FUTURE ENERGY HUB
University of Stavanger

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Can solar energy be profitable in Forus, Norway?

VRI Forprosjekt - Deling av strømproduksjon for økt lønnsomhet med solenergi

Project Partners

Norsk Solar AS, Forus Næringspark AS, Rogaland Fylkeskommune and the University of Stavanger

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Introduction

This report is the result of a VRI pre-project partly funded by the county council of Rogaland. The goal of this project is to increase collaboration between industry and academia. The outcome of this project has been an ongoing dialogue to facilitate innovation on solar energy in Forus, Norway, between Norsk Solar AS, Forus Næringspark AS and the University of Stavanger.

The main goal of this pre-project has been to explore the possibilities and challenges of optimising sharing of energy between buildings in Forus. Being able to produce and use solar energy locally could lead to lower costs and fewer losses. By establishing systems for energy sharing between buildings, it could be possible to achieve a higher share of locally produced solar energy. The motivation for doing so is to reduce the need for costly grid upgrades and achieve a higher renewable energy penetration in the grid.

Sub-goals:

- Evaluate ways for solar energy production locally at Forus
- Evaluate challenges and possibilities within the current framework
- Investigate potential extra electricity production from solar that is not accounted for in standard calculations (reflection, cooling, etc.)
- Evaluate the potential for multi-use of land (e.g. building integrated or ground-based with farming underneath the panels)
- Evaluate concepts that secure the highest possible local usage of locally produced energy
- Describe a possible concept that the partners can develop further.

In the next chapters, we investigate the following to achieve the main goal and sub-goals:

1. Explain the energy demand for different consumers
2. Explore the power production from solar energy
3. Model a specific case at Forus, using measured energy demand data and weather data
4. Discuss the results, possibilities and the way forward

- ***All figures and graphs in this report without a reference are developed by the authors.***
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Solar Energy – A case study for Forus

1. Electricity demand profiles for various consumers

What type of energy consumers are located at Forus, and how are their energy profile?

- Commercial (Offices, shops, dealers)
- Industrial (Production, workshops, etc.)
- Some Residential (Not a focus in this study)

How a building is used is the critical driver for how the energy demand varies throughout the day and year. Industrial and agricultural users typically have a flat energy use throughout the day, as the production of goods is kept constant. On the other hand, commercial buildings have their primary energy use in office hours and opening hours (8-19), with a peak around noon. Comparing this to residential buildings, they have their energy peaks in the evening, when the inhabitants are at home, before dropping back down to a baseload when people go to sleep [1]. Figure 2 shows the total electricity consumption for an average day in a large city in the Northern hemisphere.

In later chapters, we will show how the energy demand relates to solar energy production. The critical takeaway is to make the solar energy system as profitable as possible; one should use the energy locally when produced. Doing so avoids excess energy that must be stored or sold to the grid. Because of this, commercial and industrial buildings usually are even better candidates for solar energy systems than residential buildings.

Figure 1 The Forus Area consist mostly of industry, warehouses and stores [2]

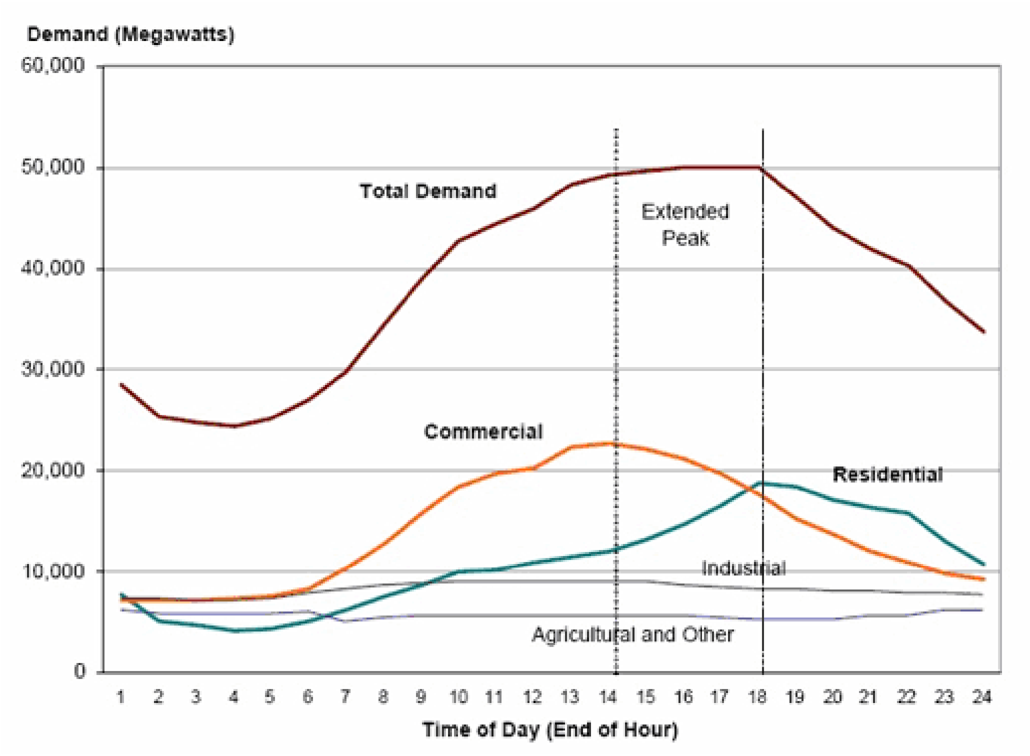


Figure 2 Overview of the total daily average electricity demand for a large town in the northern hemisphere. It is broken down into commercial, residential, industrial, agricultural and other [1].

