels less relevant in cases of less available surface area. Polycrystalline panels are made from large blocks of molten silicon which is cooled and solidified, while monocrystalline panels are usually made of pure silicon which are doped with elements such as boron or phosphorus [13].

The majority of the solar cell market is dominated by crystalline silicon, approximately 80% of all solar panel production is using this technology [15]. Photons from sunlight reaches the panel, where the photons gets absorbed by a semiconducting material. The silicon is divided in two parts, n-doped and p-doped, these parts direct the current of electrodes [16].

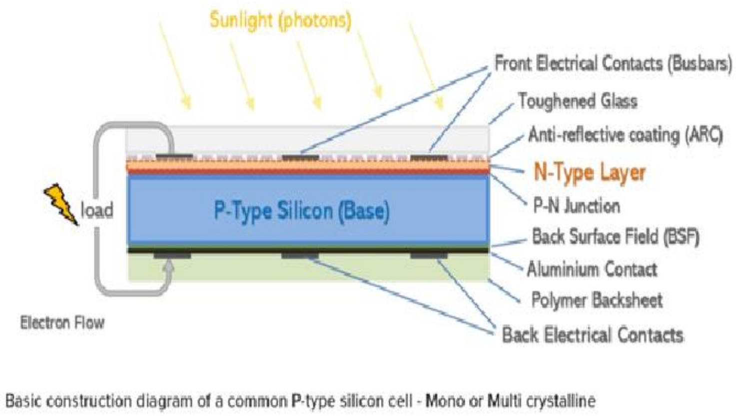


Figure 7 A illustration of a PV cell [15].

When the light arrives at the cell, some of the light may be absorbed by crystal, thus creating an electron-hole pair. The electron-hole pair is only generated by the light quanta where $h*v>E_G$. The electric field *E* in the barrier, separates this electron-hole pair. The electrons have a negative charge, which forces the electrons opposite to the field direction and thus accumulate in the n-zone. The holes migrate in the field direction to the p-zone thus creating an electric current [17].

2.1.4 Standard test condition (STC)

There are many different producers and suppliers of solar panels in the industry, these different panels need to be tested and evaluated with respect to each other. Thus, a standard test condition is determined in order to provide equal testing grounds for the different solar panel products. The standard test conditions sets some standard environmental conditions for testing of solar panels.

The standard test conditions are;

- Cell temperature, $T_c = 25°$
- Air mass ratio, AM = 1.5
- Solar Irradiation = 1000 W/m^2

2.4.5 Panel and inverter

Solar panels

Producers of solar panels often provides several types of solar panels, given the buyer a variety to choose from. According to Socellekraft AS the most popular solar panels on the market today is 300W monocrystalline and 275W polycrystalline. Table 1 gives a short overview of the electrical data comparison for two types of panel during STC.

Table 1 Electrical data for "Talsun solar" panels during STC. Same dimensions, but different type.

Type	**Polycrystalline solar module, 60-cell series**	**Monocrystalline solar module, 60-cell series**
Max power	275Wp	300Wp
Voltage at max power (Vmpp)	31.7 V	32.9 V
Current at max power (Impp)	8.69 A	9.12 A
Open circuit voltage (Voc)	38.7 V	39.7 V
Short circuit current (Isc)	9.17 A	9.58 A
Panel efficiency	16.8%	18.3%
Power tolerance (positive)	+3%	+3%

Inverter

There are several types of inverter systems, namely:

- **String inverter** is the most commonly used inverter, both in homes and in commercial power plants. With a string inverter, several modules are connected in series, which is then connected to the inverter. The disadvantages of using a string inverter is that the current flowing through the string is the same. As illustrated in table 1 the panels have a max current of 9.1A (300W monocrystalline panel). Therefore, the current varies between 0A – 9.1A, depending on the PV production. If two strings are connected in parallel, the current of those strings are added together. If a panel in the string produces a smaller current than the others, due to shading or other circumstances. This will not only restrict the production of the effected module, but the whole string.

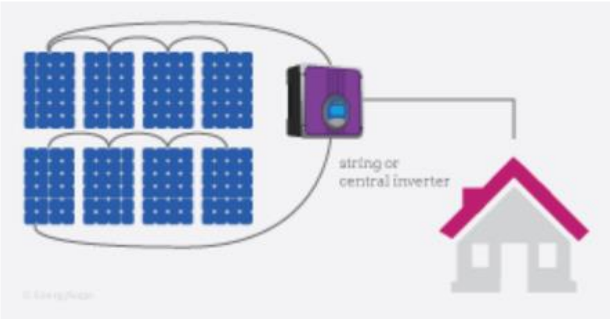


Figure 8 Visualisation of a string inverter system.

- **Microinverters** are useful for smaller PV installations. A microinverter is a small box installed on the back of one or two panels. Its mission is to directly convert the DC current from the panels into AC current utilized in the electric grid. This inverter does not have the same problem as a string inverter. If a module is affected by shading, it will not affect the rest of the system. Therefore, the other modules can produce at max power, even though one or two panels are exposed to shading, this will increase the overall efficiency of the system. The downside of microinverters is the high initial cost, making this only suitable for small PV systems.

Figure 9 Visualisation of a microinverter system

- **Power optimizer** is a hybrid between the two solutions mentioned above. Power optimizers are utilized in cooperation's with a string inverter. The power optimizer can be connected to 1-4 panels for each optimizer. The optimizer can be placed on panels which are exposed to shading in some parts of the day (commonly used around chimneys). These optimizers track the voltage and current of each MTTP and adjust its voltage accordingly, avoiding unnecessary "mismatch" losses to the system [18].

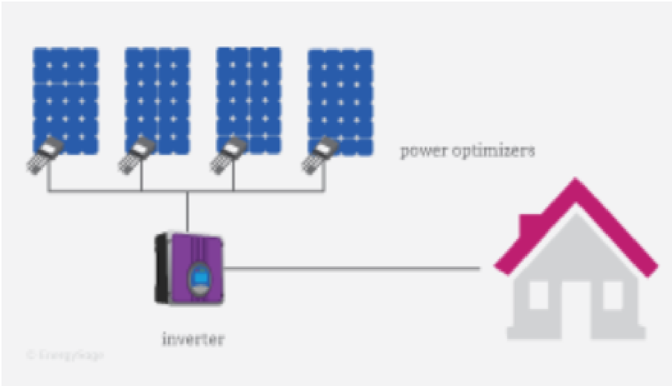


Figure 10 Visualisation of a power optimizer system

2.1.6 PV energy storage

Due to the inconsistency in power production for PV systems, the electricity must often be stored for later use. Despite a series of energy storage technologies, the existing solutions provide inadequate efficiency. For the large PV systems, where the powerplant is dimensioned to supply hundreds of households with energy, a molten-salt storage is commonly used. This storage system uses molten-salt to store energy in the form of thermal heat. However, this solution is only relevant for large scale power plants and is not applicable for energy storage in PV systems for residential households.

For small PV systems, the best way to storage energy is to utilize batteries. Lithium batteries has had an evolution in capacity and efficiency over the past 25 years, and the development is still going strong, where some sources predicts a future energy density of lithium batteries as high as $500W \cdot h \cdot kg^{-1}$ [19]. The prices of lithium batteries today do not justify installing a battery storage system for the common household, and given the status quo, it is more economic to sell excess energy to a power supplier [10].

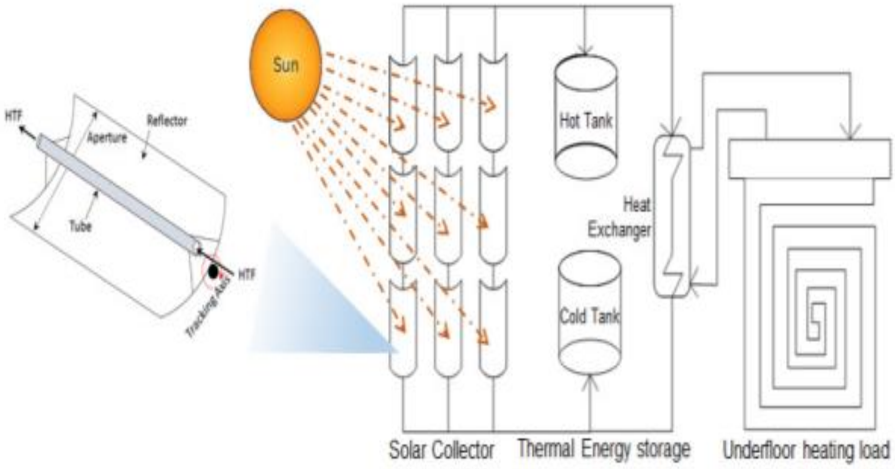


Figure 11 Illustration of a thermal storage system for a PV power plant. Commonly used in lager PV systems [20].

2 .2 Solar potential

2.2.1 Solar irradiation

The sun is a large sphere consisting of very hot gasses, which generates tremendous amounts of heat through various fusion reactions. The sun is constantly irradiating approximately 3,846x10^{26} W, where only a small percentage of the irradiation reaches the earth's surface. The specific rate of energy which is received at an area perpendicular to the rays of the sun is the solar constant I_{sc}. I_{sc} fluctuates over the course of a year and has a mean value of 1367 W/m^2. The maximum value occurs in January at 1414 W/m^2, and the minimum value is at 1322W/m^2 in July. The solar constant is the amount of energy which reach the edge of the atmosphere. The earth revolves around the sun with a small tilt, consequently the distance from the earth to the sun varies throughout the day. A new value which incorporates the angle to the sun, can be calculated at any given day of the year, by the use of equation 2.1.

$$Isc' = Isc\ (1+0{,}033\cos(\frac{360n}{365})) \qquad (2.1)$$

Where n is the day of the year, starting with n=1 the first day in January, hence n=365 the last day in December.

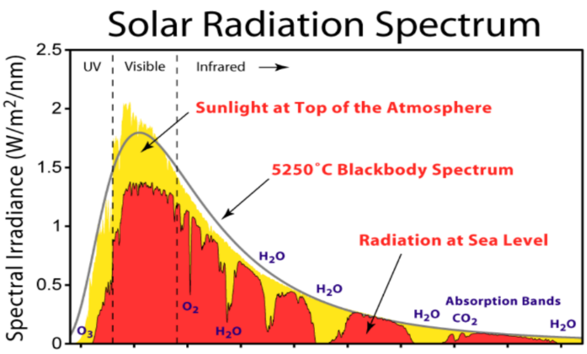


Figure 12 Spectrum of solar radiation, including; top of the atmosphere and sea level. Graph from Wikipedia.com

2.2.2 Earth's movement

During the summer, the tilt from the earth's axis is inclined towards the sun, while during the winter, the tilt is inclined away from the sun. This is known as solar declination (δ). The declination varies from a maximum value of 23.45° on june 21, to a minimum value of -23.45° on decemeber 21. The elevation of the sun is not constant throughout the year, and it depends on longitude and solar declination. These two factors determine how much total irradiation is sent to the surface of the earth at a given geographical location.

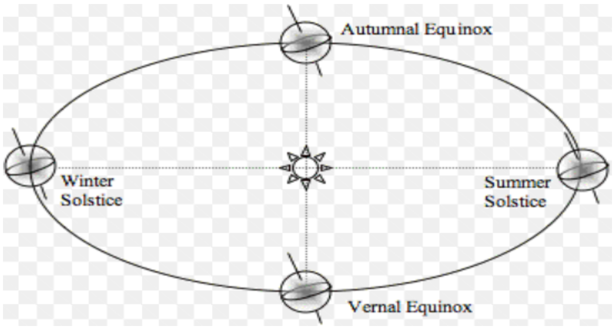


Figure 13 Earth's orbit around the sun, showing the position and tilt of earth at all seasons.

This Declination can be caluculated by equation 2.2;

$$\delta(\text{in degrees}) = 23.45° \sin\left[\frac{360}{365}(284+n)\right] \tag{2.2}$$

2.2.3 Angles to help describe irradiation

The sun rises in the east and sets in the west. In addition, the suns position in the sky moves from north to south throughout the year. An analysis of the suns position, would reveal that the angle of the suns highest point is changing every day. The exact angle and position of the sun is determined by time of day, longitude and day of year. These factors affect the design of a PV power system, especially if the system is without tracking. In this thesis, part of aim is to determine the impact orientation will have on solar production, and which orientation will lead to the highest production throughout the year. Figure 14 and 15 show relevant angles for the module setup and orientation.

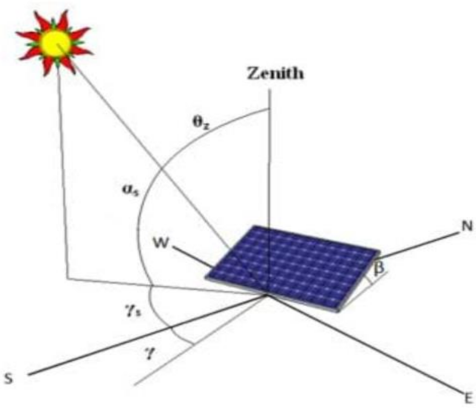


Figure 14 Relevant angles for a PV setup, giving the angles necessary to determine irradiation. θ_z is the zenith angle, α_s is the altitude angle and γ_s is the azimuth angle [21] .

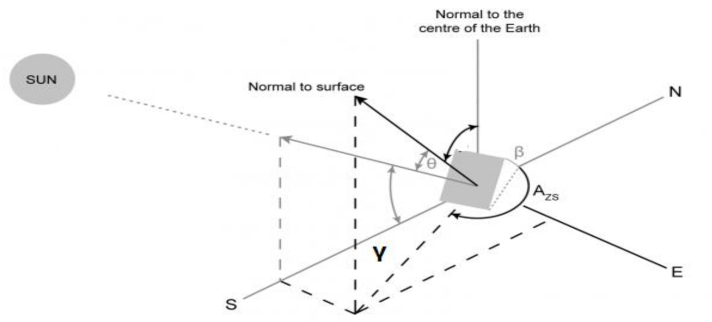


Figure 15 Angles which describe the module setup. ß is tilt of the panel while is the θ angle between the sun and the normal to the panel *[22].*

Angles and formulas that describe the suns position in the sky.

- **Zenith angle, θ_z:** The angle between the line that points to the sun and the vertical line. This represent where the sun is in the sky. At sunrise, this angle is at 90°.
- **Altitude angle, α_s (Sun height)**: The angle between the line that points to the sun and the horizontal line. At sunrise, this angle is at 0°
- **Azimuth Angle γ_s (Sun position)**: The angle between solar position and the horizontal south. This angle is measured in the horizontal plane and is close to -90° at sunrise, and close to 90° at sunset, depending on the season.

Angles that describe beam radiation to a tilted plane at a certain location:

- **Angle of incidence, θ:** The angle between the line that points to the sun and the line normal to the panel.
- **Hour angle, ω:** The suns angular displacement, eat or west. The rotation of the sun is 15° per hour. At 11:00 the angle is -15°, at 12:00 the angle is 0°, and at 13:00 the angle is 15°.
- **Surface azimuth angle, γ (orientation):** The angle between the normal to the panels and south. The angle is measured in the horizontal plane. This angle is 0° when panels are pointed south, 90° for west and -90° for east.
- **Collector slope, β:** The angle between the panel and the horizontal. When the panel is flat to the ground, the angle is 0°.
- **Declination, δ:** The angle between the line that points to the sun and the equator.
- **Latitude, φ:** The angle north or south of equator.
- **Profile angle:** The angle between the normal to the panels and the rays of the sun perpendicular to the panels plane.

Using angles from this subchapter, an average daily global radiation on a horizontal surface can be calculated by equation 2.3.

$$Hg = a + b\left(\frac{hours\ of\ sunshine}{\frac{2}{15} * \cos^{-1}(-tan\,\phi\,\tan\delta)}\right) * Ho \qquad (2.3)$$

The a and b are constants for specific location on earth. Ho is the daily radiant and can be calculated by equation 2.4.

$$Ho = \frac{24*3600}{\pi} * Isc * \left(1 + 0.033 * cos\frac{360n}{365}\right) * (cos\phi * cos\delta * \sin\omega + \frac{\pi*\omega}{180}\sin\delta\,\sin\omega) \qquad (2.4)$$

Where Isc is the solar constant.

The hour angle can be calculated by equation 2.5.

$$\omega = \cos^{-1}[-\tan(\phi - \beta)\,tan\delta] \qquad (2.5)$$

2.2.4 Earth's absorption

The energy irradiated from the sun is attenuated by scatter, reflection and absorption. Hence the global irradiance G_H, on the horizontal plane $G_{H,}$ is significantly smaller than the total extra-terrestrial irradiance G_{ex}. G_{ex} is the irradiation above the atmosphere, while G_H, is the irradiation which reaches the surface. G_H is always smaller than G_{ex} due to a large loss of energy as the irradiation passes through the atmosphere. About 29 % of the energy is reflected by the atmosphere, 23 % is absorbed by the atmosphere, and 48 % is absorbed by earth's surface [23]. This shows that 71 % of the total irradiation is absorbed by earth's system, which indicates that the earth must irradiate 71 % to space for the earth to maintain its energy balance and avoid further global warming.

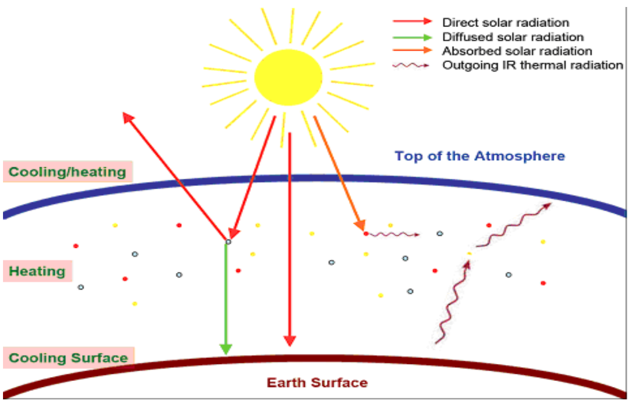


Figure 16 Overview of the attenuated irradiation from the sun [40].

2.2.5 Irradiation at sea level

The irradiation to a tilted plane at sea level is composed of direct beam irradiation, diffuse solar irradiation and diffuse reflected irradiation. The direct beam irradiation R_B is determined by inclination angle β, azimuth γ and the latitude φ.

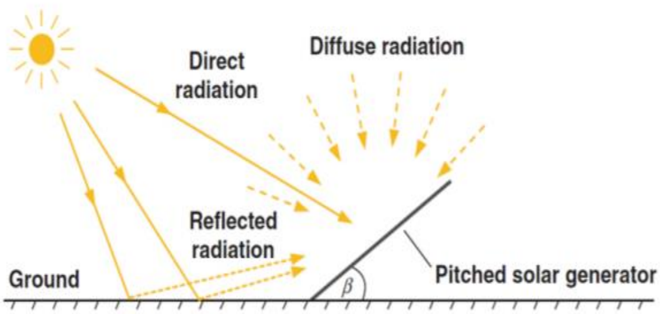


Figure 17 Illustration of the three irradiation types at sea level. Direct-, diffuse- and reflected irradiation. Source: PV system and design practice.

Direct irradiation

As the irradiation from the sun passes through the atmosphere, the overall power is reduced. This is due to reflection, absorption by molecules and scattering from impurities in the air. The amount of reduction in overall energy is determined by air mas (AM). Due to earths movement in relation to the sun, the distance from the earth to the sun varies throughout the time of day and day of the year, this affects the air mass ratio, which is an indication of which inclination the sun has at a given point of the day. The air mass is AM0 at the edge of the atmosphere and AM1 when the sun is perpendicular to the earth. In the standard test condition, the air mass is always AM1.5.

$$AM = \frac{1}{Cos\ (\gamma)} \qquad (2.6)$$

Where γ is the zenith angle.

The ratio of the beam irradiation flux on a tilted surface is called the *tilt factor*, this is shown by $r_{b;}$

$$rb = \frac{\cos\theta}{cos\theta z} = \frac{sin\delta \sin(\phi - \beta) + cos\delta \cos\omega \cos(\phi - \beta)}{sin\phi\ sin\delta + \cos\phi \cos\delta \cos\omega} \qquad (2.7)$$

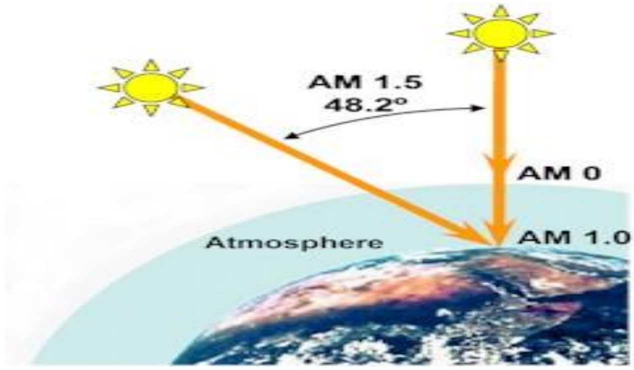


Figure 18 Showing the sun angle at AM1.5 (STC) [24].

Diffuse irradiation

The sunlight which reaches the earth surface after being scattered in the atmosphere is defined as diffuse irradiation. While direct irradiation is travelling in a certain direction, diffuse irradiation is scattered in several directions. In direct irradiation, all rays travel in the same direction, and if this path is blocked, shading will occur.

The tilt factor for diffuse irradiation (r_d), is the ratio diffuse irradiation is reaching a tilted surface, this can be given by equation 2.8

$$rd = \frac{1 + cos\beta}{2} \qquad (2.8)$$

Reflected irradiation

The sunlight that is reflected on any surface is described as reflected irradiation. The amount of energy reflected depends on the surface material and area. Some material has a higher reflection value than others. Asphalt has a low reflection factor, while snow and water have a high reflection factor.

The reflected irradiation factor for a tilted surface is given by $r_{r,.}$ Assuming that the reflected irradiation is diffuse and isentropic, and that the reflectivity is ρ, the tilt factor is be given by equation 2.9.

$$rr = \frac{\rho(1 - cos\beta)}{2} \qquad (2.9)$$

Total irradiation on tilted surface

The flux of direct beam irradiation and diffuse beam irradiation; is given by I_b and $I_{d.}$ The total flux on a tiltied surface is calulcated by equation 2.10.

$$IT = Ib * rb + Id * rd + (Ib + Id) * rr \qquad (2.10)$$

The ratio of the flux falling on a tiltied surface at any given instant is given by equation 2.11.

$$\frac{IT}{Ig} = \left(1 - \frac{Id}{Ig}\right) * rb + \frac{Id}{Ig} * rd + rr \qquad (2.11)$$

2.2.6 Geographical variations

Resource base is mostly dependant on solar irradiation on the given location, and in the sunniest places in the world, this value can reach approximately 2500 kWh/m^2/year. In Norway the irradiation varies from approximately 1000 kWh/m^2/year in the south, to approximately 700 kWh/m^2/year in the north [25]. Mainly the longitude determines the intensity of solar irradiation. Seasons, local weather and diurnal will also play a part in this. Nevertheless, the main circumstances which decides whether a location is suitable for a solar installation, is mostly dependent on inclination angle, sky direction and shielding from vegetation and mountains.

Norway is relatively small country but very long for its overall size. The length of Norway leads to high variations when it comes to climate and sun conditions. The difference between the far south and the far north can be quite substantial. During the winter in the far north, the sun never clears the horizon, and during the summer in the far north, the sun never sets. The summer and winter in the far south are much closer to other northern European countries such as Sweden, Denmark and Germany, having warm summers and cold winters. As shown in figure 19 the solar irradiation in Oslo is not much different than to that of other major cities in Europe, despite the popularity of solar cells in these cities being far higher than in Norway [1].

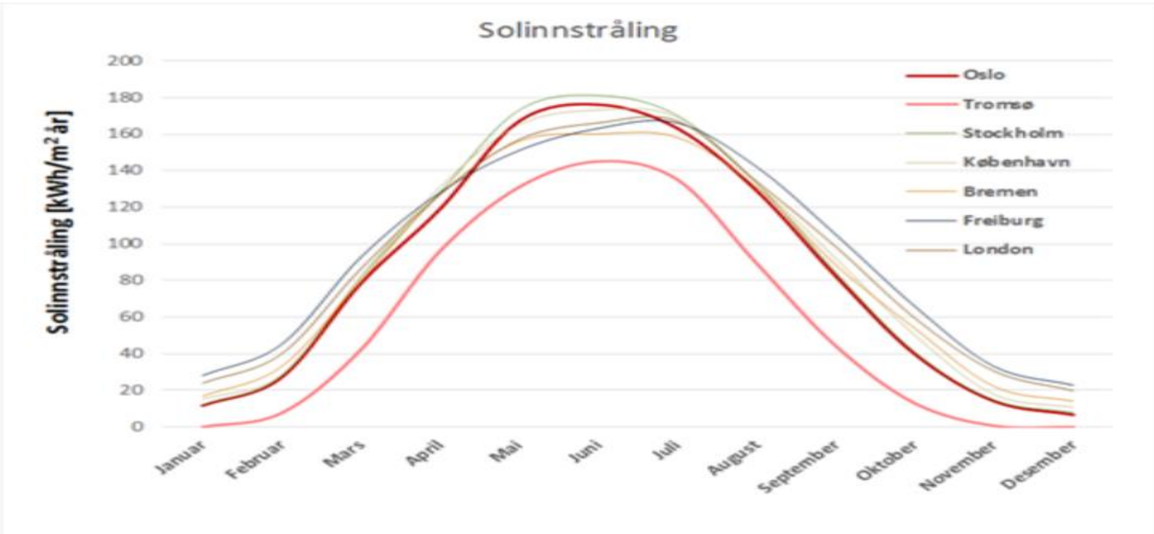


Figure 19 A graph showing the solar irradiation (kWh/m^2/year) during the whole year, comparing Oslo and Tromsø to some other major cities around Europe [25].

It can be a misconception that solar cells are not efficient in Norway, especially in the north. This assertion is true during the winter months. Looking closer to the summer months, the solar potential in the north is rather good. Norway lies on the northern and western part of the Scandinavian Peninsula, and stretches from the most northern point at 71.08°N, to the most southern point at 58.00°N, including mainland only. From the middle of November until the end of January the sun does not shine on the northern parts of Norway. During this winter season, the solar irradiation will be none existing, which causes the solar panels to have zero power production. During the summer on the other hand, the sun shines all day and night, which may result in higher production during the summer months. According to NVE (Norges vassdrag- og energidirektorat), the yearly irradiation in Tromsø is 20% less compared to Oslo. One of the advantages of having solar panels further north, is lower ambient temperatures, which results in lower cell temperatures, which in return results in higher operating efficiency [26].

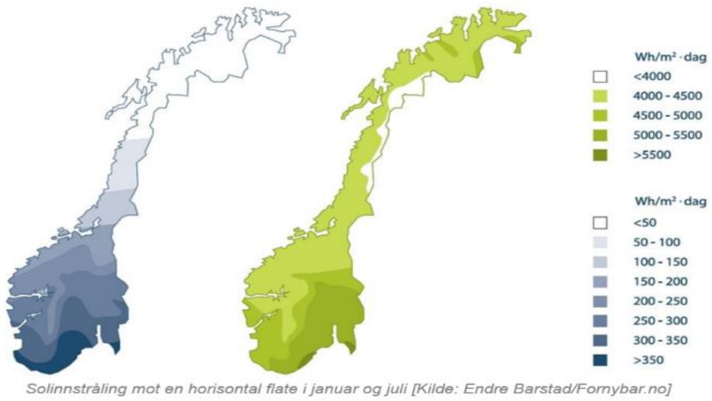


Figure 20 Solar irradiation in Norway, the illustration on the left is during January, while the illustration on the right is in July.

2.3 Government and other subsidies

As of 2019, Enova is the only nationwide organization in Norway that offer subsides for installation of solar panels in private households. Enova offers 10 000 Kr for start-up costs and 1 250 Kr for every kW installed, with a maximum of 28 750 Kr [27]. Other subside for PV systems exist in a few local governments, which vary from county to county. There are also arrangements that allows the PV owner to sell its excess produced energy. Fjordkraft is offering to buy the overproduced energy from costumers for 1 Kr/kWh, at a maximum of 5000 kWh per year [28].

2.4 Grid load and energy consumption

2.4.1 AMS

NVE has decided that within 2020, all electric grid connected households will be equipped with an AMS (Advanced measuring system). The AMS monitors the energy usage each hour, 24 times a day, and can be upgraded to sampling 96 times a day if needed (every 15 minutes). One of the main reasons NVE forced grid operators to install this system, is to make the public more aware of their energy consumption [29].

Figure 21 The new AMS meters being installed in every household within 2020

2.4.2 Electric cars

The energy demand in Norway is predicted to increase in the coming years. One of the main reasons for this anticipated rise in demand, is the increase of electric cars. In the past century, the transport section has relied mainly on transportation fuelled by fossil fuels. However, recent environmental discoveries have concluded that keeping in the same track, while polluting the environment, is not viable in the long run. Therefore, two successors to the diesel and gasoline car have appeared, hydrogen and electric cars. In Norway, the electric car has conquered the majority of the marked, while the hydrogen car is lingering. The predictions of elbil.no concludes that within 2020, there will be 400 000 electric cars on the Norwegian roads, a solid increase from the 150 000 that exist today [30]. If this prophecy of elbil.no tells any truth, actions must be done. The increase in electric cars will lead to a massive load to the electric grid, which is already working at max capacity in some occasions, especially during cold days in the winter months. There are two obvious solutions that deals with the increasing electric grid load. Expand the electric grid or implement several small measures that will reduce electric grid load. A massive expansion in the electric grid is estimated to cost billions [25], while many small measures, like producing more PV power in morning and evening, can be implemented at a fraction of the cost. This report investigates one of those small measures that may contribute to mitigating the electric grid load [31].

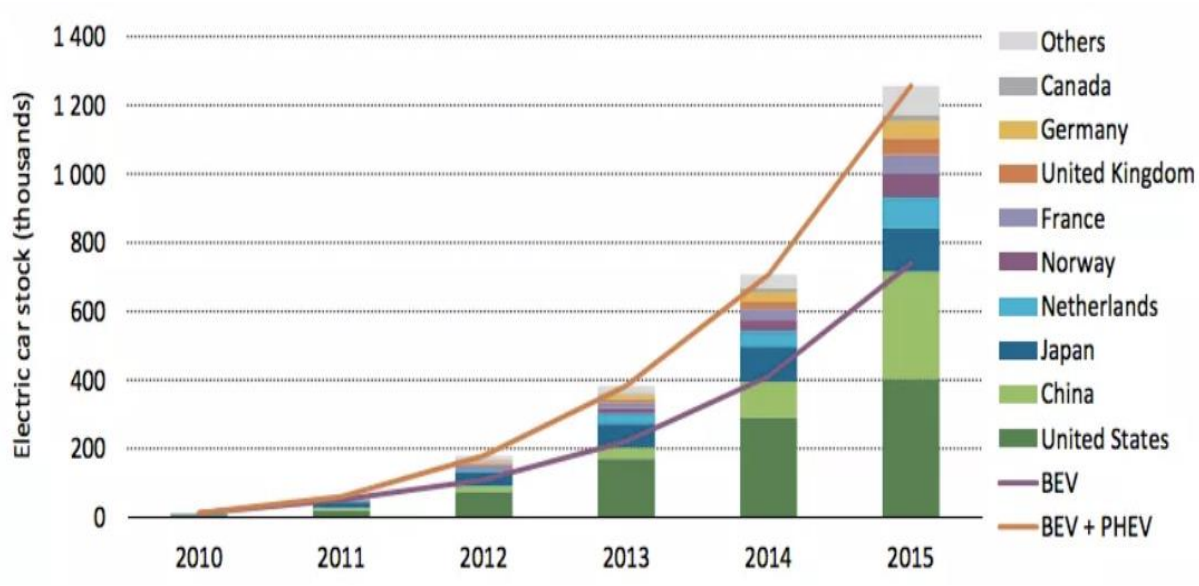


Figure 22 Overview of the increasing number of electric cars produced, showing 2010-2015 for several countries [32].

2.4.3 Consumption

PV is an unpredictable source of energy as it may vary from day to day and season to season. Thus, the consumption pattern of the individual household will decide how much of the produced energy is utilized, and how much is fed back onto the electric grid. The consumption patterns in Norway are far different from that of the southern European countries. In countries such a Spain and Portugal, there is a vast need for air-conditioning and cooling during the summer. Norway on the other hand, has a high need for heating during the winter. Approximately 80% of the energy consumed per year in Norway is for heating appliances [28]. This a is major disadvantage when it comes to consuming PV produced power. The PV production is highest during the summer, and in the summer, there is minimal need for cooling due to the cool summers. The energy produced in most of the summer months will commonly be sold to the electric grid, and selling a large part of the produced energy may make the overall profitability of the PV system decline.

2.4.4 Solar systems economics

LCOE (levelized cost of electricity) is a measurement of how cost efficient a PV system is during its lifetime. The LOCE is an efficient measure for comparison of potential profitability in different energy projects. The LOCE is measured in Kr/kWh, which indicates what the realistic price per kWh will be for a given energy installation. The total life-cycle cost (TLCC) is the total cost of the energy instalment during its lifetime, including initial investment, maintenance and decommissioning. A favourable trade of LCOE, is that the measurement is given in Kr/kWh instead of Kr/W, which is a more accurate picture of the production, making it easier to compare with other energy production sites.

The LCOE can be calculated by equation 2.12. In addition to TLCC, the input characters are Q_n which is the annual production in kWh, d is the discount rate, n is the given year and N is the number of expected lifetime years. Even though PV systems can be producing for 30 years +, this report has set the expected lifetime to 25 years.

$$LCOE = \frac{TLCC}{\sum_{n=0}^{N} \frac{Qn}{(1+d)^n}} \qquad (2.12)$$

The total life-cycle cost can be calculated from equation 2.13. Where C_n is the annual cost, N is the lifetime and d is the discount rate.

$$TLCC = \sum_{n=0}^{N} \frac{Cn}{(1+d)^n} \qquad (2.13)$$

The LCOE can be useful for comparing projects. The LCOE should be not be taken as an exact value, as the calculations include several assumptions which cannot be directly connected to other projects. Thus, it is important to list the parameters of the LCOE calculation.

The annual production Qn is changing every year because it is affected by an efficiency loss X [33]. The total efficiency drop during the systems lifetime is dependent on producer of the solar panels, and a standard max loss on “talesun solar” panels is 20% after 25 years [34]. Qn after n years can be calculated by equation 2.14

$$Qn = first\ year\ production * X^n \qquad (2.14)$$

The yearly efficiency loss with a 20% loss after 25 years can be calculated by solving for X in equation 2.15.

$$1 - 0.2 = (1 - X)^{25} \qquad (2.15)$$

3 Methodology

3.1 Case studies

As presented in introduction “1.3 Topics to explore” several questions are listed:

- How much electricity is produced with PV systems oriented to the south, as opposed to east and west, and how is the energy production distributed with regard to time of day?
- How will potential tariffs from NVE influence the profitability of power production during the morning and evening?
- How does the sun conditions change with geographical differences, and to what degree does it influence the overall power production and time of day production?
- What changes in power production can be expected if the surface azimuth angle (orientation) is adjusted?

In order to give accurate answers to these problems, several case studies will be done throughout this report. These cases studies are divided in to 4 parts.

- **Part 1:** The first simulation will explore production patterns for four geographical locations and two orientations. With focus on a system oriented directly south with an azimuth angle of 0° and a system oriented east and west with an azimuth angle of -90° and 90°. These simulations are done to narrow down the geographical locations, so that this report can go closer in details for operating conditions in a specific location.
- **Part2:** The second part of the simulation will focus on operating conditions for a PV system. In this part another orientation is added from part1, and a total of three orientation will be studied: Directly south with an azimuth angle of 0°, southwest and southeast with an azimuth angle of -45° and 45°, east and west with an azimuth angle of -90° and 90°. These simulations are done to explore the operating parameters such as voltage and current, for different orientations.
- **Part3:** The third part will explore the financial aspect of a PV system. In this part three orientations will be studied: Directly south with an azimuth angle of 0°, southwest and southeast with an azimuth angle of -45° and 45°, east and west with an azimuth angle of -90° and 90°. The production will be matched up with an energy price. This will make it possible to evaluate the value of time of day production, and overall system profitability. Finally, in this part a break-even energy price will be induced. This to study, to what extent the energy price must deviate from what is current today, for a system oriented east and west to be as profitable as a system oriented south.
- **Part4:** The final part of the simulation will explore energy output for a PV system. In this part 7 orientations are studied. Starting at an azimuth angle of 0°, then orienting the panels east and west, with intervals of -15° and 15°. This will give a good overview of how the overall production variates as the system azimuth angle deviates from directly south.

3.2 Consumption profiles

This report investigates an energy consumption profile in order to provide an overview of when energy is consumed. An energy consumption profile that cover the average household is ideal, as this would make a potential tariff for the average energy consumption more accurate. Due to the fact that every house household has its own patterns and routines, it can be difficult to assume an average household consumption. Some work at night, some work during the day, some are unemployed, some go for long holidays, all of which are factors that will affect the daily energy consumption. In order to create a consumption profile for an average household, the following assumptions are made:

- The household is in Norway.
- The household consist of 4 residents.
- The profile does not consider vacation or longer absence from the house.
- The household utilize all the appliances in table 2, at a weekly basis.
- The energy consumption is different based on season.
- All 4 residents stick to their given patterns and routines.
- Different consumption in weekends are not considered.
- Some of the data is based on the daily consumption of a C4 house.

3.2.1 Average household consumption

The average yearly energy consumption for a detached house in Norway is approximately 20 000-25 000 kWh. The energy profile estimated in this chapter is based on a household of four persons. A detailed overview of the energy profile and the power consumption of typical household appliances is presented in table 2.

Table 2 Showing an estimated consumption for a average household. Also includes how much energy each appliance normally consumes [35].

Appliances	**Rating**	**Daily time of use**	**Qty**	**Daily use (Wh/Day)**
Refrigerator	300W	Whole day	1	3600
Freezer	100W	Whole day	1	1600
Electric stove	2500W	Morning evening (2 hours)	1	5000
Microwave oven	1000W	Morning/evening 30min	1	1000
Toaster	800W	Morning 15min	1	200
Washing machine	700W	Evenings (4hr/week)	1	400
Vacuum cleaner	1400W	Evenings (1hr/week)	1	200

Television	100W	Evening /night (5 hours)	1	500
Computer/phone	40W	Evening/night (5 hours)	5	100
Clothe iron	1400W	Morning (1hr/week)	1	200
Hot water	2000W	Whole day (5 hours)	1	10000
Lights	10W	Morning/evening (10 hours)	10	1000
Heating appliances	2000W	Season dependent	5	0-55000
Cooling	2000W	Season dependent	1	15000-0
Total				38800-78800

3.2.2 Season based consumption

This report includes an analysis of the energy usage with regard to tariffs on the electric grid. In order to establish a relevant tariff, a daily energy consumption is defined to understand when the need for energy is most urgent. Considering that there is a deviation in consumption over the year, the energy consumption is divided in four seasons and a daily consumption profile is created for spring, fall, winter and summer. It is assumed that the winter consumption needs most energy for heating, while fall and spring needs some heat. The summer may need some energy for cooling. The four graphs shown in figure 23 and 24 are the season based daily consumption.

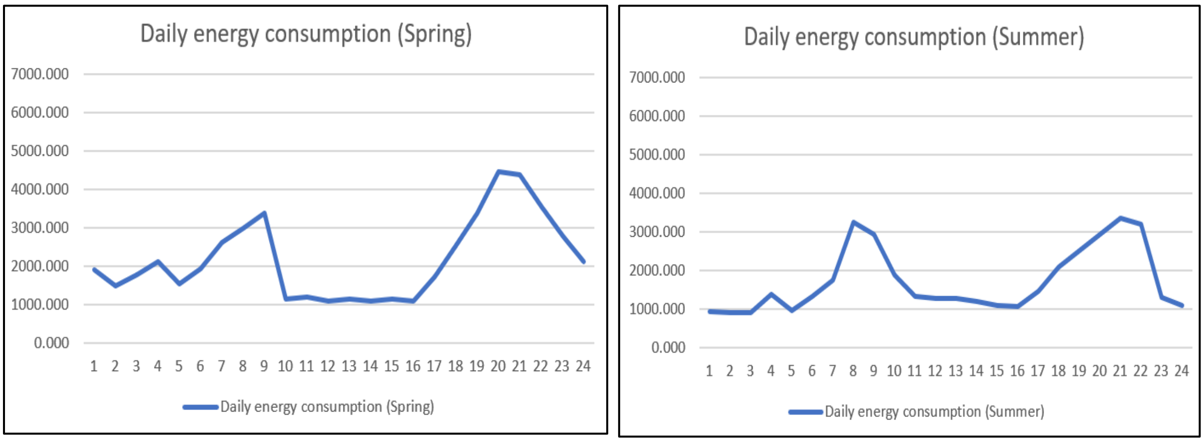


Figure 23 Overview of the daily energy consumption during spring and summer. The y-axis represents Watts the x-axis represents hour of the day.

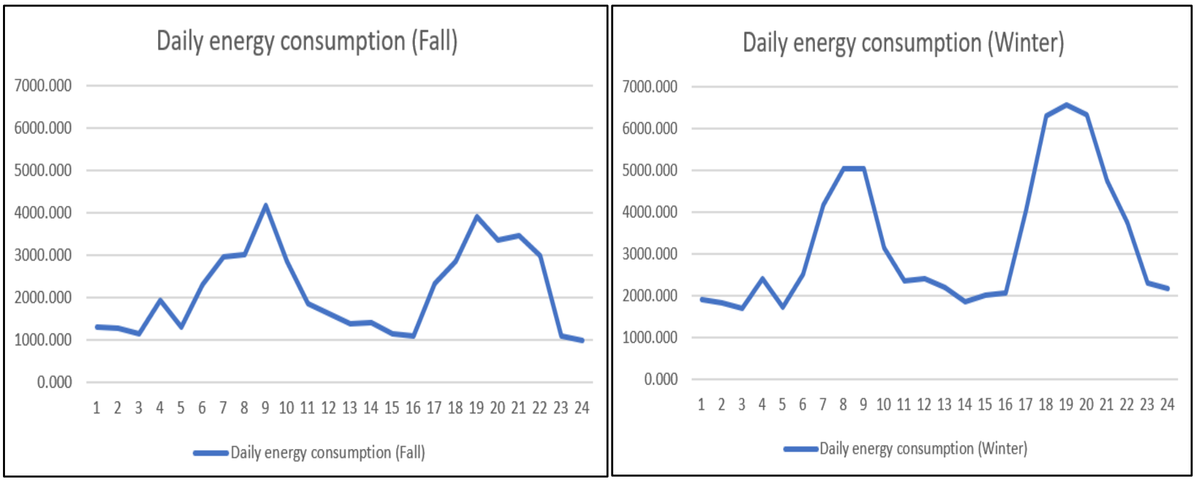


Figure 24 Overview of the daily energy consumption during fall and winter. The y-axis represents Watts the x-axis represents hour of the day.

3.3 Potential energy price, with regard to electric grid tariffs

This report requires an hour to hour energy price, which can be measured up against PV production. Taking advantage of the consumption pattern explored in the previous subchapter, a potential tariff can determined. When calculating an energy price, there are three factors to consider: the energy itself, electric grid rent and taxes. Most power suppliers let the costumer chose between a varying energy price following the marked, or a set energy price, which is often higher than the market price in the long run.

The energy price in Norway is determined by “Nordpool”. The marked price is changing from hour to hour, day to day and month to month. While exanimating these prices closely, it is possible to observe a pattern looking at historic data. Nordpool usually display higher prices (Euro/MWh) during morning and evening. Figure 25 presents the energy price hour to hour during 18th of May 2019 [3]. The changes in electricity pricing are not always as distinguishing as on this specific day. However, 8th of May is chosen as an example for visual purposes. Nordpool contain historic data for the energy price, which can be collected from their website for further reading [3].

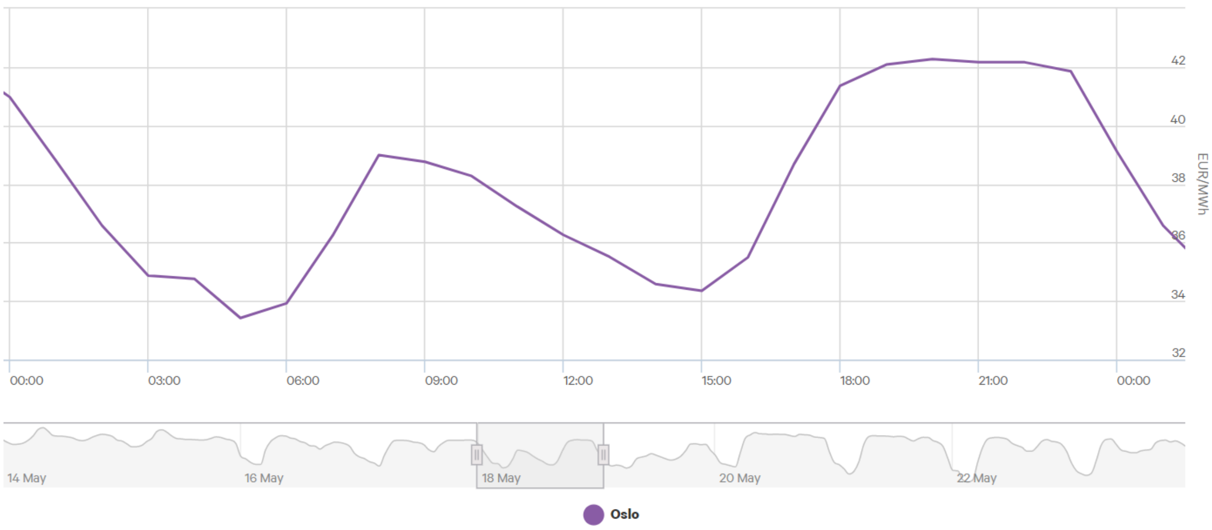


Figure 25 Showing the variating energy price in Oslo on 18th of May 2019.

Installing the AMS in every household within 2020 is the first step in reducing the overall electric grid load. Next comes the discussion of which electric grid tariffs will prove most efficient, and which tariff are manageable for the consumer, power supplier and electric grid supplier. After some discussion with employees of NVE, a potential electric grid tariff is potential today (March 25, 2019). This potential tariff has not been finalized and will be sent to hearing during the end of April. When the hearing is complete, it will be known to the public. This report will construct an electric grid tariff based on what employees of NVE know will be considered. The potential electric grid tariff is based on a threefold fee, with three potential links, based on the following three points.

- A power link that is relatively fixed in the short and medium term. This can be based on the consumers fuse size, abundant power or measured power output.
- An energy link which reflects the marginal loss costs in the grid (the marginal cost with grid loss)
- An incentive link that gives people incentive to reduce the daily power peaks which usually occurs during morning and evening. This can be based on a time of use-link or an overconsumption-link.

According to SSB [36], the average price per kWh in the 4th quarter of 2018 was 1.234 Kr/kWh, this is including grid rent and taxes. The coming electric grid tariff used in this report is based on 4 following points.

- NVE tariff suggestions.
- Nordpool prices.
- Consumption patterns.
- An average energy price given by SSB.

Following these 4 points, an estimated grid tariff can be induced. Figure 26 shows a potential energy price in the future and the energy price in the 4th quarter of 2018. The energy price below includes power price, taxes and electric grid rent.