Electricity demand by different economic sectors

Statistics Norway has broken the commercial sector further down into three main categories of consumers; Primary, Secondary and Tertiary sector [3].

- **Primary Sector (Primær)**

  Primary sector consumers include the industries involved in the extraction and production of raw materials, such as farming, logging, hunting, fishing, and mining.

- **Secondary Sector (Sekundær)**

  Secondary sector consumers include the industries involved in manufacturing. It involves the industries which produce a finished, usable product or are involved in construction. Examples include textile production, car manufacturing, and handicraft.

- **Tertiary Sector (Tertiær)**

  The tertiary sector of the economy is generally known as the service sector. Services may involve the transport, distribution, and sale of goods from producer to consumer, as may happen in wholesaling and retailing, pest control or entertainment.

Statistics Norway provide the average consumption of electrical power for an average consumer in Norway throughout the day, both for weekdays and weekends. Figure 3 summarises these findings. Knowing the average usage based on a sector is relevant for doing an overview study for solar energy potential in a given area. By knowing what type of industries are in an area and multiplying it with the sum of given industries, one can estimate the electric power demand curve for a given site.

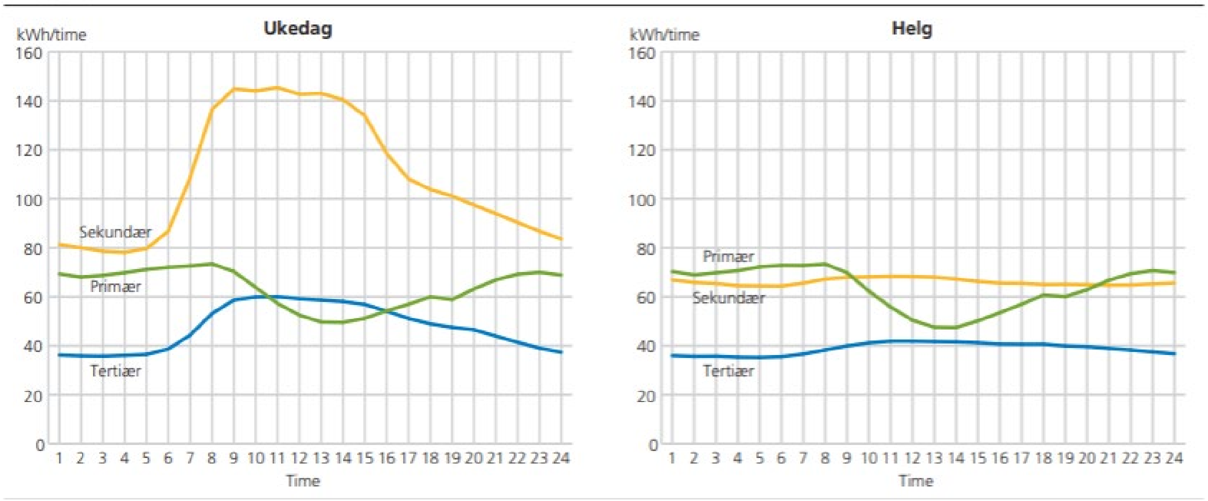
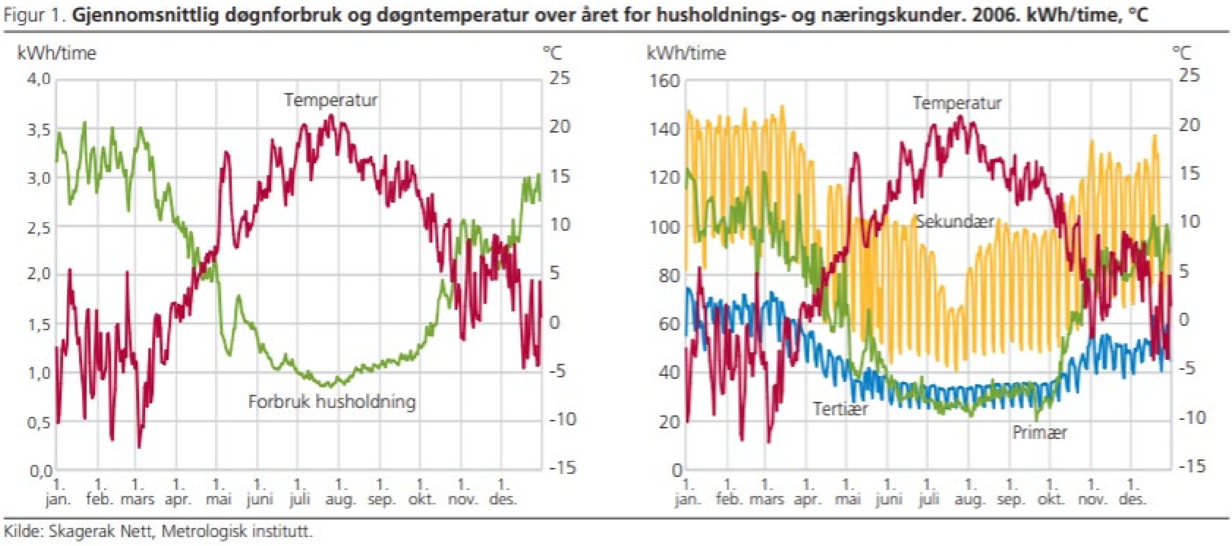


Figure 3 Consumption of electrical power for an average consumer in Norway throughout the day, both for weekdays and weekends. Here separated between primary-, secondary- and tertiary industries [3]

Annual electricity demand profiles

When investigating solar energy for a building or an area, one needs to look at how the energy demand varies throughout the year. Figure 4 shows the average daily energy demand and average temperature over a year for private and industrial consumers. Note that the energy use is inversely proportional to the outdoor temperature. Unfortunately, this also means that the energy production from PV panels is lowest when electricity (for heating) is most needed.



Figur 1. **Gjennomsnittlig døgnforbruk og døgntemperatur over året for husholdnings- og næringskunder. 2006. kWh/time, °C**

Kilde: Skagerak Nett, Metrologisk institutt.

Figure 4 Average daily energy demand and average temperature over a year for private and industrial customers [3]

2. Energy Production from Photovoltaic Panels

Power production from Photovoltaic panels (PV-Panels) depends on several sources where solar radiation, efficiency, and orientation are the most critical factors. The following subchapters will explore these different factors and how they relate to Forus.

Efficiency

The PV cell efficiency has increased considerably since its appearance. The National Renewable Energy Laboratory (NREL) is one of the leading organisations that publish yearly reports on Solar PV efficiency improvements by their technologies and materials. The latest report from NREL presented in Figure 5 shows the development of PV efficiency from 1976 to 2020 [4]:

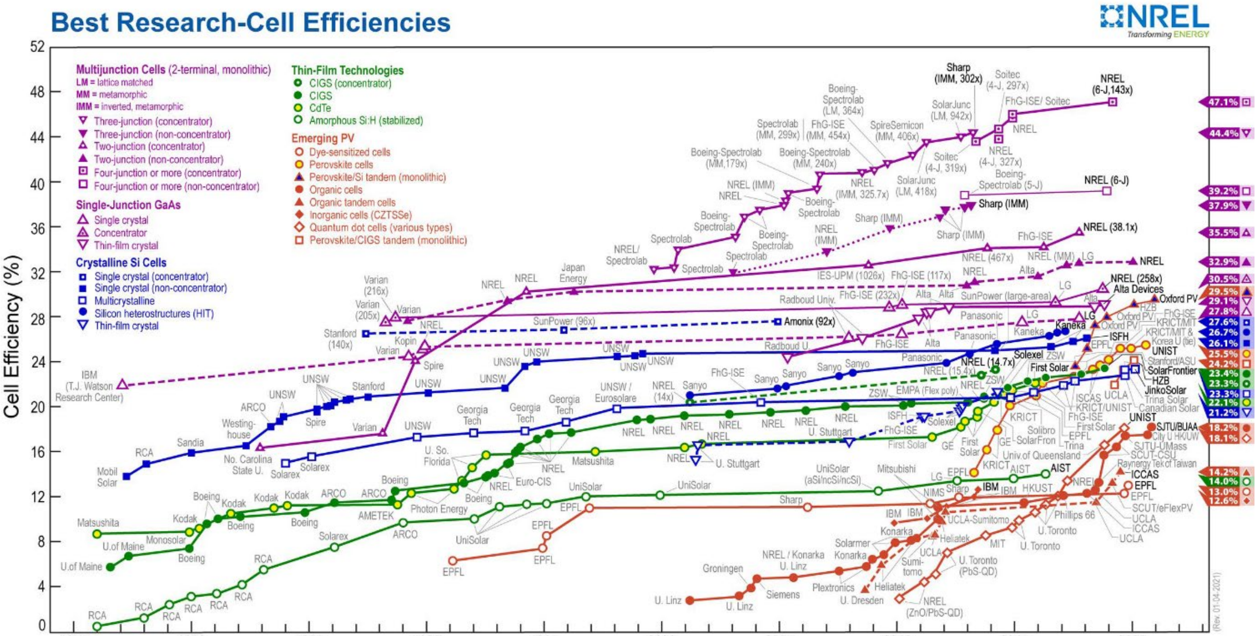


Figure 5 NREL Best Research-Cell Efficiency Chart [4]

It is worth noting that NREL assesses the PV cell efficiency in laboratory standards, meaning the best environmental conditions are applied to find out the maximum efficiency of the PV cells and not the PV modules or panels.