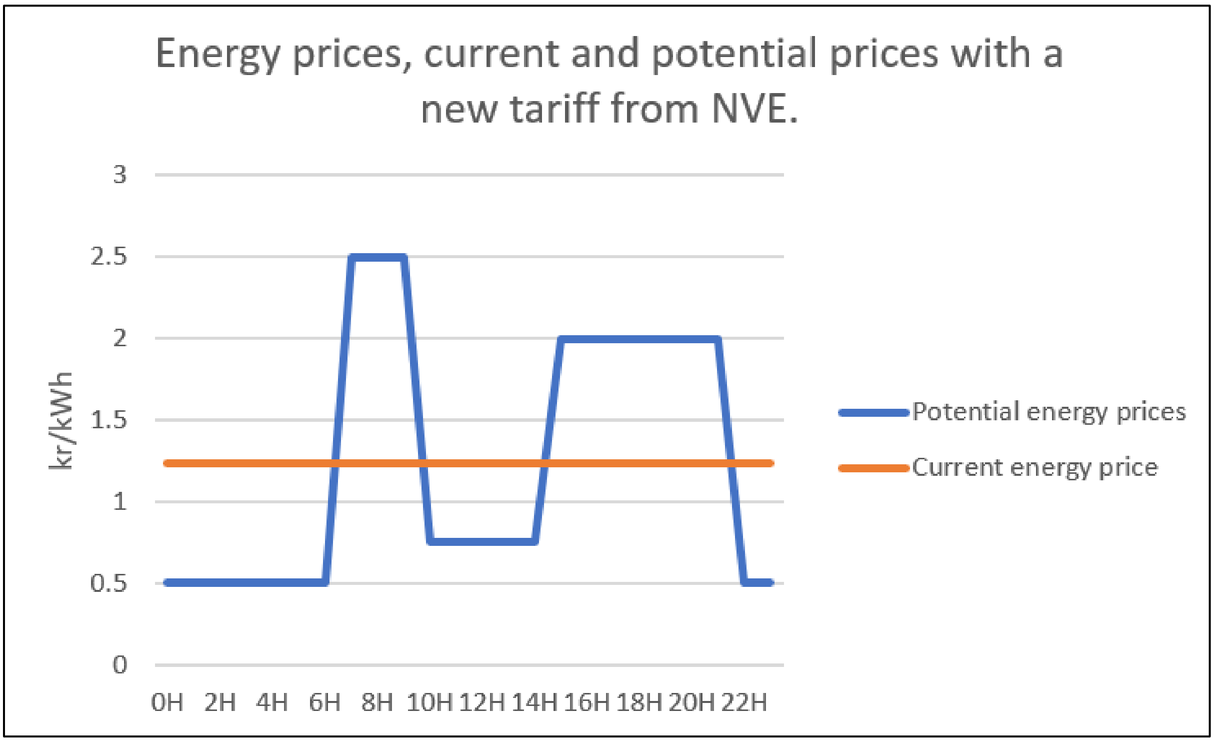


Figure 26 Overview a variating energy price, compared to a constant energy price.

3.4 Simulation software

This report does not have access to an existing PV system to monitor and compare a south oriented system to an east and west oriented system. Thus, a simulation tool is used. PVsyst can be used to simulate a PV system at any location in the world, using satellite weather conditions, relevant technical data and appropriate angles. The software allows the user to specify the orientation, location and products such as solar panels and inverters. The inverter data used in this report was provided by Solcellekraft AS, while the specific panel data was existing in the PVsyst database. The specific inverter data can be found in "appendix 8.3" and panel data can be found in "appendix 8.4".

3.5 Orientation and tilt

The aim of this report to examine the difference in production for a PV system oriented southeast and southwest, east and west and directly south. Thus, several orientations are simulated. An azimuth angle of 0°(south), 45°-45° (southwest, southeast) and 90°-90° (east, west) is focused when analysing operating conditions. The tilt is fixed and specified in a reasonable matter. The angle of rooftop will vary from house to house, where some houses use a steep angle, and other houses have no angle at all. It is possible to mount a PV system to give the panels a favourable tilt. This on the other hand, will increase the cost and reduce the wind resistance of the panels. The optimal tilt angle vary with the location, and in Norway, the average optimal tilt angle is approximately 40° according to PVsyst. This report investigates 4 different locations in Norway, with a different optimal tilt at each location. In order to keep the simulation consistent, a fixed tilt angle of $\frac{\pi}{4}$ is chosen for all simulated cases. The simulation is run several times for each geographical location.

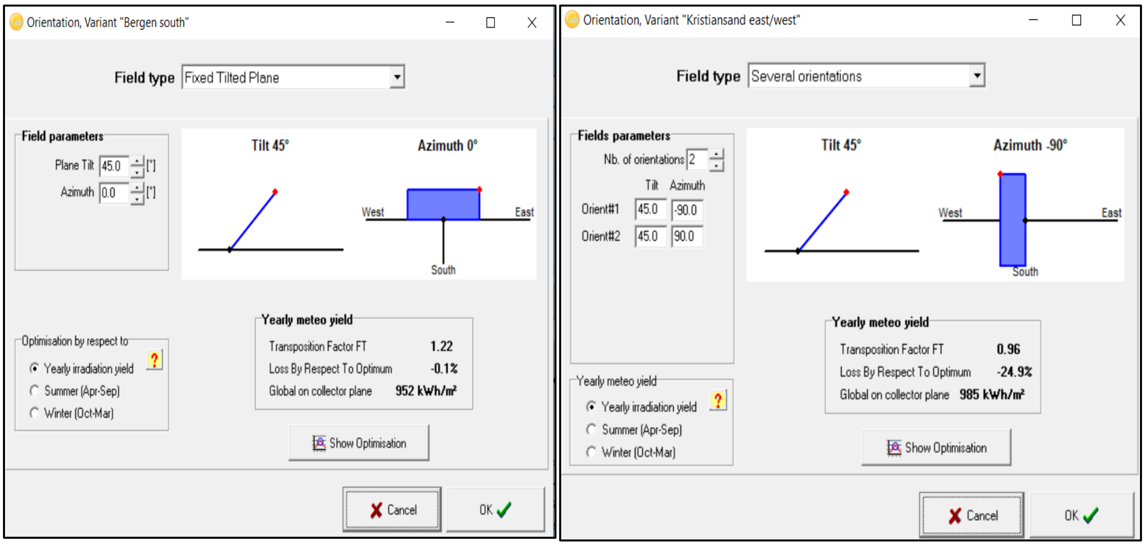


Figure 27 Showing the orientation and tilt setup in PV syst. The figure on the left shows the south orientation. The figure on the right shows two orientations, east and west. Both cases have a fixed panel tilt of 45°.

3.6 Selection of inverter and solar panel products

3.6.1 Panels

The panel added to the simulation software is 300 Watts using monocrystalline technology, from "Talsesun solar", which has its specifications within the PVsys database. This is covered in the theory section under "2.4.5 panel and inverter". This panel was chosen due to availability on the Norwegian market. Further specifications for this panel can be found in "appendix 8.4".

3.6.2 Inverter

In order to keep the initial investment costs of the system to a minimal. A string inverter is chosen, further inverter characteristics are covered during the theory section under "2.4.5 panel and inverter". Due to marked availability an inverter from Litto is added to the simulation software. Because the specifications and operating characteristics for this inverter is unavailable in the PVsyst database, they are added manually. The model chosen is Litto (LT10000HD), the operating details for this inverter can be found under "appendix 8.3".

Figure 28 displays some of the manual entering parameters for inverters in PVsyst. Including factor such as operating voltage, output frequency, nominal power etc.

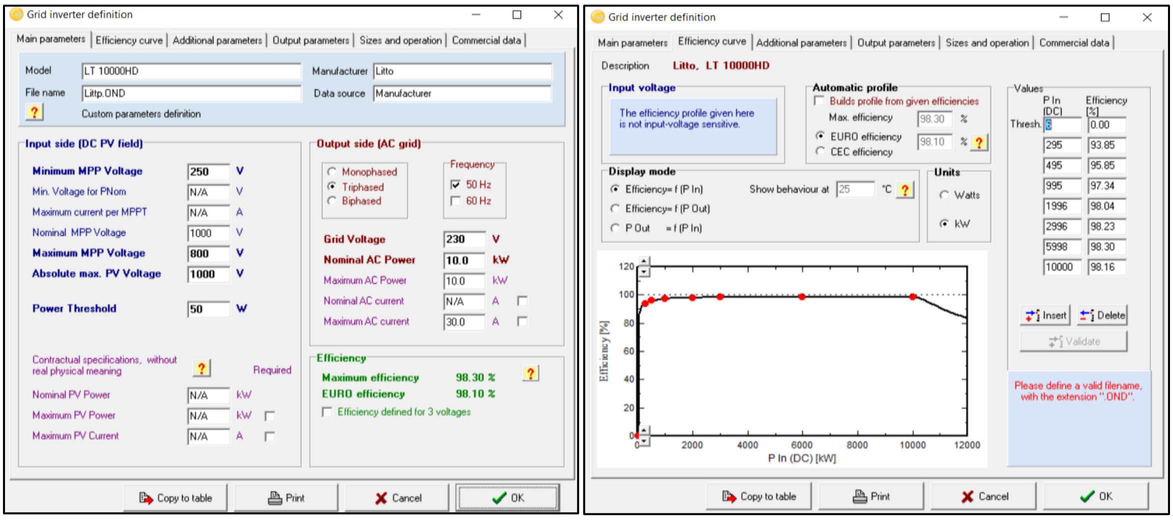


Figure 28 Showing the inverter system setup. Picture on the left shows the different operating conditions, while figure on the right shows the efficency factors. For more inverter sespifications look "appendix 8.3".

3.7 Weather data utilized in simulation

The global weather data used in the simulation is based on meteonorm 7.2. Meteonorm is a source for global weather data, which can be used for purposes such as in this report. Meteonorm monitors 8000 weather stations and five satellites which records weather data from all over the globe. It is possible to extract 30 different meteorological parameters from meteonorm. This report only considers the main parameters which effects the productions of solar cells, namely temperature and irradiation [37].

3.8 Simulated System

3.8.1 System Setup

The PV system used in this report is based on the roof being 67 square meters in the south orientation, or 33.5 square meters in the eastern and western orientation. The panels used are 300W with surface area of 1.65m^2. This makes the total installed power in the system 12kWp. The inverter is a string inverter, with two separate MPPT features. There are 10 panels for each string, and two strings in are connected in parallel per MPPT.

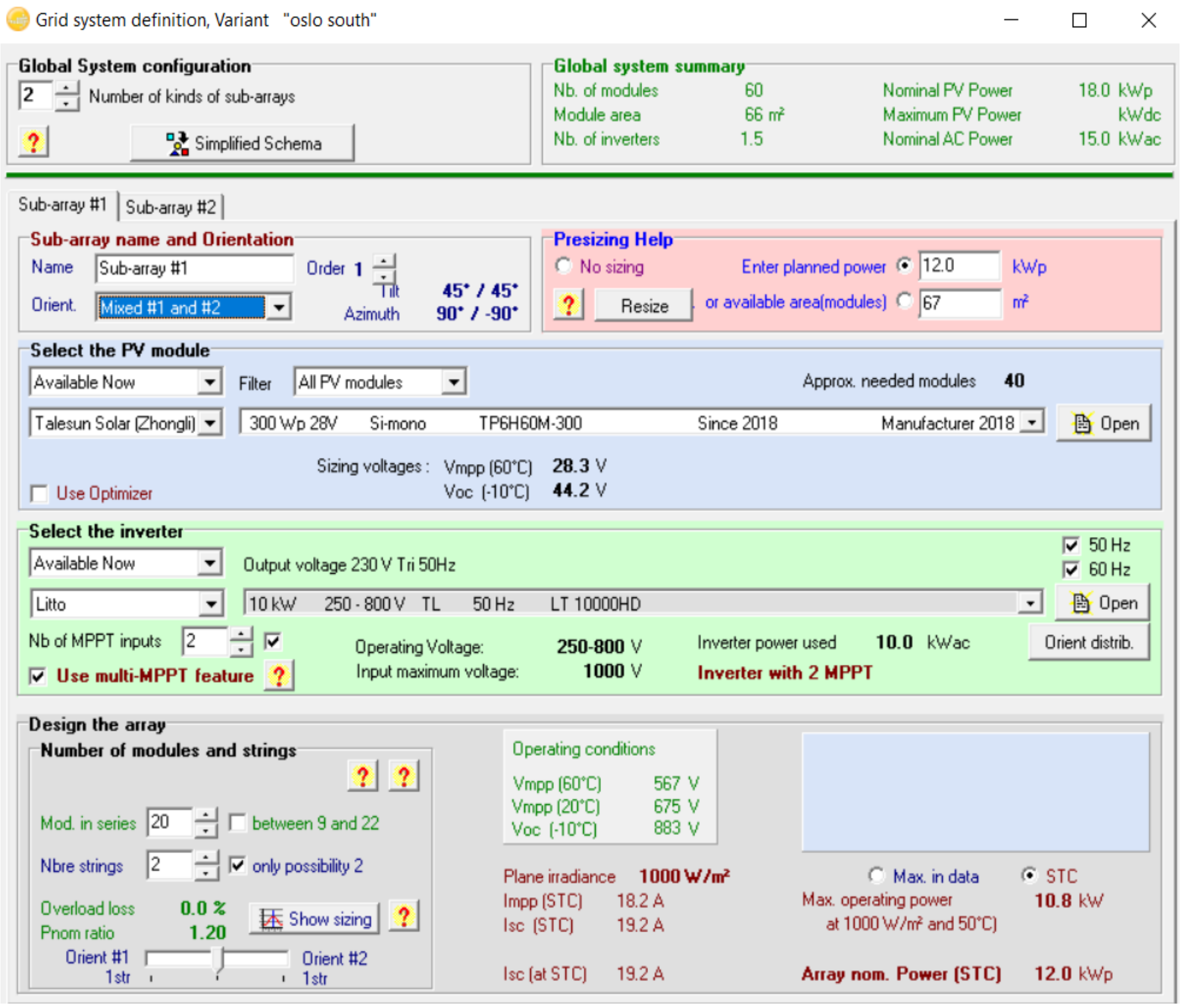


Figure 29 System specification in PVsyst, showing system power, inverter chosen, panel chosen and other details about the PV system which is simulated.

3.8.2 System cost

The initial cost of this system is provided by Solcellekraft AS [10]. Initially, there should be no extra cost to a PV system after the purchase and installation costs. The inverter is an electric device, in the same way a fridge or a freezer. These electric appliances come with an uncertainty in their lifetime, it may last 30 year, it may last 10 year, it may last one year. If the inverter were to break, it will add extra cost to the system. According to Solcellekraft AS, a system used in these simulations will cost: 167 460 Kr, including labour and parts. A full overview of the costs is presented in "appendix 8.2".

3.9 Criticism of methodology

This subchapter covers the criticism of methodology for the thesis. During a previous subchapter, “1.4 scope of work and limitations” it is mentioned that the simulation covers the surface of a lager subject and there should be done more experiments to increase the accuracy of the results and to conclude with optimal orientation and location for a PV system.

- The fixed plane tilt angle of 45° is applied to the simulation software. If this tilt angle were to be set lower or higher than 45°, it would lead to variations in the result section, the degree to the variations would depend on the extent of the changing tilt angle.
- The solar panels and inverter are two deciding factors for how efficient a PV system can be. There are countless suppliers of both solar panel and inverter. Finding the most cost efficient is difficult, and the chosen solar panel and inverter is based on insight from Solcellekraft AS, which is one of many nation-wide suppliers of PV systems.
- Weather conditions can give large variations from day to day and year to year. This can cause inconsistencies in results if the simulation is done over several years.
- The orientations focused upon in this thesis is south with an azimuth 0°, southeast and southwest with an azimuth angle of -45° and 45°, east and west with an azimuth angle of -90° and 90°. The report could include several more orientations, but due to limited resources and a restricted time frame, only three oriented arrangements are investigated in most cases.
- To monitor operating conditions, two specific days were exanimated, one in January and one in June. These days were chosen based on clear weather data on the specific day. Several more days should be monitored in order to establish a better overview of the operating conditions throughout the year.
- The energy price induced in section “2.5 Potential energy price with regards to electric grid tariff” can be consider somewhat uncertain. This because, as of yet, NVE has not published a definite electric grid tariff. Also, the electricity price may vary threw the course of a year, the electricity price from this report is used for the whole year.

4 Results and discussion

4.1 Part 1, analysis of four different geographical locations and two orientations.

As previously mentioned, this report aims to examine the different production times for one northern, southern, western and eastern location. Because the considered PV system in this thesis are to be installed on rooftops, the largest cities in each respective area is chosen. This makes Tromsø, Kristiansand, Oslo and Bergen suitable locations.

The weather data from each location is based on meteonorm 7.2, as well as data from the cities local weather station. The simulation for each of the locations are run twice, once with a 0° azimuth angle (south) and once with a 90° and -90° azimuth angle (east and west). This is expected to paint a larger picture of the variation in geographical location. In the south oriented system, 40 panels are directed south with azimuth angle of 0°. In the east and west oriented system, 20 panels are directed east and 20 panels are directed west. This results in half the system having a azimuth angle of 90°, while the other half has a azimuth angle of -90°.

4.1.1 Northern (Tromsø)

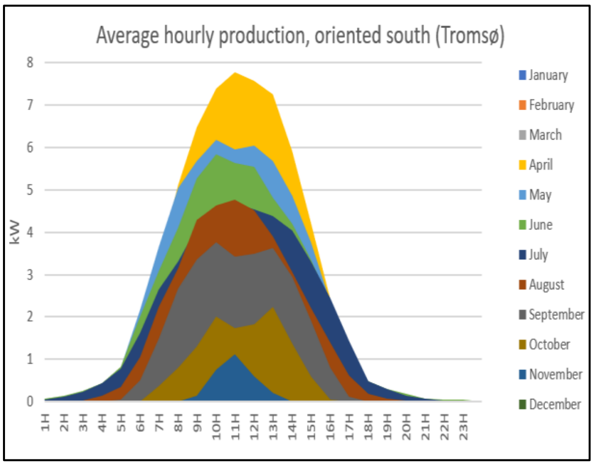
Two cases are simulated for the northern location in Tromsø. The PV system is placed at a latitude of 69.67°, a longitude of 18.93° and an altitude of 19m. The tilt of the panels is set to 45°, there is no shading from local vegetation. The total installed power is 12kW under STC.

PV system oriented south at a northern location (Tromsø)

The south oriented system gave a total production of 10678 kWh/year. As shown in figure 27, the production in April reaches an average power production close to 8 kW, with a peak production at around midday, from 10:00 until 13:00. The PV production in December and January is none existing, while production during November and February, is low.

PV system oriented east and west at a northern location (Tromsø)

The east and west oriented system gave a total production of 7913 kWh/year. As shown in figure 30, the average power production for April reaches approximately 3.5 kW, this is quite low compared to the south oriented system. Even though this average max power in April is less than half of what the south oriented system has, the yearly production is only about 20% less. This indicates a more evenly distributed power production for the east and west oriented system. As figure 30 shows, the PV system produces energy 24 hours a day in June. During 18 of those hours, the power production is more than 1 kW. The PV production in December and January is not existing, while in November and February, it is low.



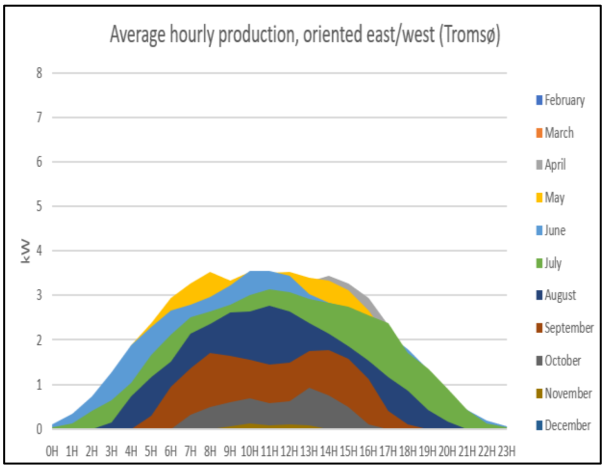


Figure 30 Graph of average hourly production for every month of the year. Left graph showing south oriented system, right graph showing east and west oriented system.

4.1.2 Eastern (Oslo)

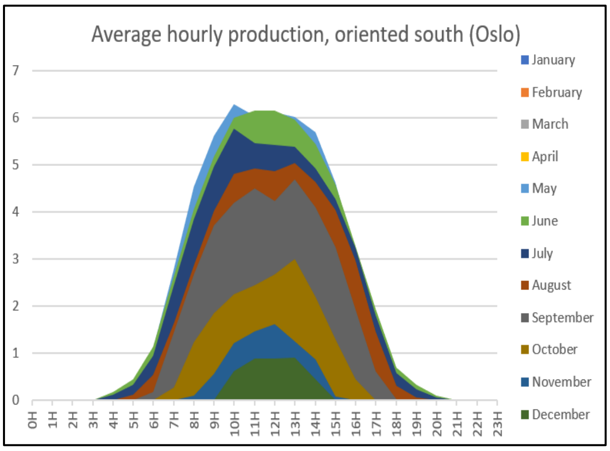
Two cases are simulated for the eastern location in Oslo. The PV system is placed at a latitude of 59.91°, a longitude of 10.68° and an altitude of 16m. The tilt of the panels is 45°, and there is no shading from local vegetation. The total installed power is 12kWp under STC.

PV system oriented south at a eastern location (Oslo)

The south oriented system gave a total production of 11498 kWh/year. As shown in figure 31, the production in the best months reaches an average power production close to 6 kW, this is less than that of the northern location. In return it is discovered that the peak production is during a longer period than in the north, which is from around 09:00 until 14:00. The deviation in production per month is not as noticeable as in the north. The PV production in December and January is not large but, it gives an impact on the overall production on the contrary to northern location. November and February have a decent production.

PV system oriented east and west at a eastern location (Oslo)

The east and west oriented system gave a total production of 8902 kWh/year. As shown in figure 31, the average power production in the best months reaches an average power close to 4 kW. This is about two thirds of the production given in the south oriented system. As shown in figure 31 the production is more spread out than that of the south oriented system, this allows the consumer to utilize more of the produced power which might help to reduce electric grid load peaks.



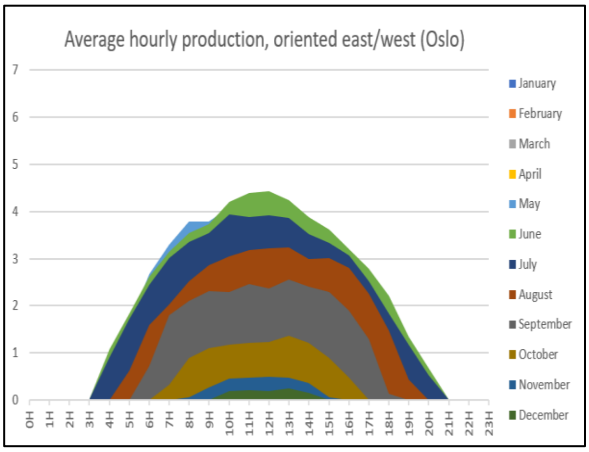


Figure 31 Graph of average hourly production for every month of the year. Left graph showing a south oriented system, right graph showing an east and west oriented system.

4.1.3 Southern (Kristiansand)

Two cases are simulated for the southern location in Kristiansand. The PV system is placed at a latitude of 58.14°, a longitude of 7.98° and an altitude of 19m. The tilt of the panels is 45°, and there is shading from local vegetation. The total installed power is 12kWp under STC.

PV system oriented south at a southern location (Kristiansand)

The south oriented system gave a total production of 13416 kWh/year. As shown in figure 32, the production in the best months reaches an average power production close to 7.5 kW, this is less than that of the northern location. This location oriented to the south gives the highest yearly production of all locations and orientations. The highest producing months are May and June.

PV system oriented east and west at a southern location (Kristiansand)

The east and west oriented system gave a total production of 10267 kWh/year. As shown in figure 32, the production in the best months reaches an average power production close to 5 kW. The graph is much wider than that of the south oriented graph, this indicates a smaller but a spread out production. The highest producing months are May and June.

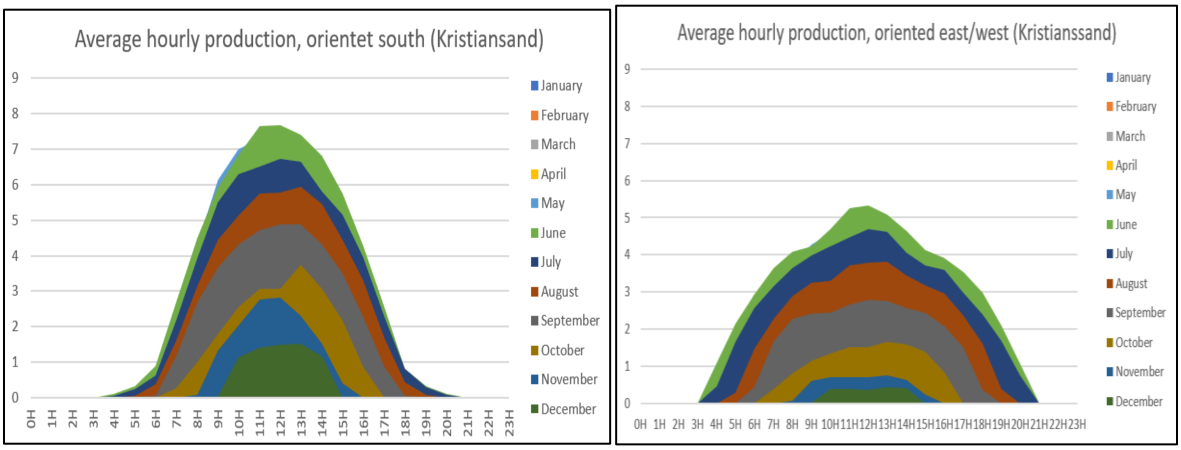


Figure 32 Graph of average hourly production for every month of the year. left graph showing south oriented system, right graph showing east and west oriented system.