The report suggests that the most efficient PV module available can reach up to 47% efficiency. However, the conventional PV cells available in the market for general applications are mostly mono-crystalline modules, shown in this chart with dark blue lines. The report indicates that mono-crystalline PVs can reach up to 27.6% efficiency in laboratory conditions. The slope of the graph demonstrates the changes in crystalline PVs over the past few decades.

Solar Radiation Components

The incident radiation to a surface on earth has three components: direct radiation, diffuse radiation and reflected radiation.

- Direct radiation is also called "beam radiation". It describes solar radiation coming in a straight line from the sun down to the earth's surface. For sunny days with a clear sky, most solar radiation is direct radiation. On overcast days, the sun is blocked by clouds, and the beam radiation is zero.
- Diffuse radiation is the sunlight that has been dispersed or scattered by particles and molecules in the atmosphere and still made it down to the surface. Diffuse radiation is commonly referred to as sky radiation because it comes from all regions of the sky. The

amount of diffuse radiation is up to 100% of total radiation for cloudy skies and 10% to 20% of total radiation for clear skies.

- The reflected radiation is the reflection of direct and diffuse radiation on the ground. This contribution is negligible unless the collector is tilted at a steep angle from the horizontal like a building façade.

Solar Radiation Spectrum

The radiation spectrum coming from the sun to the earth divides into three main groups; ultraviolet, visible light, and infrared.

- Ultraviolet (UV) is wavelengths from 250 nm to 380 nm. UV rays are invisible to the human eyes and may be dangerous in case of overexposure because they damage surfaces and colours, and age materials.
- Visible light is wavelengths from 380 nm (violet) to 740 nm (red). Visible light rays are detectable by the human eyes and enable the sight of shapes, relief, and colours.
- Short wave infrared (IR) constitutes wavelengths from 740 nm to 2500 nm. IR is invisible and is felt as heat. It comprises most of the sun's energy that hits the earth.

Figure 6 shows the solar irradiance outside (Airmass equal to Zero) and inside (Airmass equal to 1.5) of the atmosphere (Standard number ASTM G-173-03). T and D stand for total and direct incident radiation. In terms of solar radiation inside the atmosphere and at the sea level, around 3% of solar radiation on earth is UV, approximately 42% is visible light, and the rest (55%) is IR. Most of the power produced by PV panels come from the visible light spectrum [5]

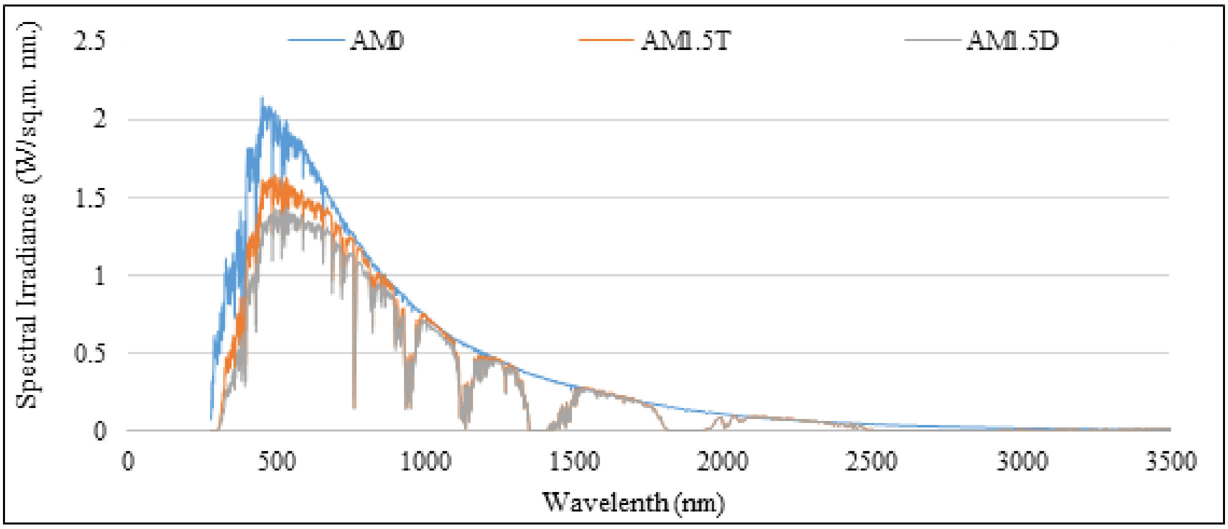


Figure 6 The solar spectral irradiance outside and inside of the atmosphere.

Solar radiation in Forus

The following graphs (Figure 7-10) provide data on the available solar radiation at Forus. It is worth noting that the orientation of the panels makes a significant difference on when in the day and year the power is produced and the total amount. The data is exported from the Photovoltaic Geographical Information System (PVGIS) database [6]

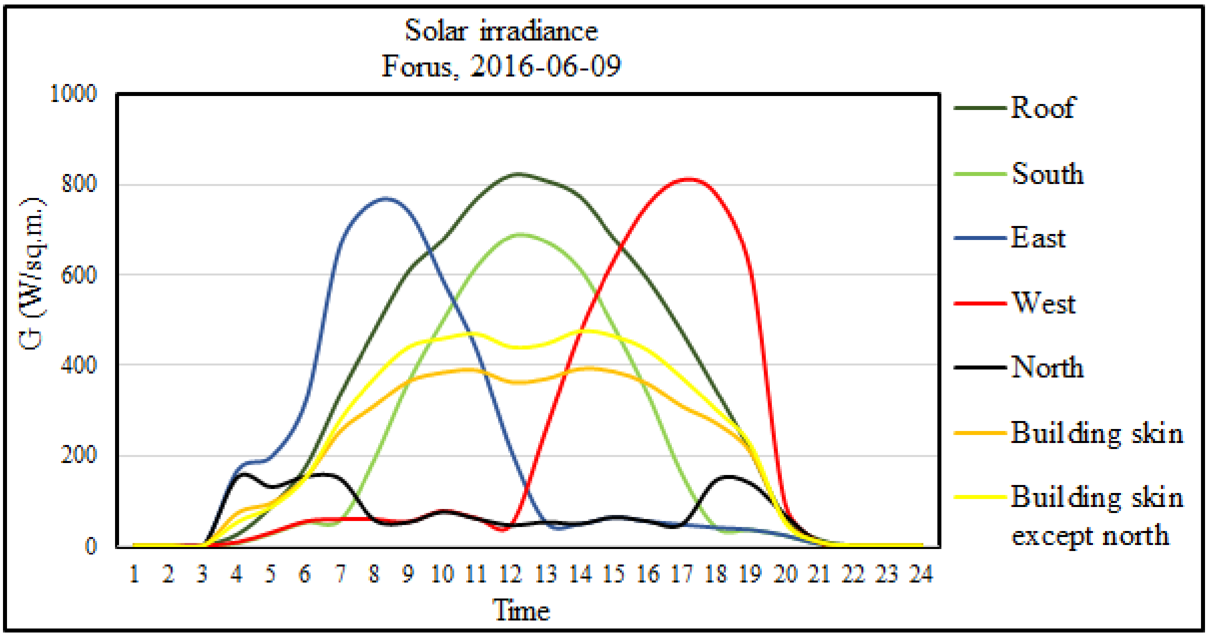


Figure 7 Solar radiation on different orientations on a sunny day in Forus

Figure 7 also shows the great potential of combining different orientations for PV systems to spread production over time and match energy supply with energy demand based on the type of demand. It is worth mentioning that the roof is defined as a flat roof, and walls (south, east, west, north) are all vertical surfaces.

Figure 8 presents the historical data of average annual incident solar radiation potential on different building orientations and building skins from 2006 to 2016. Although there are some slight variations, the figures follow the average values.

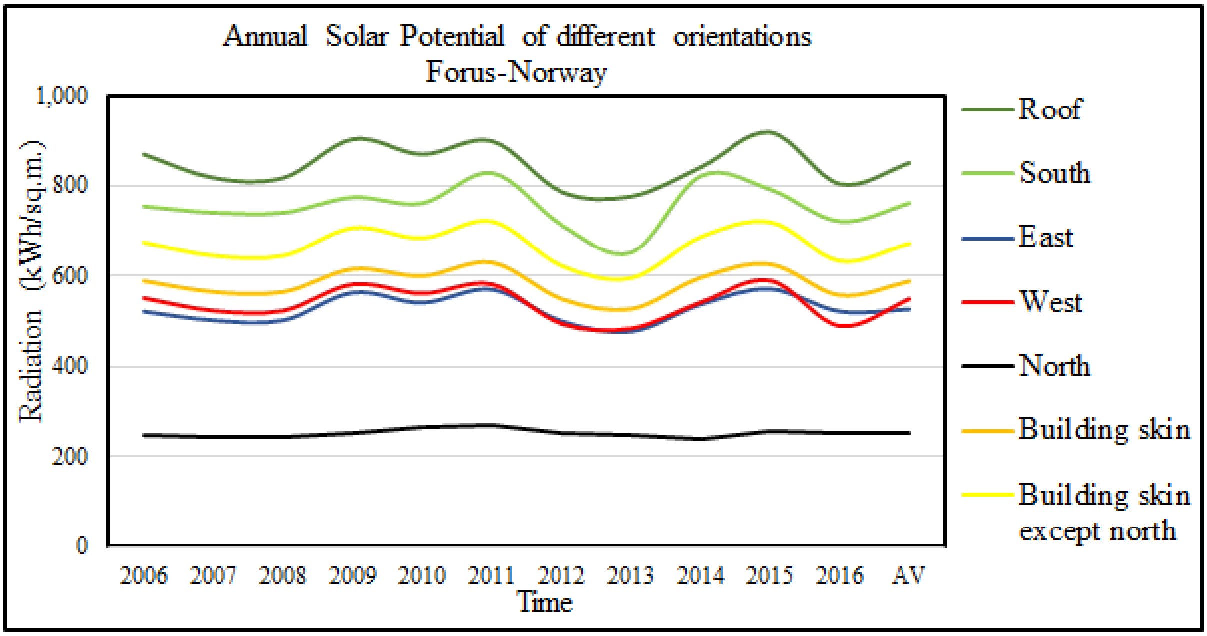


Figure 8 Historical data of annual solar incident radiation potential in Forus

To understand the values of solar radiation components on different orientations, Figure 9 and Figure 10 are presented here to show the average value of these components in 10 years (for the roof and south facade).