4.1.4 Western (Bergen)

Two cases are simulated for the western location in Bergen. The PV system is placed at a latitude of 40.60°, a longitude of 5.32° and an altitude of 19m. The tilt of the panels is 45°, and there is no shading from local vegetation. The total installed power is 12kWp under STC.

PV system oriented south at a western location (Bergen)

The south oriented system gave a total production of 9965 kWh/year. As shown in figure 33, the production during May and June reaches an average power of close to 6 kW. This is approximately the same peak power production as the eastern location. However, the total yearly producing is 14% less than that of the eastern location.

PV system oriented east and west at a western location (Bergen)

The east and west oriented system gave a total production of 7755 kWh/year. As shown in figure 33, the production May and June reaches an average power production close to 4 kW. The graph is much wider than that of the south oriented graph, this indicates a smaller but a spread out production. This location and orientation give to lowest total yearly production of all locations and orientations.

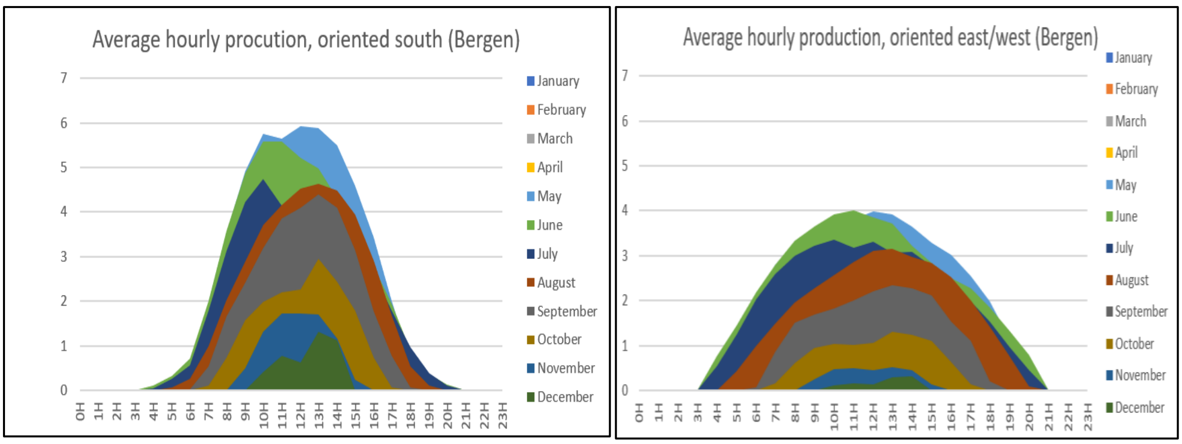


Figure 33 Graph of average hourly production for every month of the year. Left graph showing a south oriented system, right graph showing a east and west oriented system.

4.1.5 Subchapter summary

These simulations show that there are large variations in power production for different geographical locations. Looking at the total yearly production, the southern location has the highest production, while the western location has the lowest. The repeating theme from these case studies is that a higher overall production can be expected when the system is oriented directly south as opposed to east and west. The east and west orientation gave a wider graph for all cases, which indicates a more evenly distributed production. This might contribute to reduce some of the electric grid load. The south oriented system has a high peak for a few hours midday, and if future PV system are installed in every household with the said orientation, the midday production peak may cause challenges regarding electric grid load.

Looking at these different geographical variations, there is a noticeable difference in total yearly production. Kristiansand PV systems with an south orientation resulted in a production of 13416 kWh/year, while Bergen PV systems with an east and west orientation provided a production of 7755 kWh. This is a difference of approximately 42% in the yearly energy output. The northern location had the highest producing month in April, while the other locations produced the most power during May and June.

If the objective is to produce the highest amount of energy throughout the year, the best choice is the southern location (Kristiansand), oriented directly south (azimuth 0°). The worst location is the western location (Bergen) oriented east and west (azimuth 90° and -90°). On the other hand, if the objective is to have a higher production in the night-time, the northern location oriented east and west makes for the better choice. Although, night-time production is only possible during the summer months in Tromsø.

4.1.6 Further analysis

The time of day production is quite similar for three of the geographical locations, despite variations in yearly production. The southern, eastern and western location has the same production patterns during the day. The northern location indicates a different time of production, considering no production during the winter months and 24 hour a day production during the summer. Thus, only two of the four geographical locations will be analysed further, the northern location (Tromsø) and the eastern location (Oslo). Oslo is selected from the three similar locations due to the highest population, making it a highly relevant place of study.

4.2 Part 2, investigation of operating conditions.

4.2.1 Analysis of operating conditions, eastern location (Oslo)

This subchapter investigates how the operating conditions and different angles of which the sun reaches the PV system affects the power production. Three different orientations are analysed, a south oriented system (0°,) a southeast and southwest oriented system (-45° and 45°), and an east and west oriented system (-90° and 90°). PV production is dependent on weather conditions, which makes the daily production vary according to the current weather. Therefore, the daily production analysed in this report will change relatively to the weather. Taking this in to account, a sunny day in January and a sunny day in June is chosen. These two days will be used for further investigation of the operation conditions.

In this case study, PV systems in three different orientations at two specific days of the year is investigated. The south oriented system has 40 panels directly oriented south with an azimuth angle of 0°, presented on the left on each graph in the following figures. The southwest and southeast oriented system has 20 panel southeast and 20 panels southwest, with an azimuth angle of 45° and -45°presented on the right on each graph in the following figures. The east and west oriented system have 20 panels east and 20 panels west, with an azimuth angle of 90° and -90°, presented on the bottom on each graph in the following figures.

Sun height, sun azimuth and array current, January.

As shown in figure 34, the suns height is low during a winter day. The azimuth angle is also low and last for a shorter amount of time compared to days later in the year. As presented in figure 34, the sun moves form about -40° to about 40°. There it is only production when the sun is up, as expected. Also demonstrated in the graphs, the array current production is higher when the orientation is to the south. The interesting factor here, is when the panels are oriented with an azimuth angle of 45° and -45°, the daily array current is only 24% less than that of system oriented directly south, while the system oriented with a full azimuth angle of 90° and -90°, the daily array current production is about 75% less. This indicates that an east and west oriented systems has far less production during the winter compared to a south oriented system.

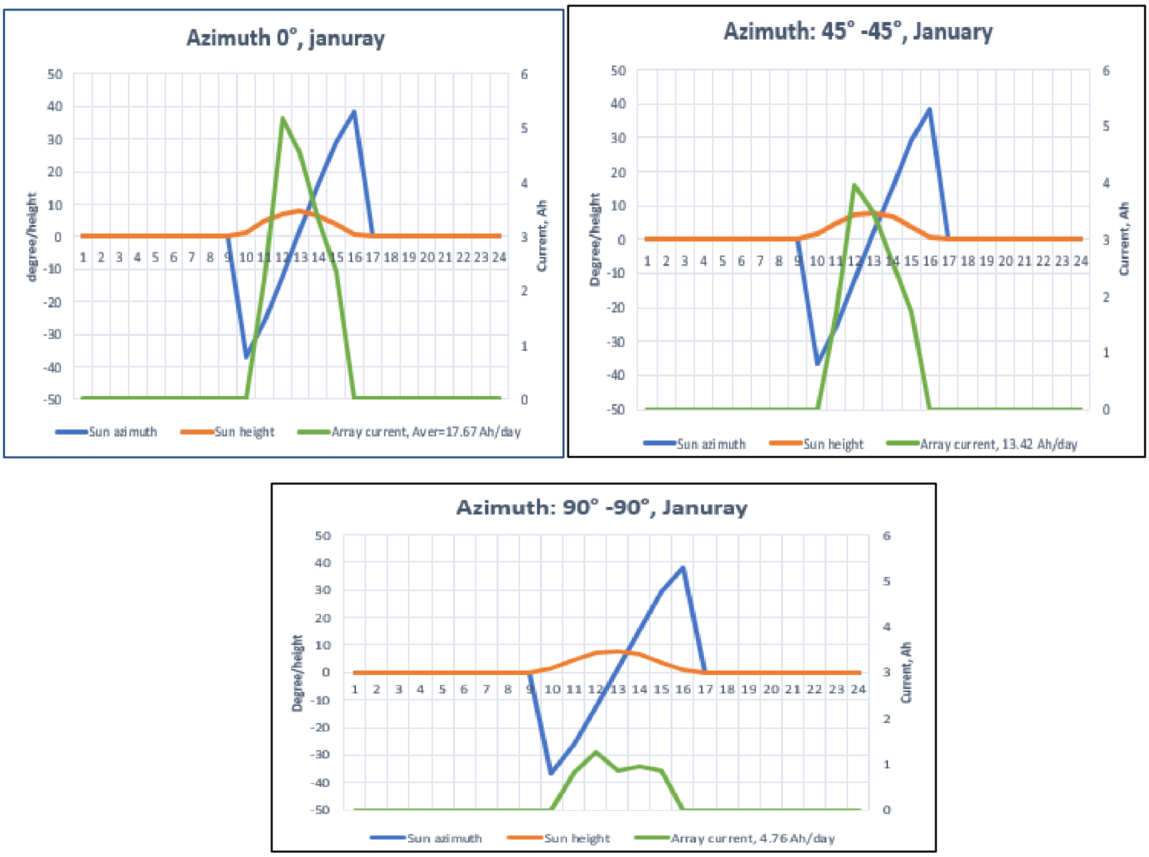


Figure 34 Sun azimuth, sun height and array current for a clear day in January. Three orientations; left graph (south), right graph (southeast and southwest) and bottom graph (east and west). Location: Oslo

Sun height, sun azimuth and array voltage, January.

Because the panels are connected in series, the voltage of the produced power is approximately the same for any chosen direction. The panels are producing during the same periods, whether the panels are directed south or east and west, as shown by figure 35. The operating interval for this location and day is for approximately 5 hours, from 10:00 until 15:00.

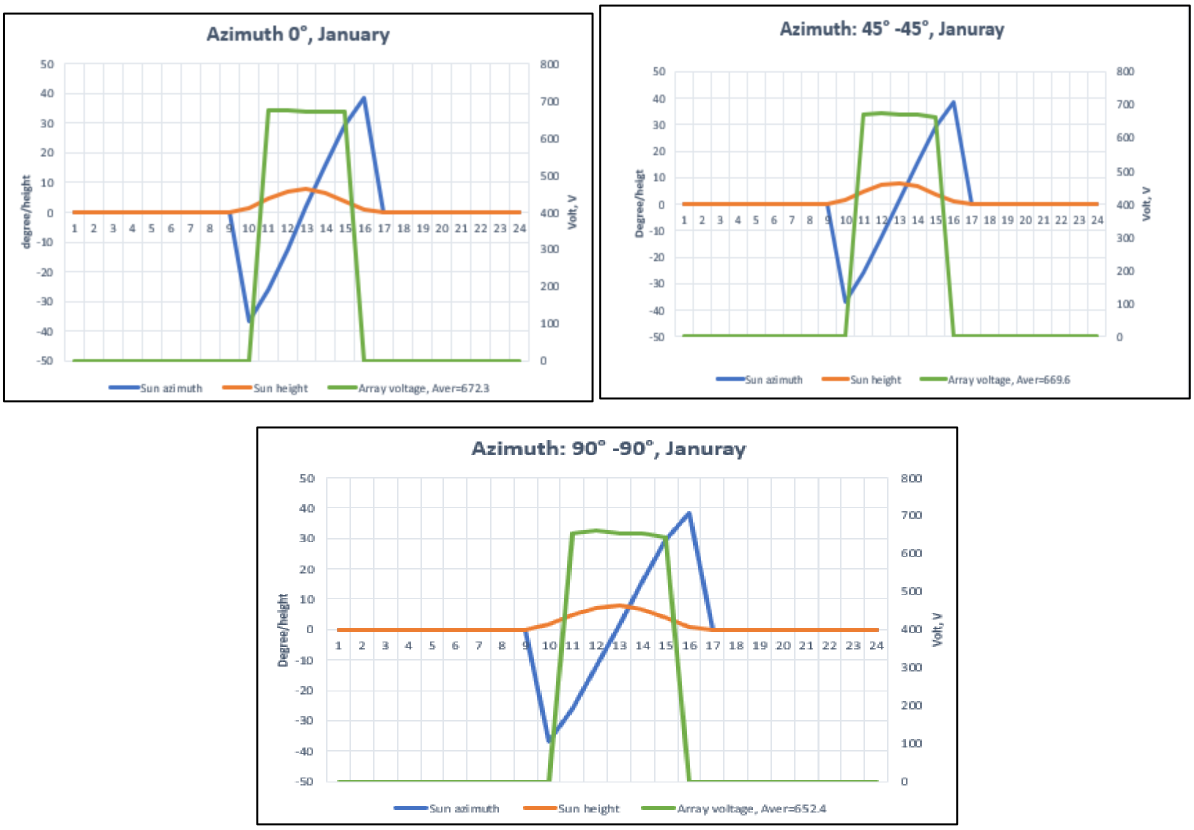


Figure 35 Sun azimuth, sun height and array voltage for a clear day in January. Three orientations; left graph (south), right graph (southeast and southwest) and bottom graph (east and west). Location: Oslo

Incidence angle with production, January

A solar cell has the highest production when the sunlight is directed straight towards the cell, which occurs when the incidence angle is 0°. In the left graph, figure 36, there is only one incidence angle because the system is oriented in the same direction, while the other two graphs have half the system oriented in two different directions. Figure 36 demonstrates that the south oriented system has a higher production at this time of year. This is due to a lower incidence angle in a longer period.

The production is shown by the orange line in figure 36. The southeast and southwest oriented system has about 24% less daily energy production than the south oriented system, while the east and west oriented system has about 75% less daily energy production. It is worth noticing that the time of production is similar, but the production to the south is far higher.

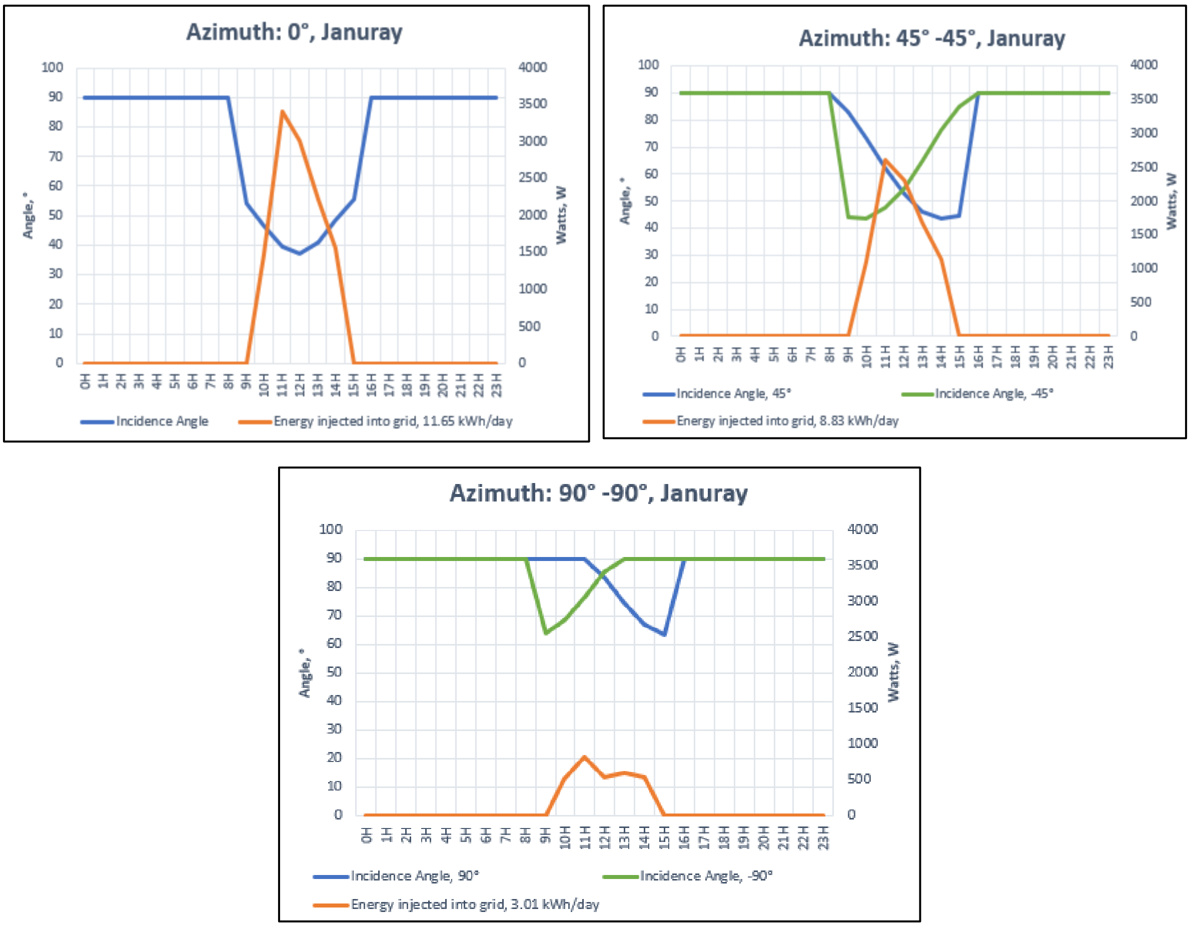


Figure 36 Incidence angle and energy output for a clear day in January. Three orientations; Left graph (south), right graph (southeast and southwest) and bottom graph (east and west).: location Oslo

Sun height, sun azimuth and array current, June

Looking at a summer day, the difference in production time of day becomes clearer. As shown in figure 37, the difference in orienting the panels –45° and 45° from directly south does not give a large impact on the daily array current production. Southwest and southeast oriented panels show signs of an evenly distributed production, whereas directly south has a higher peak. The array current production through the day with an 0° azimuth angle and an -45 ° and 45° azimuth angle is almost identical. This indicates that the deviation in orientation makes little to no difference on a sunny summer day. The east and west oriented system with an azimuth angle of -90° and 90° demonstrate a much wider production, where the daily array current production is noticeably less than that of the other two orientations. However, figure 37 shows that the system is producing more during “high peak” periods such as morning and evening.

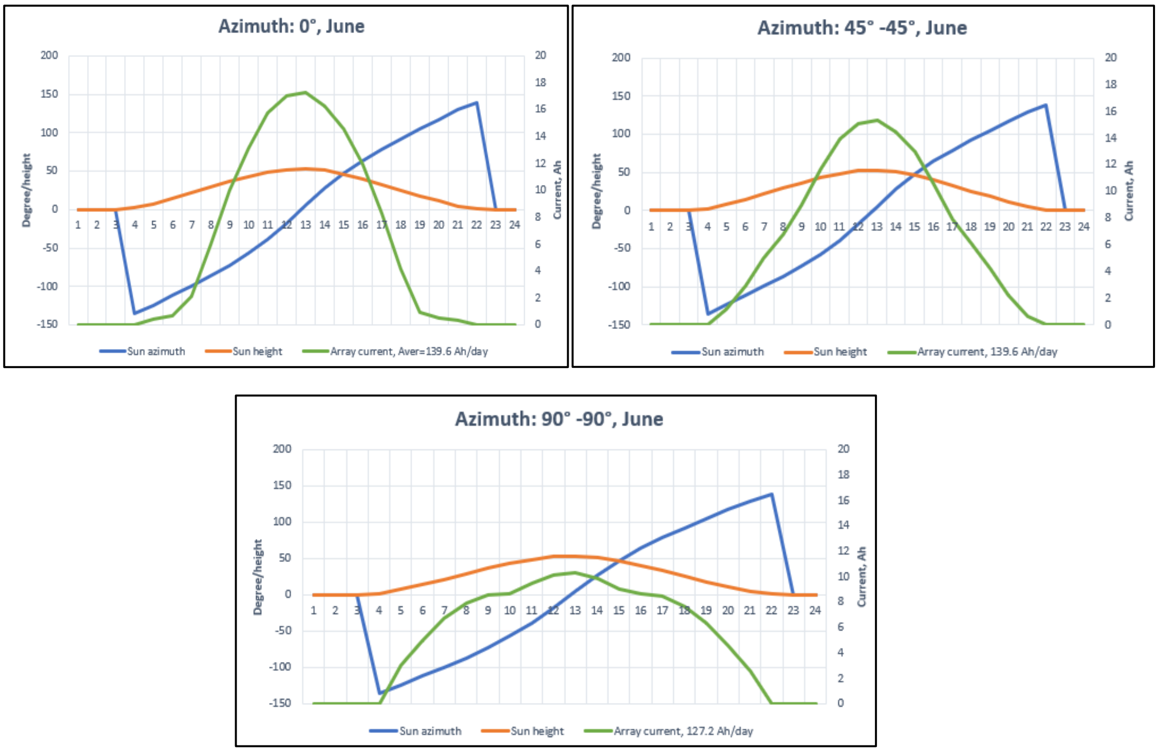
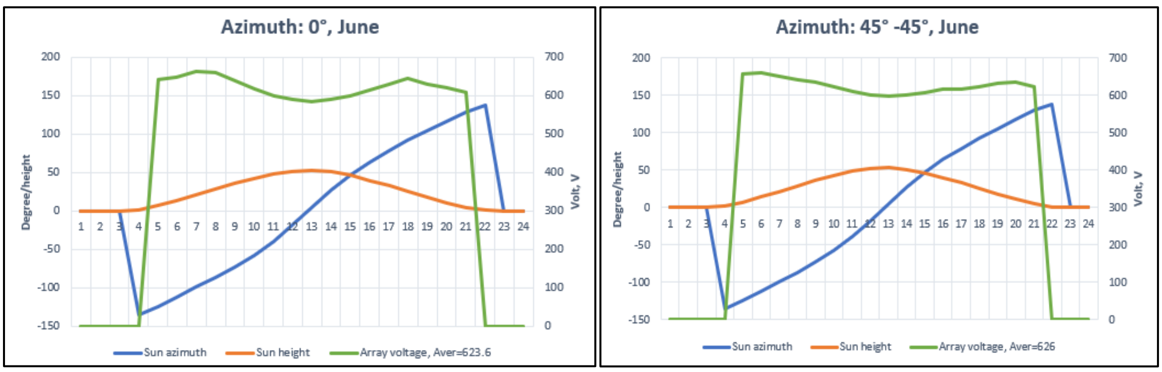


Figure 37 Sun azimuth, sun height and array current for a clear day in June. Three orientations; Left graph (south), right graph (southeast and southwest) and bottom graph (east and west). Location: Oslo

Sun height, sun azimuth and array voltage, June.

The panels are connected in series, thus the voltage is somewhat equal. The noticeable part of the graphs in figure 38 is the declining voltage when the sun is at its highest. This may be caused by an increase in the module temperature. The south oriented system is more affected by this and shows a decline in voltage midday. The south oriented system has the lowest average array voltage of the three orientations, and the east and west oriented system present a smooth graph with smaller variations than that of the two other orientations. The voltage is above zero from about 05:00 until 22:00 for all orientation, which stipulates that the system is operating and producing energy during this time interval.