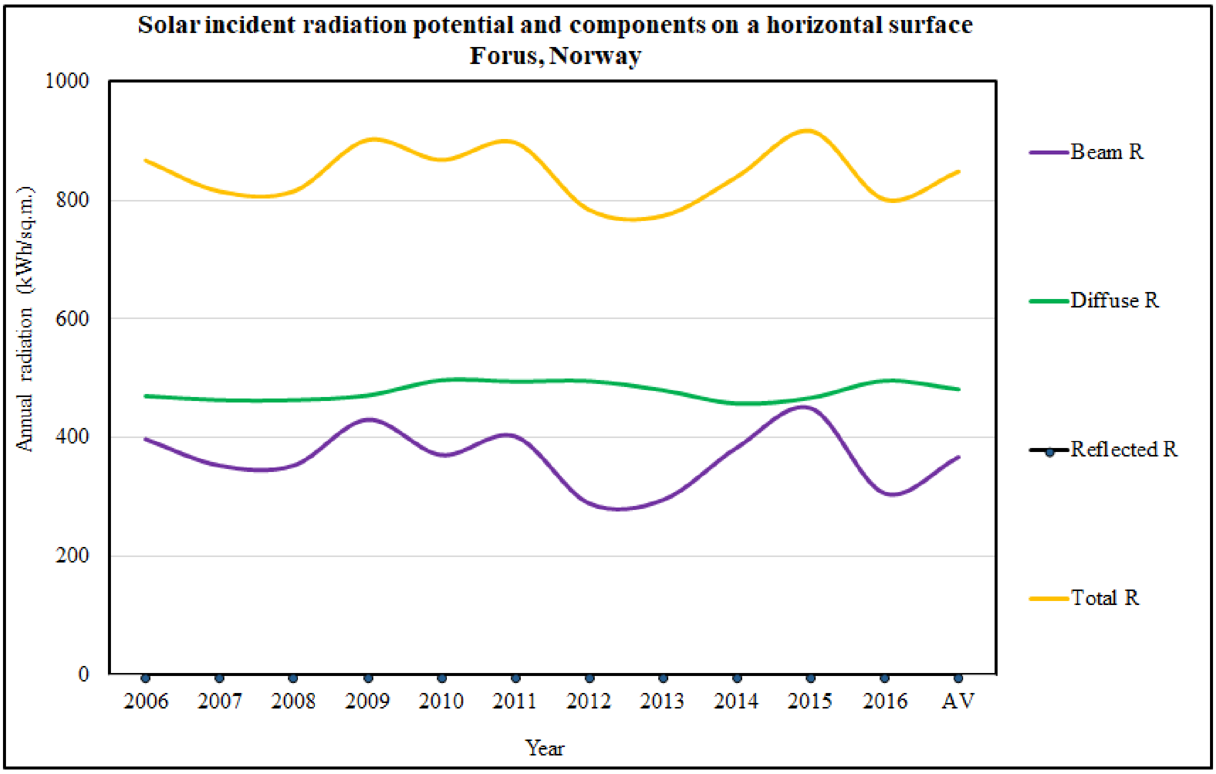


Figure 9 Solar incident radiation potential and components on a horizontal surface in Forus, Norway

The reflected radiation for a flat roof is equal to zero, as shown in Figure 9, because there is no reflection from the ground to the roof.