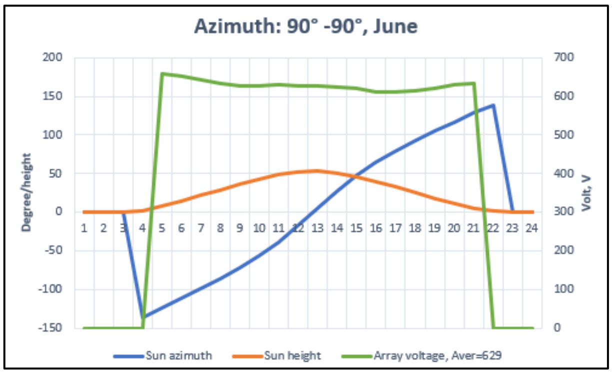
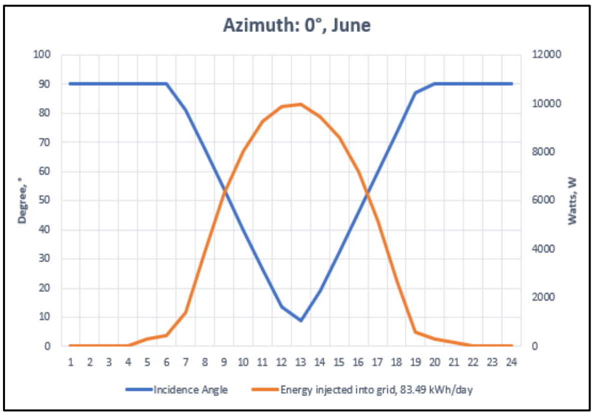
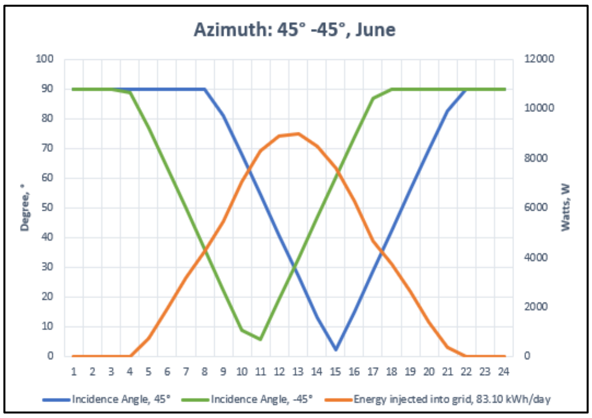


Figure 38 Sun azimuth, sun height and array voltage for a clear day in June. Three orientations; Left graph (south), right graph (southeast and southwest) and bottom graph (east and west). Location: Oslo

Incidence angle with production, June

As shown in figure 39, the total system production is affected by the incidence angle of the suns irradiation. The south oriented system has its peak when the incidence angle is at its lowest, while the other two directions have its peak when the incidence angle cross each other's graphs. This is due to both "sides" of the system working at a decent capacity. Looking at the east and west oriented system, the production is spread out. This distribution occurs because the eastern panels will have a lowers incidence angle during the morning, and during in the evening, the western panels will have a lower incidence angle.





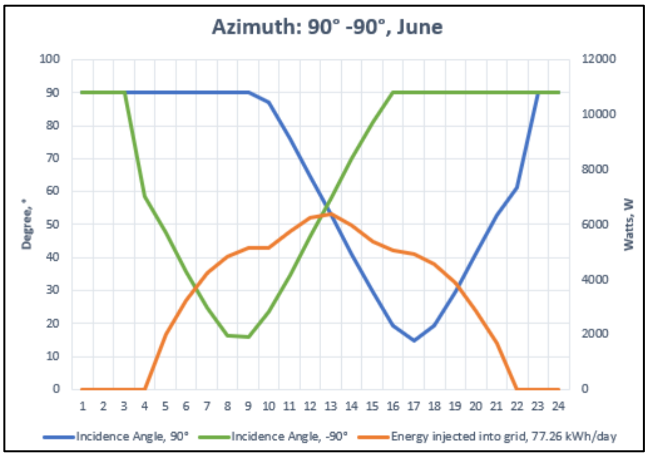


Figure 39 incidence angle and energy output for a clear day in June. Three orientations; Left graph (south), right graph (southeast and southwest) and bottom graph (east and west). Location: Oslo

Module temperature and array voltage, June.

As shown in figure 40, the module temperature in the south oriented system has a peak around noon, when the sun is at its strongest. At the same time midday, the module temperature is increasing, at this point the voltage has a short decline. It seems that the increasing module temperatures has led to a decrease in voltage, lowering the production to some degree. The same pattern can be said for the southeast and southwest oriented system to a smaller degree, while the east and west oriented system has a smaller bulk in the voltage. The average array voltage in the south oriented system is 5.4 Volt less than that of the east and west orientation, and 2.4 Volt less than that of the southeast and southwest orientation. This is visualised in figure 40.

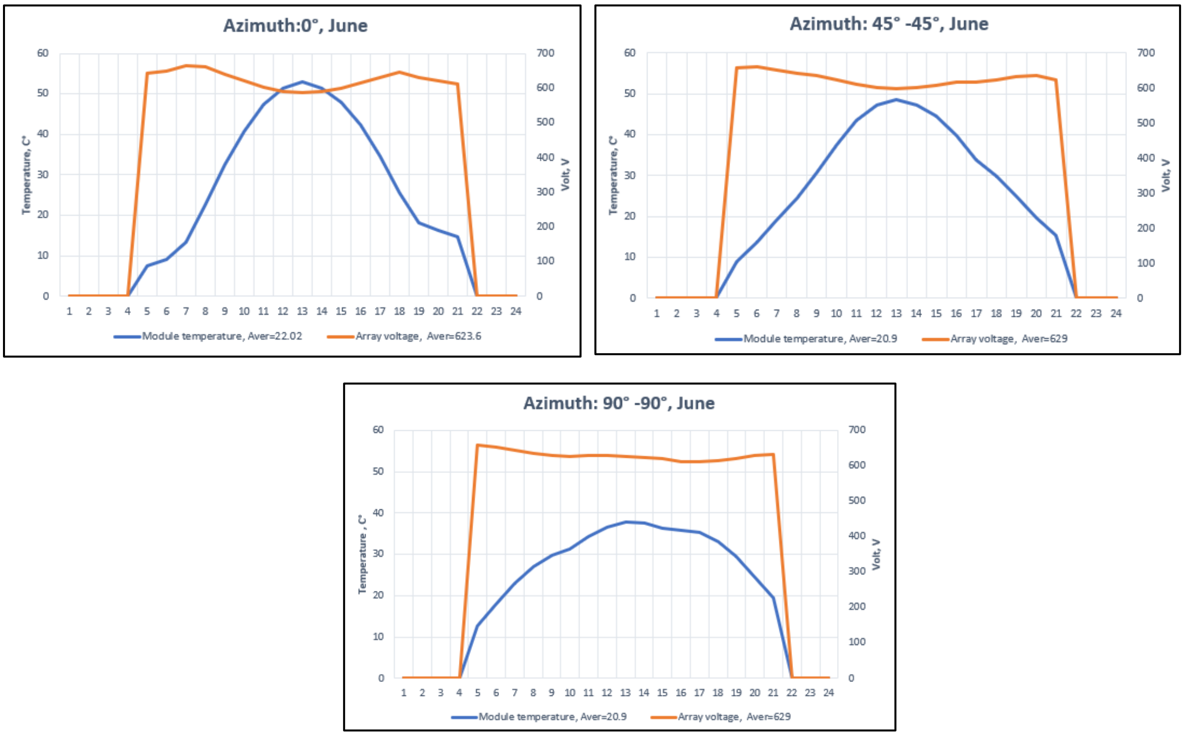


Figure 40 Module temperature and array voltage for a clear day in June Three orientations; Left graph (south), right graph (southeast and southwest) and bottom graph (east and west). Location: Oslo

Table of average daily operating values for every month, Oslo

Table 3 shows the average daily value for current, voltage and energy output, for every month of the year. As demonstrated in table 3, the average monthly operating values are different from that of the operating values for a single day in June or January, as revealed in figures 37-40. Looking at the summer months, the energy output for a clear day is higher than the average. This is because the average value includes days with poor solar conditions such as cloudy periods. It is also presented how the current and production variates as the months go by. Giving higher values in late spring and summer. The voltage is higher during the winter months due to colder weather and better operating conditions for the PV system.

It is demonstrated in table 3 that the azimuth angle of 90° and -90° oriented system is falling behind in energy output every month, especially during the winter. The azimuth angle of 0° has far better average operating values during winter, early spring and late fall. During the summer months, the operating values are quite equal, especially to the system with and azimuth angle of 45° and -45°. The system with azimuth angle 45° and -45° has its peak in June and July, where this orientation has the highest daily energy output out of all orientations. It should be mentioned that this is by negligible numbers and that a system with azimuth angle of 0° is close to identical to a system with azimuth angle of -45° and 45° in June, July and May.

Table 3 Showing average operating values for each month, including average daily current, average operating voltage and average daily energy output. Number coloured with green showing the highest value and red showing the lowest. Three orientations (azimuth: 0°, 45° and -45°, 90° and -90°) is also included in the table. Location: Oslo

Azimuth angle	Average daily current (A)	Average daily operating voltage (V)	Average daily Energy output (kWh)
January			
0°	12.5	677.7	8.3
45 -45°	9.7	654.9	6.4
90 -90°	4.1	646.4	2.6
February			
0°	26.5	682.2	17.7
45 -45°	21.9	668.8	14.7
90 -90°	13.0	666.2	8.7
March			
0°	59	667.4	38.2
45 -45°	51.3	660.0	33.2
90 -90°	34.5	659.7	22.7
April			
0°	71.6	653.6	45.2
45 -45°	67.9	642.6	42.8
90 -90°	54.9	649.8	35.0

May			
0°	87	638.9	53.6
45 -45°	86.3	638.8	53.2
90 -90°	77.8	639.3	48.4
June			
0°	90.3	628.5	54.8
45 -45°	90.5	627.5	54.9
90 -90°	83.9	629.9	51.3
July			
0°	85.6	622.5	51.3
45 -45°	85.5	622.7	51.4
90 -90°	78.6	623.4	47.7
August			
0°	70.1	624.3	42.1
45 -45°	67.8	623.4	40.9
90 -90°	58.1	622.7	35.4
September			
0°	57.3	639.7	35.4
45 -45°	52.3	632.2	32.3
90 -90°	39.9	630.7	25.0
October			
0°	29.4	651.2	18.5
45 -45°	24.9	644.7	15.7
90 -90°	16.3	642.3	10.4
November			
0°	11.6	649.7	7.5
45 -45°	9.4	640.2	6.0
90 -90°	5.1	635.5	3.2
December			
0°	6.9	668.1	4.6
45 -45°	5.3	655.0	3.5
90 -90°	2.2	650.3	1.4

4.2.2 Subchapter summary, operating conditions eastern location (Oslo)

The production in January is low, which could be expected due to overall less sunlight during the winter months. Orienting the panels with a lesser azimuth angle yields a higher production during the winter months. Operating conditions during a clear summer day shows some interesting results. The production is almost identical for a system with 0° azimuth angle and a system with -45° and 45°

azimuth angle. Orienting the panels 45° to the east or west, does not appear to influence the overall production on a clear summer day. The production for a system with an azimuth angle of -90° and 90° is less than that for a system oriented south. During the winter months, the production is less than half, while in the summer, the production is similar with around 7-8% less daily production than that of the other system orientations. Also, in the system with an azimuth angle of -90° and 90°, the production is spread-out during the day. The figures presented in this subchapter demonstrates how much of the power is produced in a short amount of time (midday), especially when the orientation is directly south. The east and west orientation have far smaller peaks and an evenly distributed production.

In January, the voltage is somewhat higher than in June. This is due to temperatures being lower during the winter months. On a clear day in June, the voltage has a drop due to an increasing module temperature, which is especially noticeable when the panels are oriented directly south. It is interesting to observe how an increase in module temperature affects the system voltage, where the south oriented panels are far more affected than that of the east and west oriented panels. This is particularly visible during a clear day in June, and not as noticeable in the average values shown in table 3. The voltage drop is easy to spot in a clear day where the sun is shining several hours to the system, but when analysing average values as shown in table 3, the voltage has smaller variations and the difference in operating conditions are harder to spot.

The east and west oriented system has some advantages when looking closer to time of day production and operating conditions. The power produced in this orientation is more evenly distributed, and will avoid the large production peak midday as opposed to the south oriented system. However, the overall yearly production is making this option less attractive.

4.2.3 Analysis of operating conditions, northern location (Tromsø)

The same simulated case studies are carried out for a northern location (Tromsø). Using the same conditions with three orientations at two specific days. The south oriented system has 40 panels directly oriented south with an azimuth angle of 0°, showing to the left on graphs in the following figures. The southwest and southeast oriented system has 20 panels facing southeast and 20 panels facing southwest with an azimuth angle of 45° and -45°, presented to the right on the graphs in the following figures. The east and west oriented system has 20 panels facing east and 20 panels facing west with an azimuth angle of 90° and -90°, showing at the bottom on the graphs in the following figures.

Sun height, sun azimuth, array voltage, energy production, incidence angle and array current, January.

As shown in figure 41, there is zero power production in January for the northern location. Looking above in the previous subchapter, the results for the eastern location are different and show some power production in January. The results presented in figure 41 can be expected during December and January, as well as parts of February and November as presented in table 4. No further analysis is required for the operating condition on a winter day.

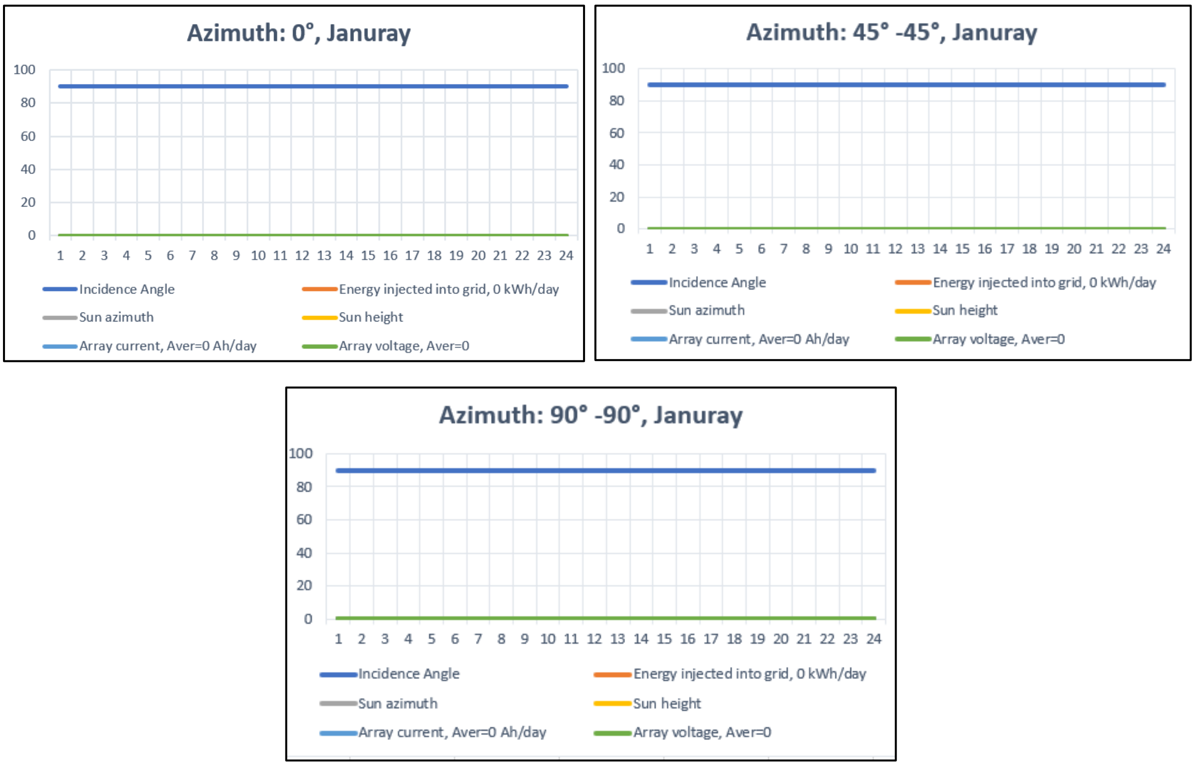
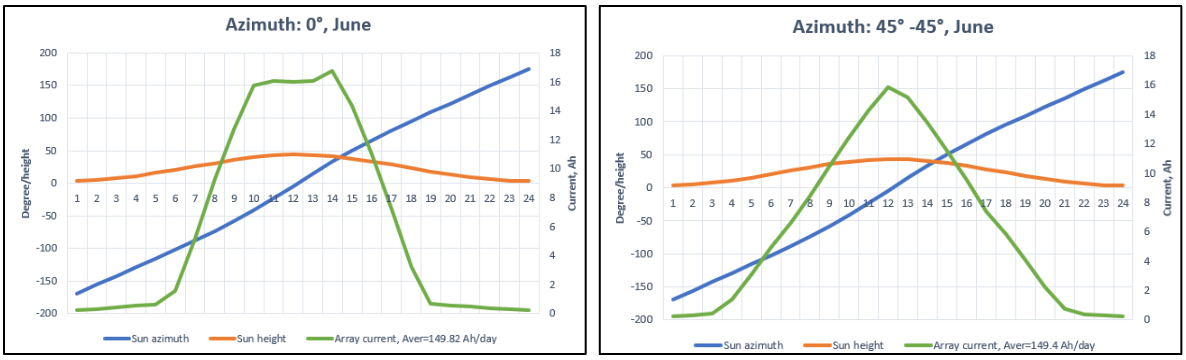


Figure *41* Inc*idence angle, sun azimuth, array current, array voltage, energy output and sun height for a clear day in June*. *Three orientations; left* graph *(south), right* graph *(southeast* and *southwest) and bottom* graph *(east* and *west). Location: Tromsø.*

Sun height, sun azimuth and array current, June

As shown in figure 42, the system with an azimuth angle of 0° and the system with an azimuth angle of -45° and 45° show approximately the same average current per day. Despite the graphs showing somewhat different patterns, as the south oriented system has a longer peak and a steep climb, the southeast and southwest oriented system has a shorter peak but a slack climb. The east and west facing system have somewhat less array current throughout the day and a far less peak production. This orientation can boast about having a decent array current early morning and late night.



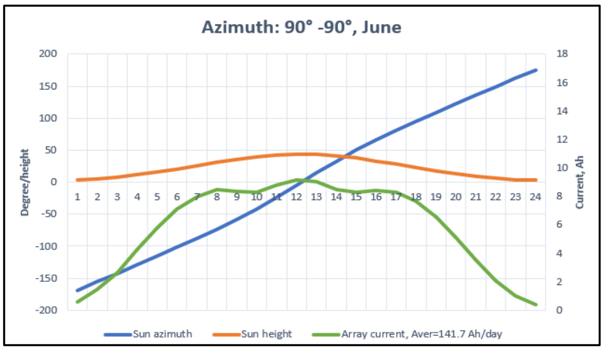


Figure 42 Sun azimuth, sun height and array current for a clear day in June Three orientations; left graph (south), right graph (southeast and southwest) bottom graph (east and west). Location: Tromsø

Sun height, sun azimuth and array voltage, June.

As shown in figure 43, all three orientations have an operating voltage 24 hours a day. This indicates that the system is running 24 hours a day with a continuous production. The voltage is quite similar for all three orientations, with some higher ups and downs for the south oriented system, as well as the southeast and southwest oriented system. The east and west oriented system have a steady operating voltage, with less variations throughout the day.

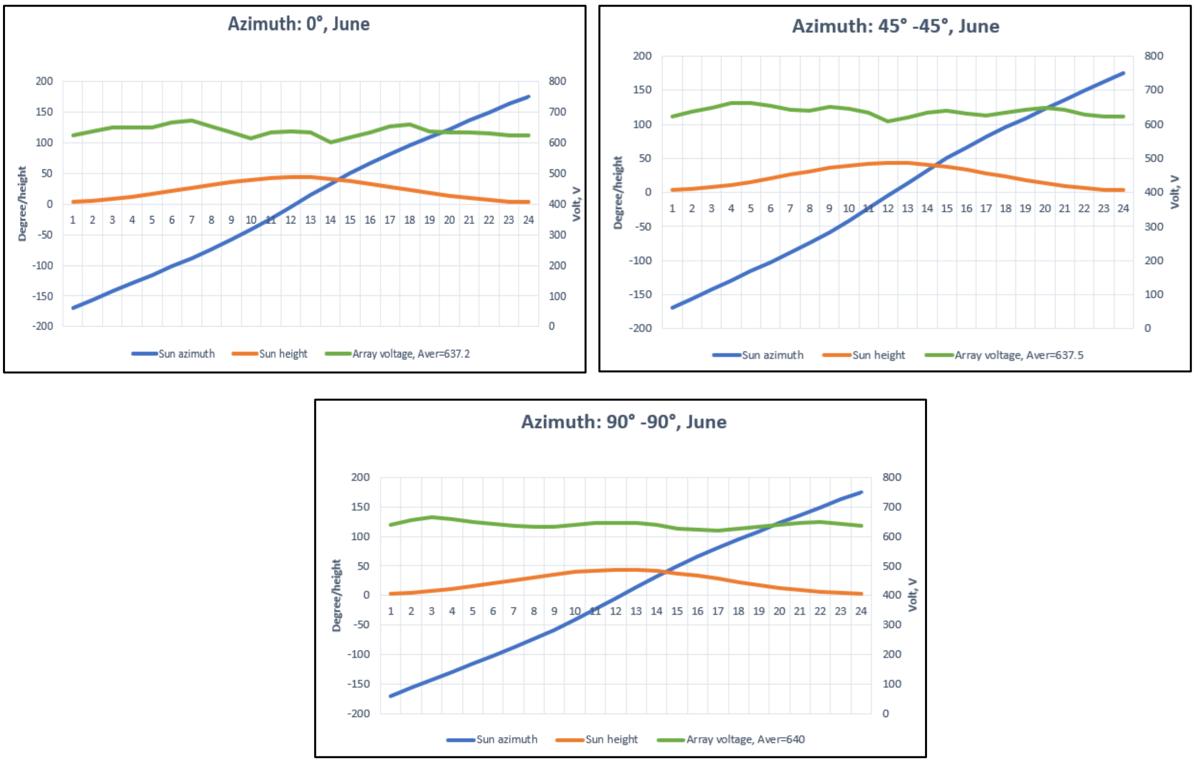


Figure 43 Sun azimuth, sun height and array voltage for a clear day in June Three orientations; left graph (south), right graph (southeast and southwest) bottom graph (east and west). Location: Tromsø

Incidence angle with production, June

As shown in figure 44, the total daily production on a clear summer day in the northern part of Norway is higher than that of a southern location. As demonstrated in figure 44, there is a decent 24 hour/day production when the panels are oriented east and west. This allows the consumer to utilize self-produced power at all hours of the day. In the south oriented system, the production decreases in the mornings and evenings. In return, the south oriented system has a higher daily production. Similar to the eastern location, the systems with an azimuth angle of 0° and system with an azimuth angle of -45° and 45° are close to identical when it comes to daily energy output on a clear day in June.

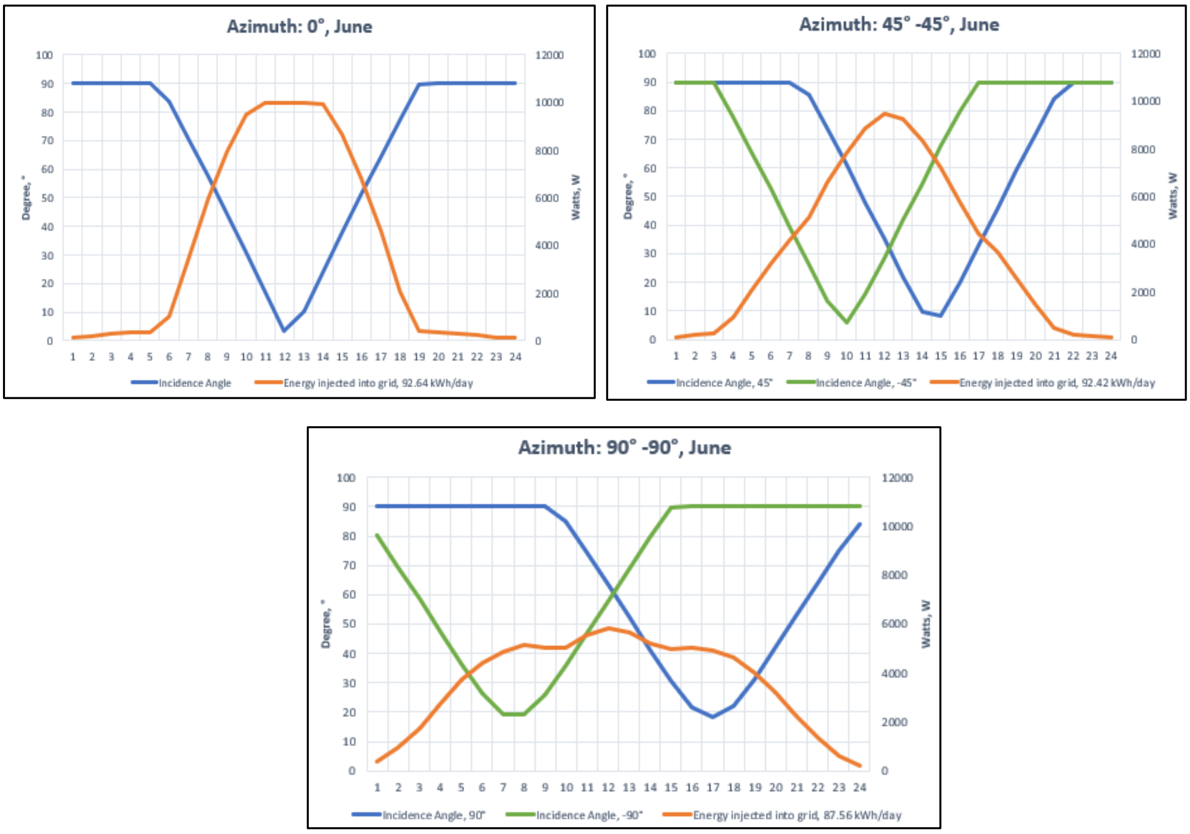


Figure 44 incidence angle and energy output for a clear day in June Three orientations; left graph (south), right graph (southeast and southwest) bottom graph (east and west). Location: Tromsø

Module temperature and array voltage, June.