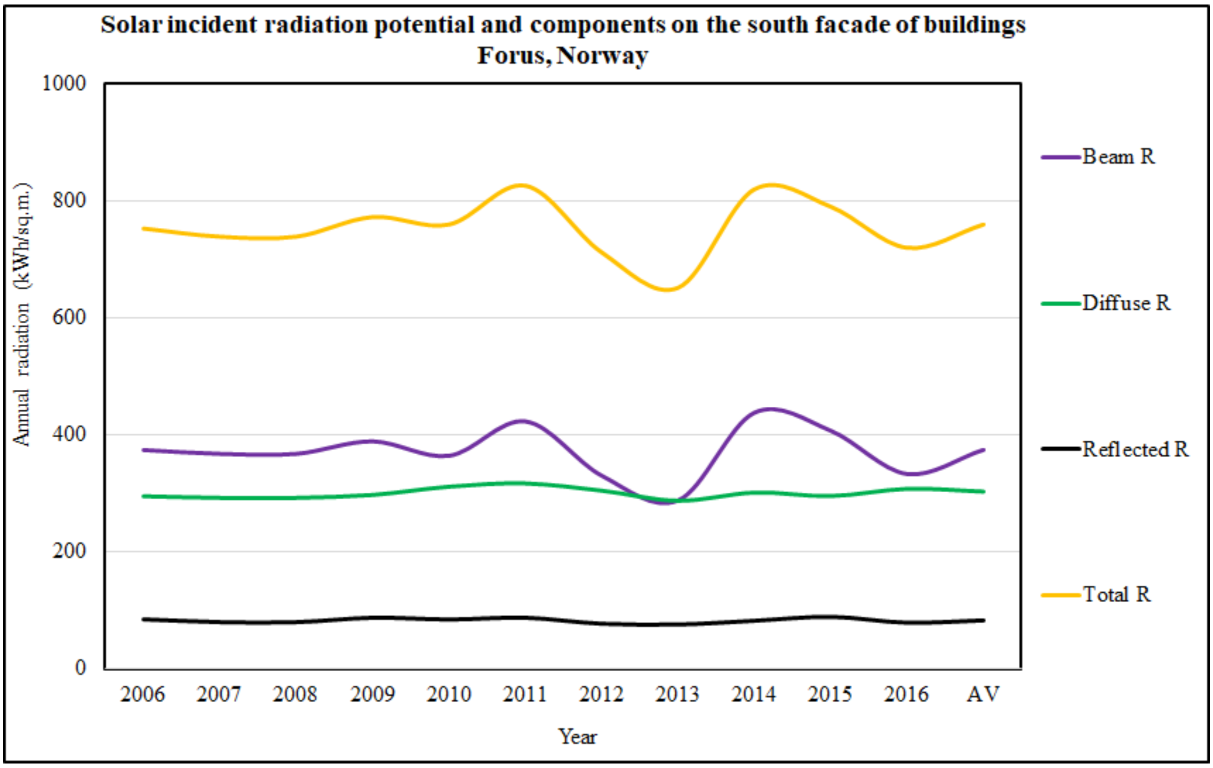


Figure 10 Solar incident radiation potential and components on the south facade of buildings in Forus, Norway

As can be found from the figures, the contribution of average annual diffuse radiation and beam radiation to the total radiation in the Forus area is close together because of the site's climate with several cloudy days.

3. Modelling a Solar Energy case at Forus

HOMER Energy

Name: Electric Load #1

January Profile

Hour	Load (kW)
0	6.01
1	6.24
2	7.13
3	6.25
4	6.06
5	6.09
6	6.21
7	5.89
8	20.24
9	45.15
10	42.39
11	41.56
12	43.83
13	40.35
14	29.93
15	31.03
16	7.79
17	6.32

Time Step Size: **60** minutes

Random Variability

Day-to-day (%): **19.213**

Timestep (%): **15.146**

Peak Month: **May**

Metric	Baseline	Scaled
Average (kWh/d)	341.92	341.92
Average (kW)	14.25	14.25
Peak (kW)	92.56	92.56
Load Factor	.15	.15

Load Type: ● AC ○ DC

Scaled Annual Average (kWh/d): 341.92

☐ Efficiency (Advanced)

Efficiency multiplier: 1

Capital cost (£): 0

Lifetime (yr): 10

Figure 11 A screenshot of the HOMER energy interface.

HOMER Energy is a microgrid modelling tool, not to be confused with the well-known Simpson's character. The National Renewable Energy Laboratory (NREL) developed HOMER but sold it to HOMER Energy LLC in 2009. The name is an acronym for *"Hybrid Optimization Model for Electric Renewables"* [7]. A software tool like HOMER will simplify the work of evaluating a range of different system designs. The program gives the ability to simulate both grid-connected and off-grid systems. When designing a power system, there is a range of decisions: Which power resources are optimal for the specific system? What size should the different components be? What is the optimal amount of storage?

Given so many variables, the modelling task will quickly lead to thousands or millions of different system configurations to be considered. With a micropower modelling tool, a person can simulate all these configurations simultaneously. The built-in optimisation algorithms in HOMER will subsequently categorise the results after the preferences set by the user [8].

How the energy simulator works

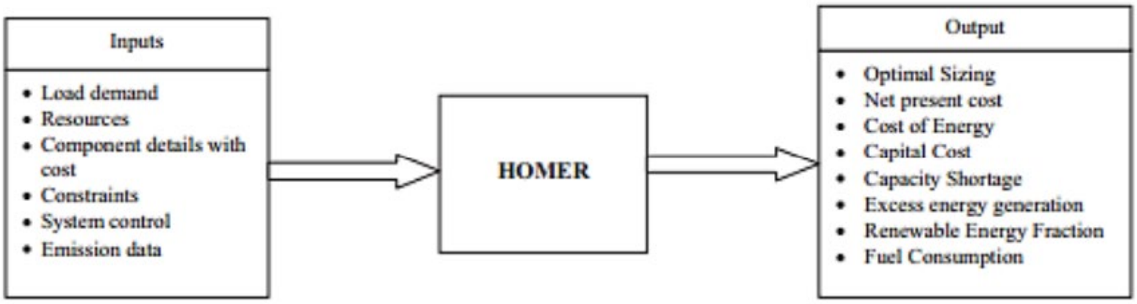


Figure 12 Schematic representation of how HOMER energy works. Component parameters, resources and demand data are inputted. Homer energy will calculate and output; optimal sizing, costs, performance, etc. [9].