The voltage is not as affected by the temperature in the north compared to the south when looking at a clear day. There is some reduction in voltage when the temperature reaches its peak. The cell temperature is higher than 0 degrees Celsius over the course of the entire day, which makes the overall variations throughout the day smaller. This is shown in figure 45. Looking at the east and west orientation, the temperature never reaches the same level that of the south oriented system.

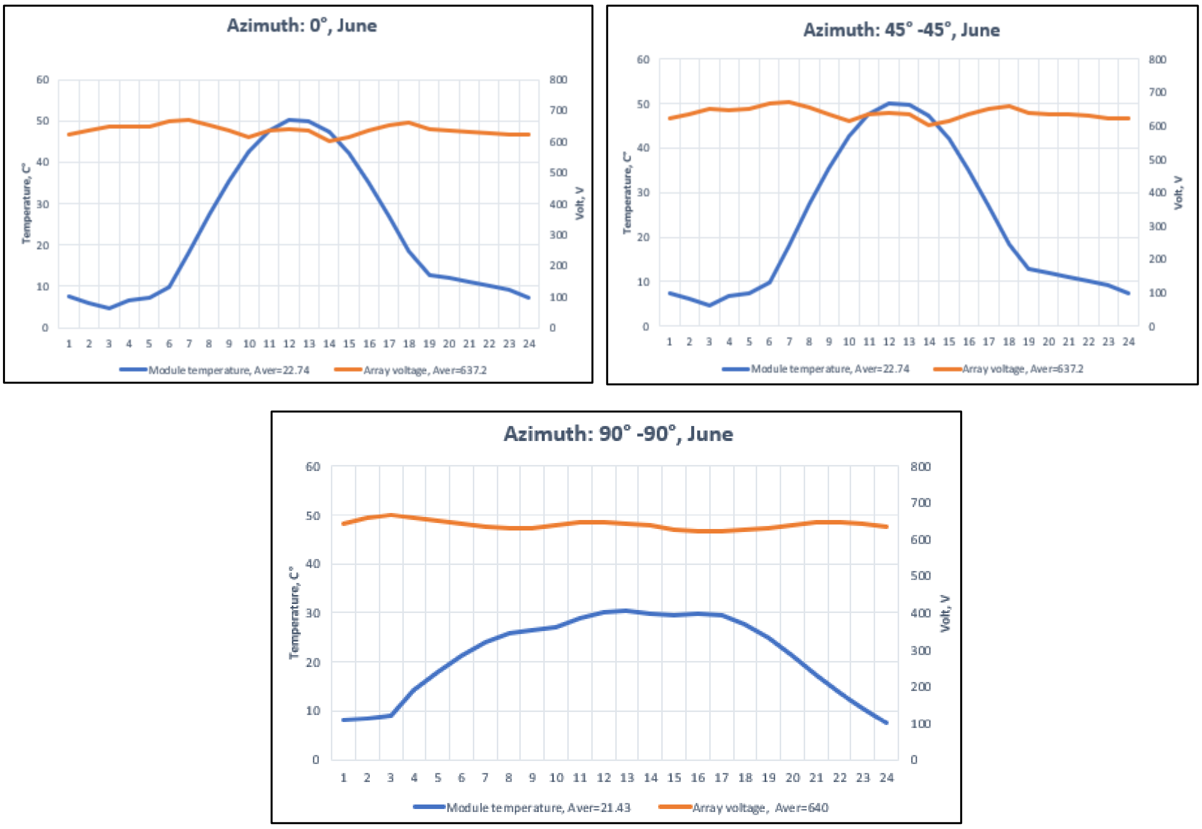


Figure 45 Module temperature and array voltage for a clear day in June Three orientations; left graph (south), right graph (southeast and southwest) bottom graph (east and west). Location: Tromsø

Table of average daily operating values for every month, Tromsø

Table 3 shows the average daily value for current, voltage and energy output for each month of the year. As presented in chapter "2.2 solar potential", it can be expected that the average operating values for January and December are 0, and the output energy for February and November are relatively small. Looking at monthly average values, it can be observed that the voltage during the summer months is lower for a system oriented directly south. Even though the voltage variations are small, this likely occurs due to an increase in module temperatures. The summer energy output is close to identical for system with an azimuth angle of 0° and a system with an azimuth angle of -45° and 45°. This was also the case for a clear day in June, demonstrated in figure 44. The variations in power production becomes clearer as the season moves to fall and spring. In figure 42-45, a clear day in June was analysed. As presented in table 4, the northern location is producing more energy in April and May compared to June.

Table 4 showing average operating values for each month, including average daily current, average operating voltage and average daily energy output. Number coloured with green showing the highest value and red showing the lowest. Three orientations (azimuth 0°, 45° and -45°, 90° and -90°) is also included in the table. Location: Tromsø

Azimuth	Average daily current (A)	Average operating voltage (V)	Average daily Energy output (kWh)
January			

0°	0	0	0
45 -45°	0	0	0
90 -90°	0	0	0
February			
0°	21.9	671.6	14.8
45 -45°	16.6	669.1	11.2
90 -90°	6.6	656.0	8.6
March			
0°	63.4	678.7	41.9
45 -45°	52.5	676.2	34.9
90 -90°	30.4	678.7	20.4
April			
0°	93.8	651.9	60.1
45 -45°	86.2	665.1	55.9
90 -90°	63.8	667.8	41.9
May			
0°	86.9	651.9	55.1
45 -45°	84.3	653.1	53.6
90 -90°	74.5	653.3	47.8
June			
0°	83.0	631.1	50.4
45 -45°	81.8	642.1	50.9
90 -90°	76.2	641.3	47.9
July			
0°	71.7	635.8	44.7
45 -45°	71.2	636.5	44.7
90 -90°	67.6	635.9	42.2
August			
0°	60.1	640.1	36.0
45 -45°	57.1	641.1	35.9
90 -90°	47.6	640.6	30.0
September			
0°	45.6	647.5	28.8
45 -45°	40.1	648.1	25.4
90 -90°	28.0	646.1	17.9
October			
0°	19.7	667.5	12.7
45 -45°	16.1	665.7	10.3

90 -90°	9.5	681.7	6.0
November			
0°	4.4	667.5	2.9
45 -45°	3.3	680.9	2.1
90 -90°	0.9	664.1	0.5
December			
0°	0	0	0
45 -45°	0	0	0
90 -90°	0	0	0

4.2.4 Subchapter summary, northern location

Looking at the figures and tables in this subchapter, it is shown that the operating conditions for a summer day in the northern location is better than that of the southern location. The northern location can produce energy 24 hour a day during the summer months, while the southern location can provide energy for approximately 18 hours. During the winter months the northern location has 0 hours of production, while the southern location can produce for approximately 5 hours on a clear winter day.

Once again, the produced power during a summer day is nearly identical for a system with an azimuth angle of 0° and a system with an azimuth angle of -45° and 45°. A system with an azimuth angle of -90° and 90° has about 6-7% less production compared to the other orientations on a clear summer day. As shown in figure 43, the voltage is constant around 600V on a summer day, this is due to the system continuously producing power. The array voltage stays about the same throughout the day, while the array current is changing depending on irradiation at a specific point of the day. A voltage drop, at midday is not as noticeable in Tromsø compared to Oslo.

There are some advantages with orienting the panels in an east and west orientation in Tromsø. The production is spread out and there is decent production 24 hours a day, at least on a clear summer day. Setting the panels east and west avoids the large peak in production midday, which can contribute to a better energy flow to the electric grid. A significant disadvantage with the orientation, is the overall production, which is considerable smaller than that of a south oriented system, questioning the financial aspect of this orientation.

Investigating operating condition in Oslo and Tromsø, it is discovered that during the late spring and summer, Tromsø has better operating conditions and thus a higher average production. Looking at a clear day in June, the daily operating conditions show more promising results. The downside for the northern location is the overall lack of production during the winter months.

4.2.5 Further analysis

The next chapter will take a closer look into the time of day production and incorporate a financial factor. Tromsø and Oslo will be investigated further, and an energy price based on a potential tariff as well as the energy price in the final quarter of 2018 will be used as the value of kWh. The next chapter also investigates the LCOE of the systems.

4.3 Part 3, financial analysis for northern and eastern location (Tromsø and Oslo)

4.3.1 Matching time of production with price of energy

This subchapter takes a closer look into the time of day production, which is compared with two different energy prices. The chapter will include a short financial analysis, looking at the value of the kWh produced. Three different orientation will be analysed using two location, namely Oslo and Tromsø. At the end of this section, a break-even energy price will be induced. This analysis will contain two orientations. The break-even energy price is with regards to a system oriented south contra a system oriented east and west

Oslo

Figure 46 shows the average daily production for the four seasons, as well as a potential energy price using potential tariffs. The following left graph is based on a south oriented system with an azimuth angle of 0°. The following right graph is based on a southwest and southeast oriented system with an azimuth angle of 45° and -45°. The following bottom graph is based on an east and west oriented system with an azimuth angle of 90° and -90°.

As demonstrated in figure 46, for a system oriented south and a system oriented southwest and southeast, an average day during spring and summer has a high production. The negative side of this is that the production is peaking when the price of electricity is low. During the summer, the east and west oriented system has a production that drops below the tariff line at around 19:30, while in the other two directions this occur earlier. This indicates a higher value of the power produced at this time of day in the east and west oriented system.

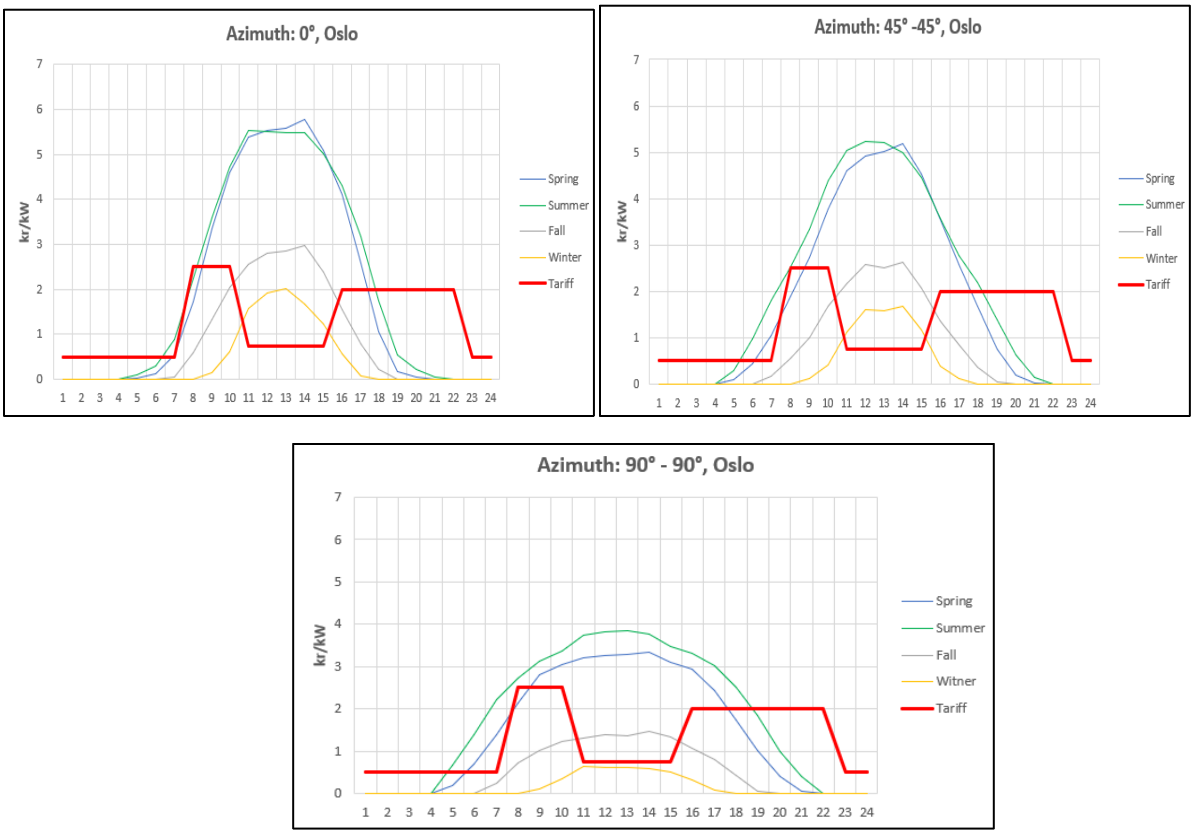


Figure 46 Graphs showing the average daily energy output for all season matched up with a variation energy price. Three orientations: Left graph (south), right graph (southeast and southwest) and bottom graph (east and west). Location Oslo.

Table 5 gives the value of the kWh produced per season, using a variating energy price as well as a set price of 1.23 kr/kWh. The production is divided into four seasons, this due to a high difference in average production during summer contra winter. As shown in table 5, the south oriented system provides the highest value in spring, fall and winter, regardless of the variating energy price. The interesting factor shown in table 5 is that a southwest and southeast oriented system provides a higher value during the summer. The east and west orientation provides the lowest value in all orientations, with the large difference being in the winter. In the winter months the produced value of a east and west oriented system is close to one third of the south oriented system (using 1.23kr/kWh).

Table 5 Showing the potential value for he energy produced by the system. Both using a variating energy price and a constant energy price. Number coloured with green showing the highest value and red showing the lowest. Three orientations are included in the table. Location Oslo

Oslo all seasons			
Orientation and azimuth angle	**Average daily energy output for season (kWh)**	**Potential value of energy, using variating price kWh value (kr)**	**Potential value of energy, using current kWh price of 1.23 kr/kWh**

			(kr)
Spring			
South 0°	45.67	60.96	56.12
Southwest and southeast 45° -45°	43.05	57.61	52.96
West and east 90° -90°	35.07	50.46	43.14
Summer			
South 0°	48.83	67.27	60.06
Southwest and southeast 45° -45°	48.99	67.36	60.26
West and east 90° -90°	44.29	63.46	54.48
Fall			
South 0°	20.14	25.21	24.77
Southwest and southeast 45° -45°	18.06	22.49	22.21
West and east 90° -90°	12.41	17.37	15.26
Winter			
South 0°	9.80	9.46	12.05
Southwest and southeast 45° -45°	8.19	7.71	10.07
West and east 90° -90°	3.82	4.16	4.70

Tromsø

Figure 47 shows the average daily production for the four seasons, as well as a potential energy price, using potential tariffs. The following left graph is based on a system oriented south with an azimuth angle of 0°. The flowing right graph is based on a system oriented southwest and southeast with an azimuth angle of 45° and -45°. The following bottom graph is based on a system oriented east and west with an azimuth angle of 90° and -90°.

As figure 47 shows, the east and west oriented system is producing more energy in the periods with higher energy cost. In return, this orientation is producing far less during midday. The east and west orientation may cover more of the energy consumed, considering the relative high production in the early morning and late night. The production peak for a south oriented system occur when the price of energy is low.

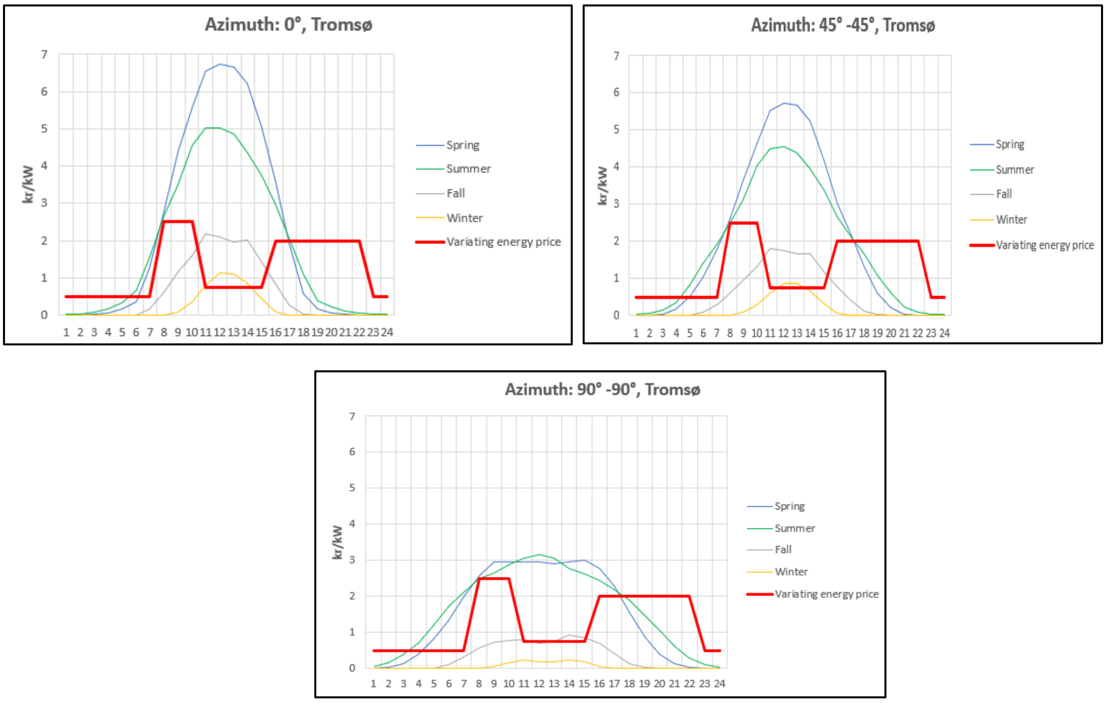


Figure 47 Graphs showing the average daily energy output for all season matched up with a variation energy price. Three orientations: left graph (south), right graph (southeast and southwest) and bottom graph (east and west). Location Tromsø.

Once again does the south oriented system gives the highest production at spring, fall and winter. However, during the summer months, it is more profitable to have the panels oriented southeast and southwest with a constant energy price of 1.23 kr/kWh, seeing as the production is slightly higher. Using a tariff with variating energy prices, the south oriented system gives the highest value, regardless of season.

Table 6 Showing the potential value for he energy produced by the system. Both using a variating energy price and a constant energy price. Number coloured with green showing the highest value and numbers coloured with red showing the lowest Three orientations are included in the table. Location Tromsø

	Tromsø all seasons		
Orientation with azimuth angle	**Average daily energy output**	**Potential value of energy, using**	**Potential value of energy, using**

	for season (kWh)	variating price kWh value (kr)	Current kWh price of 1.23 kr/kWh (kr)
Spring			
South 0°	52.12	68.8	64.12
Southwest and southeast 45° -45°	48.15	63.49	59.22
West and east 90° -90°	36.03	50.75	44.31
Summer			
South 0°	43.57	59.34	53.59
Southwest and southeast 45° -45°	43.7	59.06	53.75
West and east 90° -90°	39.04	54.14	48.02
Fall			
South 0°	14.42	18.13	17.74
Southwest and southeast 45° -45°	12.64	16.08	15.55
West and east 90° -90°	7.70	10.83	9.48
Winter			
South 0°	4.89	4.57	6.02
Southwest and southeast 45° -45°	3.75	3.53	4.62
West and east 90° -90°	1.28	1.41	1.58

4.3.2 LCOE for the systems

Table 7 shows LCOE for both Tromsø and Oslo. The parameters used in the calculations is also shown in table 7. The producer of solar cells often has a warranty that includes a max efficiency loss of 20% after 25 years, this is due to wear and tear. Knowing that after 25 years the total efficiency loss is 20%, a yearly efficiency loss can be calculated to be 0.9%, this from "equation 2.15". The lifetime of the LCOE calculations is set to 25 years, this is based on the length of the warranty. Many PV system has an expected lifetime of more than 25 years, this may lead to some inaccuracy in the LCOE calculations preformed in table 7. The total cost is set to 167 460 Kr, this is the initial installation cost, there is no maintenance cost included. This is based on that all components last 25 years. The discount rate is set to 3%, which is a standard discount rate, according to NREL [38].

Table 7 Showing the financial aspect of the PV system. Numbers coloured with green showing the lowest LCOE and numbers coloured with red showing the highest LCOE. Three orientations and two locations are included in the table.

Cost and LCOE, system size 12kW						
OSLO						
Orientation with azimuth angle	System cost (kr)	Efficiency loss per year	Lifetime (years)	Discount rate:	Price per Watt Kr/W	LCOE (kr/kWh)
South 0°	167 460	0.9%	25	3%	14	0.643
Southwest and southeast -45° 45°	167 460	0.9%	25	3%	14	0.660
West and east -90° 90°	167 460	0.9%	25	3%	14	0.831
TROMSØ						
South 0°	167 460	0.9%	25	3%	14	0.693
Southwest and southeast -45° 45°	167 460	0.9%	25	3%	14	0.748
West and east -90° 90°	167 460	0.9%	25	3%	14	0.935

4.3.3 Break-even energy price

Using data such as time of day production from previous subchapters, a break-even energy price can be presented. This break-even value is based on that a system oriented south with an azimuth angle of 0°, will provide the same value as a system oriented east and west with an azimuth angle of -90° and 90°, during a full year. With an energy price that favours a more east and west orientation a break-even energy price is shown in figure 48. The average energy price throughout the day is 1.24 Kr/kWh (close to previous of 1.23 Kr/kWh). However, the energy price is manipulated to find the break-even point. Having a value of 0.15 Kr/kWh in the highest producing hours, 11:00-15:00. Look “appendix 8.5” for an hour to hour price.

The break-even price presented below shows a similar pattern as the energy price using potential tariffs, investigated previously in this subchapter. With high price in the morning, low price midday and high pricesin the evening, the break-even energy price can be considered an extreme version of the potential tariff energy price induced during methodology, in section “3.2 Potential energy price, with regards to electric grid tariffs.”.

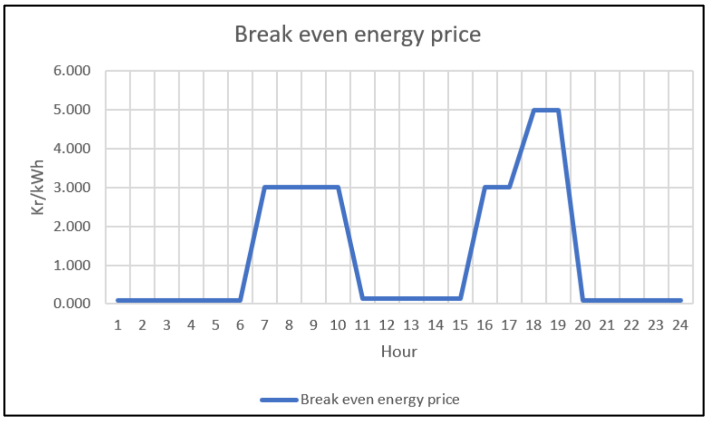


Figure 48 Break-even energy price for a system oriented south with an azimuth angle of 0° and a system oriented east and west with an azimuth angle of -90° and 90°

Figure 49 shows the break-even energy price matched with average daily production for all seasons. As shown in figure 49, the value of kWh is low as the PV production is peaking. Figure 49 compare a system oriented south and a system oriented east and west. As illustrated in figure 49, the break-even energy price has a far higher value as the production from the east and west oriented system is higher than that of a south oriented system.

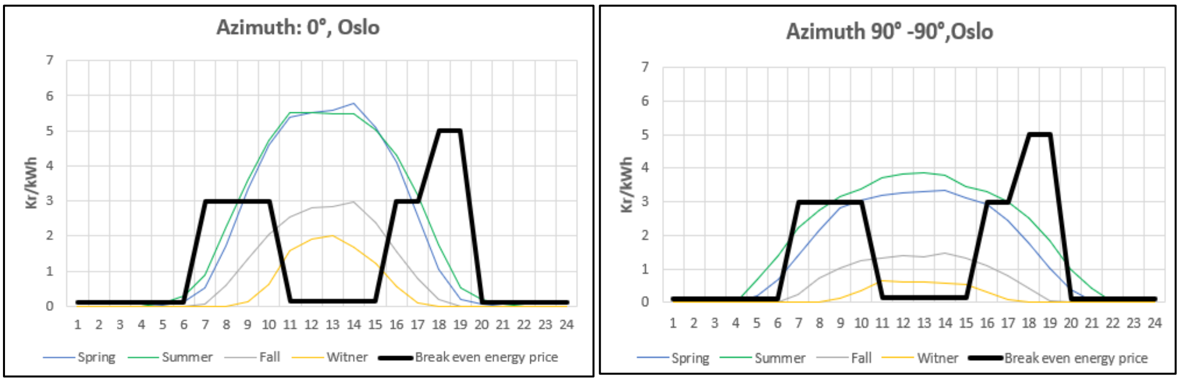


Figure 49 Break-even energy price, matched up with average daily production for all season

Table 8 gives the average daily value of the energy prouced, using the break-even enery price. All seasons and two orientations are included in table 8. Table 8 also gives the added total value throughout the year.

Table 8 showing the value of the average daily energy produced for all seasons, using the break-even energy price.

Oslo all season		
Orientation with azimuth angle	**Average daily energy output for season(kWh)**	**Potential value of energy, using break-even energy price from figure 48 (Kr)**
Spring		
South 0°	45.67	60.94
East and west -90° 90°	35.07	60.74
Summer		
South 0°	48.83	72.17
East and west -90° 90°	44.29	78.37
Fall		
South 0°	20.14	22.19
East and west -90° 90°	12.41	18.64
Winter		

South 0°	9.80	5.42
East and west -90° 90°	3.82	3.00
Sum, total value for the entire year.		
Orientation	**Yearly production (kWh)**	**Yearly value, using break even energy price (Kr)**
South 0°	11498	**14620**
East and west -90° 90°	8902	**14620**

4.3.4 Subchapter summary

From a financial point of view, the best orientation throughout the year is orienting the panels to the south with an azimuth angle of 0°, this is the case for both Oslo and Tromsø. However, If the objective is to maximize the value during the summer month, the production is slightly higher as the panels are oriented southeast and southwest, as shown in table 5 and 6. From previous graphs during this subchapter it can be shown that the east and west oriented system is producing energy with a more even graph. This orientation produces more when the value of kWh is higher. Using the energy priced demonstrated in table 5 and 6, this favourable production time cannot make up for the lesser overall production. Even though this is not the case today, a lower value of the kWh in the midday production peaks is potential for future energy prices. Simulations with similar cases using a different energy price, may prove more favourable for an east and west oriented system, given the value of kWh midday is reduced.

The LCOE analysis showed that the cost per unit of power is far lower for a south oriented system. As the installation costs are equal, regardless of orientation, the system with the highest production would give the lowest LCOE. This was to be expected as LCOE does not consider time of production.

The break-even analysis showed that the energy price must deviate far from what is current as of today. The break-even energy price made the energy produced midday nearly worthless, as this energy price favoured an east and west oriented PV system.

4.3.5 Further analysis

The next chapter only includes one geographical locations (Oslo), this location is most relevant due to population density. Close to one third of the population of Norway live in Oslo or close to the Oslo region. Further analysis does not consider production time of day, it only consists of monthly sums of kWh for several orientations.

4.4 Part 4, investigation of production as the azimuth angle change with intervals of 15°, location Oslo.

4.4.1 Overview of energy output for 7 different orientations

Figure 50 shows the monthly production throughout the full year. Looking at figure 50, it is shown that the south oriented system has the highest production for most months. The difference in the production for a system that has 0° azimuth angle and a system that has -30° and 30° azimuth angle is perceptible small. The total yearly production is only 300kWh less. The difference in production is quite noticeable during winter, early spring and late fall. In this period the production for azimuth 0° compared to azimuth -90° and 90° is usually more than double in favour of azimuth 0°. However, during summer, late spring and early fall the production is more even and the production only deviates with about 10%, depending on the given month. The pattern figure 50 demonstrate shows that the production is highest in the south oriented system and then the production decrease as the orientation moves east and west. The first 4-5 orientation changes are not as noticeable as the last 2-3. It is easier to spot the difference in production, if the lower producing months are analysed.

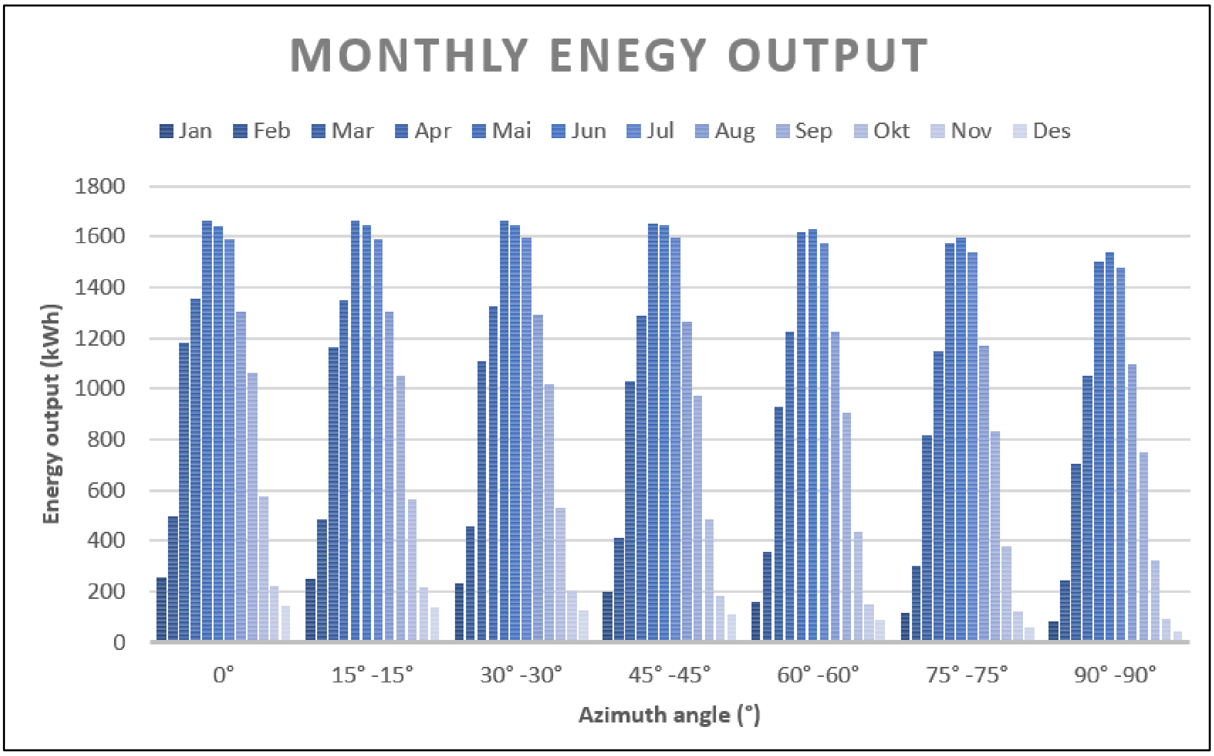


Figure 50 Showing the monthly energy output for 7 orientations. Location: Oslo

Figure 51 gives the total production during the year for a 12kW PV system. This figure gives the same results as figure 50. However, the yearly production is added to one pole. From a yearly perspective, the south oriented system is far more favourable than that of a east and west oriented system.

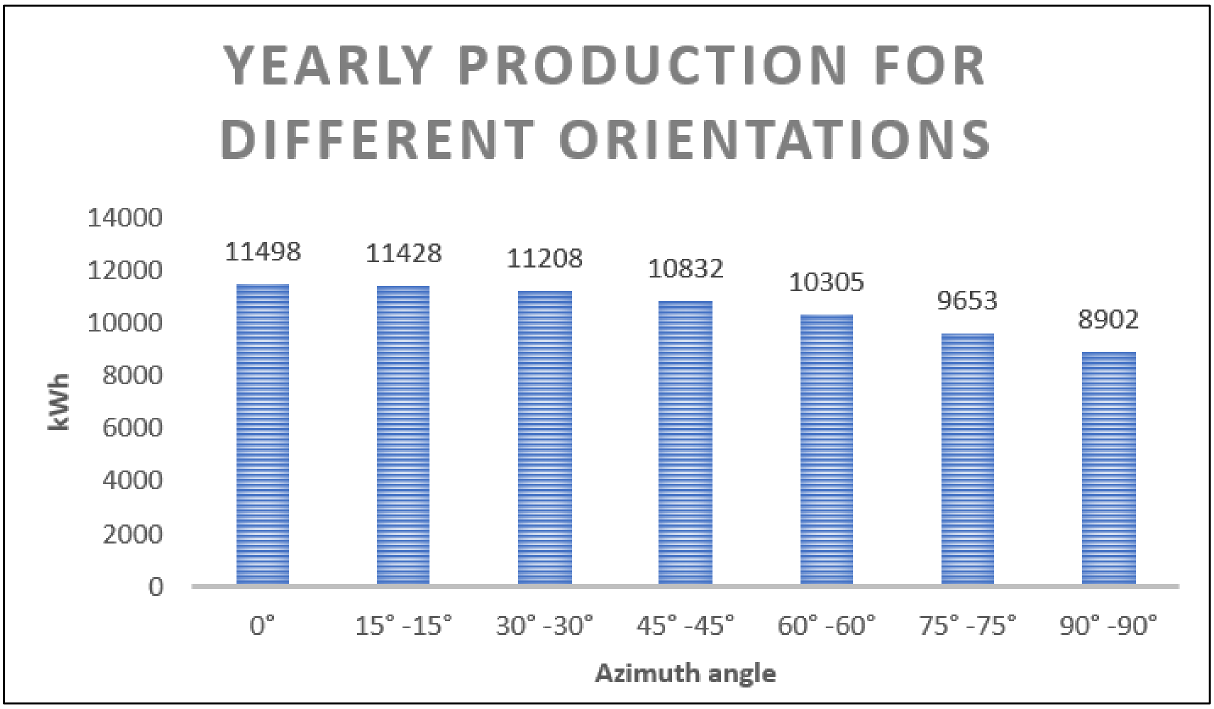


Figure 51 Showing the yearly energy output for 7 orientations. Location: Oslo

4.4.2 Subchapter summary

Looking at the production for changing azimuth angles with intervals at 15°, there is a difference in energy output. The noticeable change comes when the azimuth angle exceeds 45° east or west. The larges variations in production occur during the winter months. During the summer, the orientation makes less difference. The fascinating part is how little the orientation matters when changing the orientation 15° and 30°. This indicates that a roof facing southeast or southwest with an azimuth angle of 0-30° can still expect a yearly production close to optimal.

5 Conclusion

The objective of this thesis was to get a better overview of how the orientation of a PV system will affect the energy production of solar cells. Eight cases were analysed to see how a changing geographical location and orientation will impact the overall production. Looking at the geographical location, it was clear that this made a large impact, both on overall production and time of day production. The overall results demonstrated that the southern part of Norway have the best solar conditions, while the western part of Norway have the worst, having a lower overall production. The best operation condition on a clear summer day was found in the northern part of Norway, with a high daily peak production and a 24-hour voltage, allowing a continuous production. During the winter months, the worst operation condition occurred in northern part of Norway, where the sun never rises for a long period of time.

A PV system oriented directly south as opposed to an east and west oriented system, has a considerable higher production throughout the year. The east and west oriented system has a higher production during morning and evening, where the energy can be argued more valuable. However, this does not make up for the overall lack of production, given the current energy prices. A system oriented between directly south, and directly east and west appear to show far better prerequisite for an overall production. This type of system has a higher production during the summer months, compared to directly south. This is only by a tiny margin and the two orientation is mostly identical, considering average daily production during the summer months. Over the course of a year, this orientation falls behind, and the best choice is still directly south considering a year-round production.

An increase in cellular temperatures had a higher impact on the operating voltage for a system oriented directly south. The south oriented system had a noticeable decrease in voltage at midday, while the east and west oriented system was less affected.

Based on the result found in this report, a recommendation can be concluded. As of today, the best orientation for a PV system is to orient the solar panels directly south. However, since PV system has a life expectancy for +25 year, it is worth investigating how the energy price is expected to change before deciding on the optimal orientation. The current energy price gives a relatively high value on the power produced midday, and if this value is to decrease to a certain degree, an east and west oriented system may be the better choice.

6 Further work

There are several areas that can be explored further within the topics covered in this report.

- The increasing temperature in the module was more affected in a south oriented system than that of an east and west oriented system. It would be interesting to monitor difference in voltage and to monitor the temperature conditions where ambient temperatures and irradiation are far higher than that of a northern country. Preforming the same simulations in more south located country such as Spain and Portugal, may increase the impact increasing temperatures have on the PV systems.
- The variations in energy prices is based on potential tariffs and Nordpool prices. The tariff are currently being developed, and it may take some adjusting time before a definite tariff will be implemented. It would be interesting to carry out the simulation again with a more accurate price of energy.
- This report is done using weather data from meteonorm. It would be interesting to see the simulations performed in this report done practically, where several solar panels could be adjusted in different orientation and a production could be monitored for real time observations.
- A consumption pattern is hard to determine, and it would be interesting to accurately monitor a household consumption and match this up to the PV production for the different orientations. A study such as this can be used to determined how much of the energy produced is consumed by the household.

7 Appendixes

8.1 Overview of the daily energy output for 7 orientations.

Table 9 Below showing daily energy output for 7 orientations. Location: Oslo

Date	E_Grid kWh/day 0°	E_Grid kWh/day 15° -15°	E_Grid kWh/day 30° -30°	E_Grid kWh/day 45° -45°	E_Grid kWh/day 60° -60°	E_Grid kWh/day 75° -75°	E_Grid kWh/day 90° -90°
01.01.	1.83	1.80	1.72	1.58	1.40	1.21	1.09
02.01.	12.37	12.02	10.95	9.22	6.95	4.60	2.61
03.01.	16.85	16.35	14.88	12.50	9.43	6.34	3.75
04.01.	2.70	2.66	2.53	2.32	2.04	1.75	1.49
05.01.	0.01	0.01	0.02	0.04	0.07	0.11	0.14
06.01.	11.65	11.33	10.37	8.83	6.83	4.76	3.02
07.01.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08.01.	5.97	5.80	5.27	4.43	3.40	2.51	1.78
09.01.	11.63	11.30	10.33	8.77	6.83	4.98	3.45
10.01.	7.63	7.43	6.83	5.87	4.67	3.53	2.55
11.01.	3.54	3.47	3.26	2.93	2.52	2.18	1.89
12.01.	12.20	11.87	10.88	9.28	7.20	5.08	3.30
13.01.	8.16	7.95	7.33	6.32	5.03	3.79	2.80
14.01.	0.02	0.02	0.02	0.04	0.07	0.11	0.14
15.01.	1.77	1.76	1.73	1.69	1.64	1.57	1.52
16.01.	14.18	13.80	12.64	10.76	8.40	6.20	4.40
17.01.	18.34	17.85	16.39	14.00	10.82	7.31	4.31
18.01.	8.64	8.44	7.83	6.85	5.59	4.31	3.26
19.01.	28.06	27.27	24.89	21.00	15.91	10.70	6.15
20.01.	8.31	8.12	7.53	6.58	5.36	4.12	2.99
21.01.	14.16	13.80	12.72	10.98	8.65	6.09	3.84
22.01.	28.53	27.74	25.36	21.47	16.35	11.10	6.51
23.01.	5.61	5.52	5.23	4.77	4.19	3.67	3.24
24.01.	0.26	0.26	0.28	0.32	0.38	0.43	0.48
25.01.	0.73	0.73	0.76	0.79	0.84	0.88	0.92
26.01.	0.02	0.02	0.03	0.05	0.07	0.10	0.13
27.01.	16.09	15.70	14.53	12.64	10.17	7.62	5.32
28.01.	1.06	1.07	1.09	1.13	1.17	1.22	1.25
29.01.	5.13	5.05	4.84	4.52	4.19	3.88	3.57
30.01.	9.12	8.90	8.25	7.23	6.09	4.98	3.99
31.01.	2.28	2.28	2.27	2.27	2.25	2.24	2.22
01.02.	4.54	4.48	4.32	4.06	3.75	3.48	3.26
02.02.	0.55	0.55	0.57	0.61	0.66	0.71	0.75
03.02.	19.51	19.04	17.64	15.43	12.77	9.97	7.35
04.02.	10.89	10.67	10.00	8.95	7.73	6.51	5.44
05.02.	34.41	33.48	30.75	26.48	21.55	16.47	11.64
06.02.	10.67	10.45	9.82	8.88	8.00	7.25	6.48
07.02.	19.29	18.83	17.45	15.27	12.70	10.02	7.50

08.02.	8.66	8.54	8.18	7.60	6.88	6.09	5.35
09.02.	9.08	8.88	8.28	7.34	6.32	5.31	4.35
10.02.	1.44	1.45	1.47	1.51	1.55	1.60	1.64
11.02.	16.40	16.04	14.99	13.36	11.47	9.46	7.44
12.02.	16.20	15.85	14.80	13.13	11.18	9.25	7.45
13.02.	20.13	19.71	18.48	16.50	14.03	11.34	8.74
14.02.	17.04	16.69	15.65	14.01	12.06	10.13	8.36
15.02.	31.92	31.22	29.11	25.68	21.18	16.11	11.20
16.02.	18.35	17.88	16.57	14.75	12.72	10.70	8.76
17.02.	14.36	14.13	13.47	12.46	11.18	9.76	8.38
18.02.	41.74	40.71	37.76	33.49	28.33	22.71	17.23
19.02.	22.66	22.19	20.87	19.10	17.11	14.86	12.45
20.02.	13.82	13.59	12.94	12.13	11.09	10.04	9.22
21.02.	23.98	23.47	22.04	20.06	17.70	15.14	12.62
22.02.	4.49	4.48	4.47	4.44	4.40	4.36	4.32
23.02.	28.34	27.75	26.07	23.70	20.89	17.81	14.82
24.02.	35.47	34.68	32.41	29.06	24.95	20.40	15.95
25.02.	32.16	31.47	29.49	26.54	22.99	19.16	15.46
26.02.	4.35	4.35	4.34	4.33	4.31	4.29	4.28
27.02.	12.63	12.50	12.13	11.58	10.91	10.20	9.52
28.02.	23.73	23.31	22.09	20.22	17.92	15.33	12.66
01.03.	14.33	14.17	13.72	13.03	12.16	11.22	10.32
02.03.	11.13	11.04	10.78	10.37	9.85	9.31	8.89
03.03.	16.80	16.53	15.76	14.62	13.35	12.13	11.01
04.03.	41.87	40.99	38.43	34.43	29.56	24.29	19.12
05.03.	34.53	33.82	31.83	29.21	26.25	23.19	20.32
06.03.	56.48	55.18	51.44	46.15	39.76	32.84	25.97
07.03.	24.15	23.77	22.66	21.07	19.06	16.82	14.74
08.03.	3.68	3.68	3.70	3.71	3.73	3.75	3.77
09.03.	2.18	2.19	2.21	2.24	2.28	2.31	2.35
10.03.	17.29	16.97	16.08	14.92	13.57	12.13	10.74
11.03.	22.82	22.41	21.35	19.82	17.94	15.90	13.92
12.03.	11.21	11.16	11.01	10.77	10.43	10.05	9.65
13.03.	29.09	28.66	27.37	25.33	22.61	19.31	15.78
14.03.	62.36	61.10	57.81	52.98	47.02	40.52	33.74
15.03.	66.03	64.71	61.25	56.03	49.42	42.09	34.34
16.03.	65.28	64.01	60.70	55.79	49.56	42.54	35.06
17.03.	71.32	69.91	66.30	60.90	54.08	46.35	37.95
18.03.	52.58	51.71	49.57	46.27	41.94	37.13	32.00
19.03.	65.52	64.25	60.99	56.12	49.98	43.12	35.74
20.03.	45.64	44.96	43.28	40.72	37.39	33.72	29.86
21.03.	30.18	29.78	28.56	26.60	23.96	20.87	17.91
22.03.	64.80	63.58	60.55	56.08	50.52	44.36	37.63
23.03.	76.87	75.90	73.07	67.57	60.64	52.68	43.84
24.03.	42.85	42.26	40.77	38.54	35.64	32.48	29.03
25.03.	41.46	40.89	39.93	38.78	37.51	35.98	33.73
26.03.	51.61	50.71	48.46	45.13	41.06	36.61	31.81

27.03.	15.59	15.44	15.05	14.47	13.71	12.93	12.07
28.03.	57.93	56.93	54.18	50.17	45.27	40.00	34.29
29.03.	64.67	63.54	60.64	56.23	50.74	44.62	37.86
30.03.	4.80	4.80	4.81	4.82	4.83	4.84	4.86
31.03.	18.31	18.13	17.68	17.01	16.12	15.19	14.18
01.04.	17.16	17.09	16.87	16.54	16.12	15.74	15.33
02.04.	4.16	4.17	4.18	4.19	4.21	4.22	4.25
03.04.	8.85	8.83	8.80	8.77	8.72	8.68	8.64
04.04.	45.31	44.93	43.77	41.86	39.44	36.72	33.56
05.04.	39.66	39.42	38.63	37.26	35.48	33.38	30.93
06.04.	35.26	35.06	34.34	33.20	31.78	30.61	28.14
07.04.	75.91	75.28	73.10	69.24	64.03	57.71	50.34
08.04.	70.37	69.73	67.60	63.98	59.20	53.52	47.00
09.04.	58.44	58.25	57.28	55.30	52.51	48.83	44.37
10.04.	29.49	29.80	30.47	31.11	31.50	31.45	30.67
11.04.	32.76	32.75	32.62	32.17	31.41	30.41	28.74
12.04.	62.10	61.74	60.26	57.59	53.83	49.32	44.16
13.04.	57.86	57.48	56.17	53.92	50.90	47.16	42.89
14.04.	30.37	30.18	29.66	28.86	27.89	26.69	25.46
15.04.	24.56	24.71	24.88	24.84	24.51	24.04	23.26
16.04.	5.67	5.66	5.65	5.65	5.65	5.66	5.67
17.04.	55.34	55.04	53.84	51.69	48.69	45.03	40.94
18.04.	81.21	81.17	80.07	76.58	71.61	65.35	56.98
19.04.	69.53	69.10	67.63	65.10	61.49	56.90	51.44
20.04.	58.61	58.46	57.77	56.23	53.70	50.40	46.35
21.04.	24.62	24.51	24.19	23.68	23.03	22.32	21.68
22.04.	18.53	18.48	18.35	18.15	17.90	17.62	17.32
23.04.	16.79	16.76	16.66	16.53	16.36	16.18	15.98
24.04.	25.22	25.45	25.99	26.64	26.93	26.82	26.34
25.04.	83.48	83.62	83.33	80.83	76.56	70.87	63.90
26.04.	47.79	47.65	46.89	44.75	41.78	38.05	33.81
27.04.	68.96	68.63	67.51	65.51	62.43	58.42	52.56
28.04.	61.40	60.84	59.17	56.71	53.53	49.81	45.70
29.04.	70.71	70.29	68.88	66.47	62.95	58.50	53.24
30.04.	75.21	75.02	74.25	72.57	69.66	65.53	60.26
01.05.	62.65	62.50	61.79	60.06	57.24	53.57	49.31
02.05.	44.92	44.84	44.56	44.00	42.86	41.43	39.56
03.05.	65.99	65.89	65.49	64.42	62.28	59.16	55.15
04.05.	65.82	65.61	64.80	63.13	60.43	56.72	52.30
05.05.	58.27	58.20	57.89	57.03	55.48	53.26	50.41
06.05.	43.22	43.51	44.24	44.83	45.04	44.90	44.06
07.05.	24.96	24.93	24.93	24.87	24.83	24.63	24.38
08.05.	67.88	67.60	66.69	65.02	62.62	59.33	55.28
09.05.	46.17	46.13	46.05	45.79	45.16	44.09	42.60
10.05.	71.87	71.71	71.03	69.47	66.91	63.54	58.92
11.05.	61.67	61.71	61.56	61.13	60.13	58.62	56.00
12.05.	17.84	17.81	17.73	17.60	17.43	17.26	17.05

13.05.	28.83	28.77	28.61	28.34	27.99	27.56	27.06
14.05.	42.04	41.85	41.34	40.52	39.45	38.23	36.71
15.05.	34.02	34.48	35.56	36.72	37.72	38.23	38.12
16.05.	28.49	28.42	28.25	27.97	27.61	27.19	26.72
17.05.	22.46	22.43	22.35	22.22	22.03	21.80	21.52
18.05.	59.19	59.17	59.00	58.54	57.47	55.68	53.27
19.05.	27.05	27.00	26.86	26.64	26.35	26.00	25.59
20.05.	65.54	65.57	65.47	64.96	63.60	61.39	58.26
21.05.	80.91	80.94	80.81	80.08	78.16	74.91	70.34
22.05.	56.13	56.73	58.22	60.01	61.09	61.25	60.38
23.05.	39.78	40.14	41.23	42.80	43.90	44.57	44.48
24.05.	53.65	53.51	53.07	52.31	50.72	48.51	45.45
25.05.	86.35	86.66	87.34	87.00	85.30	82.04	77.23
26.05.	86.63	86.96	87.68	87.43	85.87	82.76	78.08
27.05.	53.30	52.88	51.80	50.56	49.15	47.54	45.46
28.05.	38.88	39.20	39.85	40.74	41.65	42.28	42.37
29.05.	77.48	77.62	77.75	77.74	76.92	74.88	71.51
30.05.	78.57	78.67	78.65	78.24	76.87	74.33	70.59
31.05.	71.60	71.56	71.06	70.13	68.54	66.00	61.60
01.06.	65.23	65.25	64.97	64.33	62.89	60.70	57.80
02.06.	42.60	42.62	42.68	42.10	40.58	38.48	35.95
03.06.	43.31	43.48	43.99	44.87	45.34	45.51	44.87
04.06.	52.19	52.24	52.44	52.56	52.54	52.03	51.02
05.06.	59.18	59.17	59.01	58.61	57.81	56.48	54.61
06.06.	78.63	78.63	78.40	77.82	76.38	73.87	70.24
07.06.	80.70	80.76	80.68	80.26	78.92	76.36	71.57
08.06.	85.35	85.71	86.20	86.30	85.39	82.97	77.96
09.06.	85.24	85.56	85.96	85.88	84.76	82.17	78.08
10.06.	83.49	83.64	83.89	83.99	83.17	80.98	77.29
11.06.	58.96	59.00	59.18	59.32	58.90	57.78	56.00
12.06.	59.35	59.59	60.19	60.97	61.33	60.90	59.73
13.06.	41.42	41.77	42.71	44.02	45.07	45.66	45.66
14.06.	46.96	46.84	46.66	46.83	46.86	46.64	45.83
15.06.	63.47	63.35	62.83	61.92	60.44	58.29	55.54
16.06.	81.37	81.52	81.74	81.73	80.81	78.50	74.83
17.06.	86.21	86.55	87.18	87.42	86.64	84.35	80.43
18.06.	14.58	14.57	14.54	14.48	14.42	14.35	14.28
19.06.	7.00	7.00	6.98	6.96	6.94	6.93	6.93
20.06.	25.74	25.76	25.69	25.57	25.41	25.17	24.89
21.06.	42.07	42.23	42.90	43.90	45.04	45.78	46.05
22.06.	70.29	70.04	69.24	68.02	66.10	63.48	60.20
23.06.	73.73	73.78	73.81	73.61	72.66	70.68	67.65
24.06.	56.69	56.80	57.16	57.60	57.55	56.87	55.51
25.06.	52.48	52.47	52.22	51.58	50.52	49.10	47.11
26.06.	49.86	49.71	49.27	48.58	47.45	46.13	44.46
27.06.	36.64	36.58	36.44	36.31	35.96	35.57	34.83
28.06.	54.89	55.04	55.53	56.09	56.45	56.16	55.15

29.06.	19.11	19.08	19.01	18.89	18.74	18.56	18.38
30.06.	26.88	26.85	26.76	26.62	26.43	26.19	25.89
01.07.	82.46	82.54	82.58	82.34	81.19	78.68	74.88
02.07.	56.74	56.80	57.15	57.71	57.96	57.53	56.42
03.07.	71.58	71.90	72.60	73.42	73.52	72.51	70.23
04.07.	79.87	79.93	79.87	79.53	78.26	75.80	72.11
05.07.	31.44	31.36	31.28	31.21	31.20	31.00	30.77
06.07.	70.43	70.71	71.41	72.41	72.72	71.89	69.77
07.07.	80.16	80.31	80.57	80.68	79.88	77.69	74.17
08.07.	35.52	35.52	35.44	35.34	35.04	34.71	34.14
09.07.	46.52	46.76	47.38	47.74	47.32	46.48	45.00
10.07.	40.23	41.01	43.07	45.91	48.26	49.86	50.23
11.07.	76.75	76.85	77.01	77.00	76.08	73.98	70.61
12.07.	69.82	69.82	69.64	69.22	68.06	65.98	62.94
13.07.	40.84	40.70	40.39	39.84	39.11	38.10	36.96
14.07.	42.08	41.94	41.58	41.07	40.31	39.34	38.17
15.07.	42.52	42.43	42.23	41.82	41.10	40.17	38.76
16.07.	46.95	47.04	47.07	46.84	46.31	45.14	43.58
17.07.	8.34	8.33	8.31	8.29	8.27	8.26	8.25
18.07.	20.89	20.94	21.11	21.29	21.42	21.47	21.43
19.07.	44.98	45.24	45.39	45.02	44.01	42.33	40.08
20.07.	52.01	52.12	52.30	52.46	52.17	51.37	50.02
21.07.	16.58	16.56	16.53	16.46	16.38	16.28	16.17
22.07.	76.69	76.81	76.93	76.82	75.82	73.33	69.63
23.07.	19.86	19.84	19.77	19.68	19.54	19.38	19.18
24.07.	67.31	67.35	67.34	66.98	65.92	63.63	60.73
25.07.	83.43	83.60	83.52	82.73	80.67	77.13	72.15
26.07.	75.22	75.21	74.94	74.10	72.35	69.18	65.18
27.07.	57.93	57.93	57.69	56.96	55.79	53.65	50.99
28.07.	24.13	24.08	23.95	23.74	23.47	23.15	22.81
29.07.	30.16	30.06	29.78	29.38	28.77	27.96	27.15
30.07.	30.59	30.69	31.31	31.99	32.54	32.66	32.46
31.07.	69.54	69.19	68.02	65.96	63.05	59.06	54.69
01.08.	75.51	75.49	75.11	73.84	71.51	67.73	63.07
02.08.	74.09	74.12	73.88	72.83	70.73	67.19	62.80
03.08.	69.96	69.93	69.56	68.47	66.54	63.32	59.44
04.08.	42.11	41.66	40.29	38.11	35.66	32.82	30.01
05.08.	33.28	33.53	34.05	34.58	34.95	34.75	34.31
06.08.	54.17	54.08	53.60	52.56	50.97	48.63	46.16
07.08.	72.28	72.04	71.23	69.54	66.94	62.98	58.38
08.08.	61.03	61.34	61.67	61.48	60.47	58.17	55.13
09.08.	10.68	10.67	10.64	10.60	10.55	10.50	10.45
10.08.	66.41	66.22	65.39	63.65	61.04	57.38	53.00
11.08.	23.86	23.84	23.69	23.47	23.05	22.47	21.81
12.08.	60.33	60.11	59.39	57.99	55.94	52.98	49.45
13.08.	23.09	22.98	22.68	22.20	21.59	20.97	20.30
14.08.	77.70	77.49	76.53	74.37	71.06	66.29	60.47

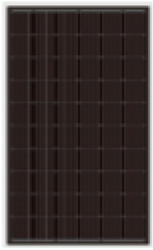
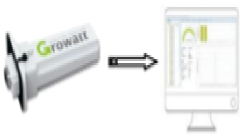
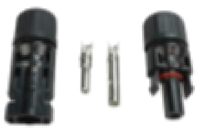
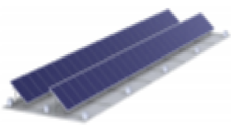
15.08.	45.17	45.22	45.23	44.82	44.01	42.49	40.47
16.08.	8.86	8.85	8.82	8.79	8.76	8.73	8.71
17.08.	65.01	65.15	65.18	64.46	62.88	60.04	56.16
18.08.	74.29	74.14	73.21	71.02	67.72	63.12	57.54
19.08.	69.24	68.96	67.76	65.32	62.03	57.71	52.62
20.08.	17.06	17.01	16.89	16.70	16.47	16.21	15.94
21.08.	26.90	26.75	26.39	25.76	24.91	24.06	23.08
22.08.	41.05	41.08	40.86	40.16	38.98	37.50	35.54
23.08.	18.46	18.41	18.28	18.07	17.81	17.50	17.19
24.08.	24.06	23.98	23.73	23.37	22.92	22.37	21.79
25.08.	3.24	3.24	3.24	3.25	3.26	3.28	3.30
26.08.	7.24	7.23	7.22	7.20	7.19	7.18	7.17
27.08.	38.70	38.50	37.96	36.95	35.57	33.90	32.04
28.08.	13.87	13.85	13.79	13.71	13.60	13.47	13.33
29.08.	34.70	34.61	34.53	34.45	34.19	33.40	32.13
30.08.	18.55	18.56	18.49	18.30	18.02	17.66	17.24
31.08.	55.53	55.09	53.52	50.98	47.64	43.69	39.35
01.09.	62.05	61.70	60.34	57.84	54.35	49.96	44.82
02.09.	54.55	54.07	52.58	49.98	46.28	41.98	37.34
03.09.	59.51	59.37	58.55	56.78	54.17	50.69	46.39
04.09.	8.54	8.52	8.50	8.47	8.44	8.41	8.38
05.09.	12.13	12.12	12.07	11.99	11.90	11.80	11.69
06.09.	25.90	25.72	25.21	24.45	23.60	22.68	21.70
07.09.	24.75	24.57	24.15	23.51	22.69	21.72	20.53
08.09.	18.12	18.05	17.86	17.56	17.18	16.75	16.31
09.09.	14.82	14.78	14.74	14.70	14.56	14.39	14.07
10.09.	16.64	16.71	16.80	16.78	16.58	16.23	15.76
11.09.	24.67	24.55	24.14	23.50	22.69	21.73	20.63
12.09.	71.36	70.46	67.84	63.68	58.28	51.74	44.36
13.09.	75.94	75.11	72.29	67.75	61.78	54.68	46.63
14.09.	59.59	58.88	56.74	53.37	49.01	43.58	37.40
15.09.	23.98	23.84	23.35	22.57	21.54	20.34	19.12
16.09.	46.71	46.19	44.57	41.86	38.33	34.10	29.69
17.09.	55.45	55.04	53.59	51.13	47.70	43.37	38.31
18.09.	68.71	67.74	64.93	60.57	54.98	48.38	41.02
19.09.	28.45	28.24	27.54	26.50	25.19	23.64	21.94
20.09.	4.24	4.24	4.25	4.26	4.27	4.29	4.31
21.09.	26.23	26.08	25.69	25.06	24.09	22.78	21.34
22.09.	36.00	35.56	34.34	32.47	30.06	27.16	24.07
23.09.	44.78	43.97	41.94	39.19	36.05	32.60	28.92
24.09.	43.71	43.15	41.61	39.43	36.84	33.90	30.69
25.09.	18.32	18.01	17.15	15.95	14.57	13.08	11.76
26.09.	37.72	37.12	35.66	33.84	31.58	28.85	25.64
27.09.	21.37	20.96	19.87	18.50	16.94	15.23	13.62
28.09.	23.93	23.57	22.67	21.52	20.47	19.10	17.44
29.09.	16.74	16.60	16.29	16.05	15.66	15.08	14.37
30.09.	37.09	36.52	34.89	32.44	29.52	26.28	22.77

01.10.	66.93	65.39	61.36	55.67	48.86	41.08	32.86
02.10.	64.93	63.44	59.50	53.95	47.33	39.82	31.83
03.10.	18.38	18.19	17.66	16.85	15.85	14.67	13.46
04.10.	4.58	4.58	4.59	4.58	4.57	4.57	4.57
05.10.	2.58	2.59	2.61	2.64	2.67	2.70	2.73
06.10.	5.65	5.65	5.64	5.61	5.57	5.53	5.50
07.10.	52.18	51.01	47.93	43.52	38.28	32.50	26.40
08.10.	5.73	5.72	5.70	5.67	5.63	5.58	5.54
09.10.	21.56	21.21	20.35	19.26	17.85	16.16	13.35
10.10.	24.73	24.23	22.76	20.47	17.81	15.20	12.74
11.10.	6.46	6.45	6.40	6.32	6.23	6.13	6.04
12.10.	2.82	2.82	2.84	2.87	2.89	2.92	2.95
13.10.	26.35	25.88	24.64	22.90	20.75	18.24	15.52
14.10.	13.18	12.92	12.25	11.34	10.32	9.28	8.24
15.10.	32.28	31.64	29.80	27.01	23.69	20.14	16.68
16.10.	14.70	14.39	13.58	12.48	11.37	10.29	9.17
17.10.	12.67	12.46	11.82	10.81	9.62	8.52	7.56
18.10.	7.05	7.01	6.89	6.68	6.44	6.24	6.02
19.10.	9.37	9.28	9.00	8.58	8.10	7.61	7.13
20.10.	8.56	8.47	8.20	7.79	7.30	6.73	6.26
21.10.	38.89	37.98	35.28	31.09	26.15	21.08	16.14
22.10.	51.37	50.06	46.20	40.36	33.57	26.41	19.32
23.10.	37.05	36.18	33.58	29.57	24.88	20.14	15.50
24.10.	16.10	15.82	15.00	13.68	12.10	10.68	9.25
25.10.	3.24	3.24	3.25	3.25	3.24	3.23	3.23
26.10.	4.26	4.25	4.21	4.16	4.09	4.01	3.94
27.10.	9.97	9.85	9.50	8.94	8.27	7.56	6.89
28.10.	1.96	1.97	1.99	2.02	2.06	2.09	2.12
29.10.	1.86	1.87	1.89	1.92	1.95	1.98	2.03
30.10.	1.23	1.23	1.25	1.29	1.34	1.38	1.42
31.10.	7.84	7.77	7.53	7.17	6.72	6.24	5.78
01.11.	10.88	10.68	10.10	9.24	8.29	7.33	6.37
02.11.	13.20	12.85	11.81	10.33	8.81	7.46	6.20
03.11.	14.18	13.84	12.83	11.39	9.88	8.63	7.41
04.11.	2.50	2.50	2.49	2.49	2.48	2.47	2.46
05.11.	0.65	0.66	0.68	0.72	0.77	0.82	0.87
06.11.	19.52	19.07	17.74	15.73	13.25	10.40	7.73
07.11.	15.60	15.25	14.24	12.66	10.56	7.93	5.18
08.11.	31.61	30.78	28.30	24.30	19.19	13.97	9.17
09.11.	5.59	5.52	5.33	5.02	4.61	4.17	3.73
10.11.	30.90	30.09	27.67	23.77	18.85	13.83	9.32
11.11.	25.85	25.19	23.23	20.04	15.89	11.44	7.44
12.11.	17.79	17.36	16.11	14.09	11.53	8.83	6.26
13.11.	0.95	0.96	0.98	1.02	1.06	1.10	1.14
14.11.	0.59	0.60	0.62	0.66	0.71	0.77	0.82
15.11.	7.39	7.24	6.81	6.12	5.34	4.68	4.08
16.11.	8.52	8.28	7.57	6.45	5.17	4.14	3.26

17.11.	2.31	2.31	2.28	2.25	2.20	2.14	2.08
18.11.	0.11	0.11	0.13	0.15	0.19	0.23	0.27
19.11.	0.64	0.65	0.67	0.71	0.76	0.81	0.85
20.11.	0.41	0.42	0.44	0.47	0.51	0.56	0.60
21.11.	0.02	0.02	0.03	0.04	0.07	0.10	0.14
22.11.	0.66	0.67	0.69	0.73	0.78	0.82	0.86
23.11.	0.82	0.83	0.84	0.87	0.91	0.95	0.98
24.11.	0.00	0.00	0.00	0.00	0.02	0.04	0.06
25.11.	8.91	8.64	7.84	6.59	5.23	4.11	3.13
26.11.	0.49	0.50	0.51	0.54	0.58	0.62	0.65
27.11.	0.81	0.81	0.82	0.84	0.87	0.89	0.92
28.11.	1.04	1.04	1.04	1.05	1.07	1.07	1.08
29.11.	1.33	1.32	1.31	1.30	1.28	1.25	1.23
30.11.	0.73	0.73	0.75	0.76	0.79	0.81	0.83
01.12.	8.66	8.42	7.71	6.59	5.25	3.97	2.83
02.12.	0.36	0.37	0.38	0.41	0.45	0.49	0.53
03.12.	5.90	5.72	5.21	4.40	3.47	2.67	2.02
04.12.	17.27	16.76	15.27	12.86	9.79	6.64	4.00
05.12.	0.27	0.27	0.29	0.32	0.36	0.41	0.44
06.12.	5.00	4.86	4.43	3.76	2.96	2.26	1.72
07.12.	1.08	1.07	1.07	1.06	1.05	1.03	1.01
08.12.	0.46	0.47	0.48	0.50	0.53	0.56	0.59
09.12.	0.00	0.00	0.01	0.02	0.04	0.07	0.09
10.12.	2.81	2.75	2.59	2.33	1.98	1.58	1.24
11.12.	5.89	5.74	5.31	4.61	3.71	2.83	2.12
12.12.	2.89	2.81	2.56	2.18	1.72	1.30	0.99
13.12.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.12.	3.32	3.23	2.97	2.56	2.04	1.55	1.21
15.12.	6.62	6.44	5.90	5.05	3.98	2.91	2.01
16.12.	11.22	10.90	9.95	8.41	6.41	4.35	2.69
17.12.	0.25	0.25	0.27	0.30	0.33	0.37	0.40
18.12.	1.03	1.02	1.00	0.96	0.90	0.84	0.77
19.12.	4.76	4.64	4.29	3.73	3.00	2.24	1.58
20.12.	0.08	0.08	0.10	0.12	0.16	0.20	0.25
21.12.	0.16	0.16	0.18	0.20	0.24	0.28	0.32
22.12.	5.45	5.28	4.79	4.00	3.06	2.20	1.54
23.12.	0.00	0.00	0.01	0.02	0.04	0.07	0.10
24.12.	0.23	0.24	0.25	0.28	0.31	0.35	0.38
25.12.	16.52	16.03	14.55	12.17	9.09	5.93	3.31
26.12.	16.63	16.13	14.65	12.26	9.17	6.02	3.41
27.12.	0.00	0.00	0.00	0.01	0.04	0.07	0.11
28.12.	0.44	0.45	0.46	0.48	0.51	0.54	0.56
29.12.	1.11	1.10	1.08	1.05	1.02	0.98	0.94
30.12.	12.88	12.52	11.43	9.67	7.35	4.85	2.76
31.12.	10.69	10.38	9.48	8.02	6.13	4.15	2.47
Total	11498.43	11428.07	11208.28	10832.68	10305.69	9652.81	8902.32

8.2 Table showing system parts and the costs.

Table 10 Below showing the parts and cost of a complete PV system.

Part	**Picture**	**Description**	**amount**	**Cost (NOK)**
300W Mono-crystalline panel		36V 20kg 1640*998*40mm	40	80 000 NOK
12kW inverter, Litto (LT10000HD)		Three phases AC 230V	1	27 160 NOK
Wifi monitoring system			1	3 600 NOK
PV Kabel		PV 4mm kabel	100m	6 200 NOK
MC4 connecter		Rated current: 30A Rated voltage: 1000VDC	40	50 NOK
Roof mounting system		Adjusted, all parts included	1	12 000 NOK
Mounting and electric work				52 000 NOK

Government subsidise			1	-25 000NOK
Sum, including VAT				167 460 NOK

8.3 Technical specification for the inverter used in the report

Technical specitications

DATASHEET	LT 5000HD	LT 6000HD	LT 8000HD	LT 10000HD
INPUT DATA (DC)				
Max. DC power	6000W	7000W	9000W	11000W
Max. DC voltage	1000Vdc	1000Vdc	1000Vdc	1000Vdc
Rated DC voltage	650Vdc	650Vdc	650 Vdc	650Vdc
MPPT work voltage range	250–800Vdc	250–800Vdc	250–800 Vdc	250–800Vdc
MPPT full load voltage range	250–800Vdc	250–800Vdc	400–800 Vdc	400–800Vdc
Input circuit number	A:2/B:2	A:2/B:2	A:2/B2	A:2/B:2
Number of independent MPP trackers	2	2	2	2
Max. input current per string of tracker A / tracker B	11A/11A	12A/12A	14A/14A	14A/14A
DC connect type	MC4 terminal	MC4 terminal	MC4 terminal	MC4 terminal
OUTPUT (AC)				
Max. AC apparent power	5000VA	6000VA	8000VA	10000VA
Rated AC output power	5000W	6000W	8000W	10000W
Rated grid voltage	3/N/PE:220/380V 3/N/PE:230/400V 3/N/PE:240/415V	3/N/PE:220/380V 3/N/PE:230/400V 3/N/PE:240/415V	3/N/PE:220/380V 3/N/PE:230/400V 3/N/PE:240/415V	3/N/PE:220/380V 3/N/PE:230/400V 3/N/PE:240/415V
Grid voltage range per phase	185V–276V	185V–276V	184V–276V	185V–276V
Rated power grid frequency	50 Hz/60Hz	50Hz/60Hz	50Hz/60Hz	50Hz/60Hz
Grid frequency range	45–55Hz/55–65Hz	45–55Hz/55–65Hz	45–55Hz/55–65Hz	45–55Hz/55–65Hz
Max. output current	8.1A per phase	9.7A per phase	13A 每相	16.2A per phase
Power factor (cos ϕ)	0.8i...1···0.8c	0.8i...1···0.8c	0.8i...1···0.8c	0.8i...1···0.8c
Current harmonics (THDI)	<3% (at rated output power)	<3% (at rated output power)	<3% (at rated output power)	<3% (at rated output power)
AC output terminal connection type	plug and play terminal	plug and play terminal	plug and play terminal	plug and play terminal
EFFICIENCY				
Max. efficiency	98%	98.1%	98.3%	98.3%
Euro–eta	98.1%	98.1%	97.8%	98.1%
MPPT efficiency	99.8%	99.8%	99.8%	99.8%
GENERAL DATA				
(W / D / H) size	400 x 480 x 250 mm			
N.W	25KG			
Install way	Wall hanging fixed			
Operating temperature range	-25℃ ~ +60℃			
Max. altitude	2000m			
Relative temperature	0%–98% No condensation			
Noise	≤ 30 dB(A)			
Night consumption	0 W			
Electrical isolation	Transformerless			
Cooling mode	Still air cooling			
Overall protection level	IP65			

8.4 Data for panel characteristics

Product Characteristics

Model No.	295W	300W	305W	310W
Warranty				
Product Warranty	10 Years			
Power Warranty	10 Years of 90% Output Power, 25 Years of 80% Output Power			
Electrical Data at STC				
Maximum Power (Pmax)	295 Wp	300 Wp	305 Wp	310 Wp
Voltage at Maximum Power (Vmpp)	32.6 V	32.9 V	33.2 V	33.5 V
Current at Maximum Power (Impp)	9.05 A	9.12 A	9.2 A	9.26 A
Open Circuit Voltage (Voc)	39.5 V	39.7 V	39.9 V	40.1 V
Short Circuit Current (Isc)	9.52 A	9.58 A	9.64 A	9.69 A
Panel Efficiency	18 %	18.3 %	18.6 %	18.9 %
Power Tolerance (Positive)	+ 3 %	+ 3 %	+ 3 %	+ 3 %
	Standard Test Conditions (STC): air mass AM 1.5, irradiance 1000W/m², cell temperature 25°C			

8.5 Break-even energy price

Table 11 Table showing the break-even energy price, hour to hour

Hour starting at 00:00	Break even energy price
0H	0.100
1H	0.100
2H	0.100
3H	0.100
4H	0.100
5H	0.100
6H	3.000
7H	3.000
8H	3.000

9H	3.000
10H	0.150
11H	0.150
12H	0.150
13H	0.150
14H	0.150
15H	3.000
16H	3.000
17H	4.940
18H	5.000
19H	0.100
20H	0.100
21H	0.100
22H	0.100
23H	0.100

8.6 Energy price with potential tariff

Table 12 Hour to hour energy price, using potential tariff

Hour starting at 00:00	Energy price using potential tariff
0H	0.500
1H	0.500
2H	0.500

3H	0.500
4H	0.500
5H	0.500
6H	0.500
7H	2.500
8H	2.500
9H	2.500
10H	0.750
11H	0.750
12H	0.750
13H	0.750
14H	0.750
15H	2.000
16H	2.000
17H	2.000
18H	2.000
19H	2.000
20H	2.000
21H	2.000
22H	0.500
23H	0.500

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