An energy modelling simulator works by doing energy balance calculations on an hourly basis for each of the 8 760 hours in a year. HOMER links the electrical demand to the energy produced by the components in a specific system for every hour. If a range of different elements and sizes have been made available, all possible configurations will be tested.

When including fuel-powered generators or batteries, HOMER will run algorithms to decide when to operate the generator and charge and discharge the batteries. After all the possible configurations have been simulated, HOMER will return all the feasible system configurations [8].

A specific case of an office building at Forus

This report has chosen to use actual measured energy data from an office building in Forus. Due to the sensitivity of data, the office building is anonymised. The energy load of the building has the following characteristics:

Time Step in measurement	1 hour
Average load consumption (kWh/day)	5761
Average load power (kW)	240
Peak load power (kW)	664
Peak electricity Month	January

The goal of analysing the solar energy potential for a specific building at Forus is to understand better how changing the price energy can be sold for will impact the overall feasibility of solar energy.

Demand profile for an office building in Forus

Plotting the energy consumption for 2019 for the office building gives the following picture:

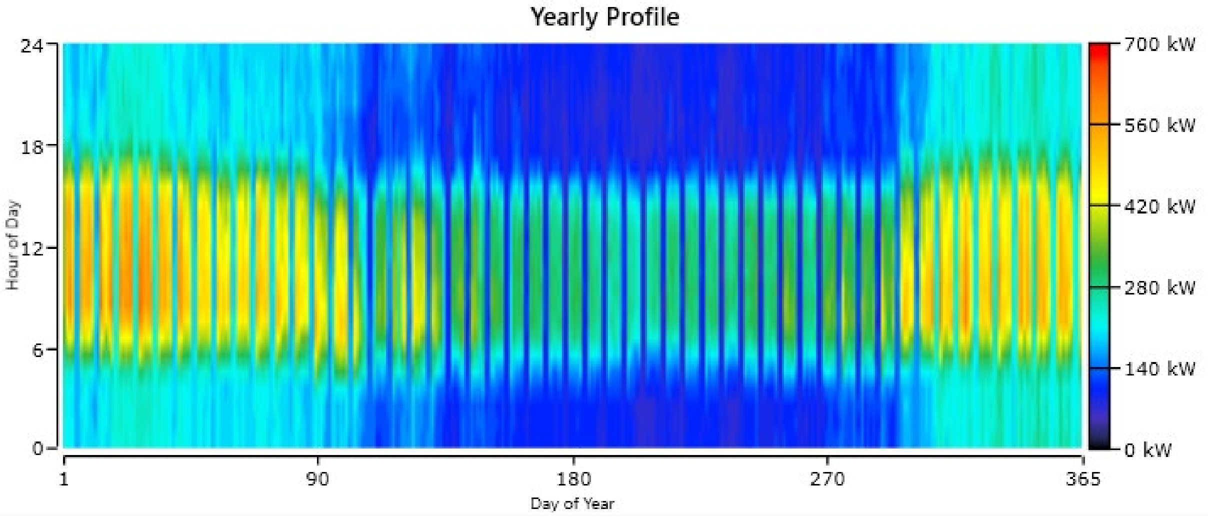


Figure 13 Yearly plotted energy consumption for an office building at Forus. It is clear from the data that most of the energy consumption occurs during the day and that the demand is substantially higher in winter than in the summer.

Solar energy scenarios

We have chosen to investigate a simplified scenario to understand better how a PV system could look and the economics of such a system.

Case study

In this case study, we have chosen to investigate a specific example using measured data for an office building in Forus. In this scenario, **electric power is bought for a flat rate of 1 NOK/kWh throughout the year and sold for a flat rate of 0.4NOK/kWh**

CURRENT SYSTEM with no solar (HOMER calculated)

The electric needs of the investigated office building at Forus, Norway, are met with a grid connection. The simulation shows that the current electricity cost will be 2.11M NOK. This calculation assumes a flat rate of 1NOK/kWh and total yearly consumption of 2,1 GWh.

PROPOSED SYSTEM with solar +

The proposed system with the same cost of buying electricity (1NOK/kWh) and selling it for 0,4 NOK/kWh. 1,080 kW of PV (60 degrees tilt, south-facing). This system would reduce the annual utility bill to 1.29M NOK over the 25-year project period. The investment has a payback of 10.78 years and an Internal Rate of Return (IRR) of 7.88%. Summary of inputs and results:

Project Lifetime:	25 yr		Cost per kW installed solar:	6000NOK
Discount rate	5%		Panel efficiency	20%
Simple payback:	10.8 yr		Net Present Value:	kr4.06M
Return on Investment:	5.27 %		Capital Investment:	kr6.48M
Internal Rate of Return:	7.88 %		Annualized Savings:	kr601,211

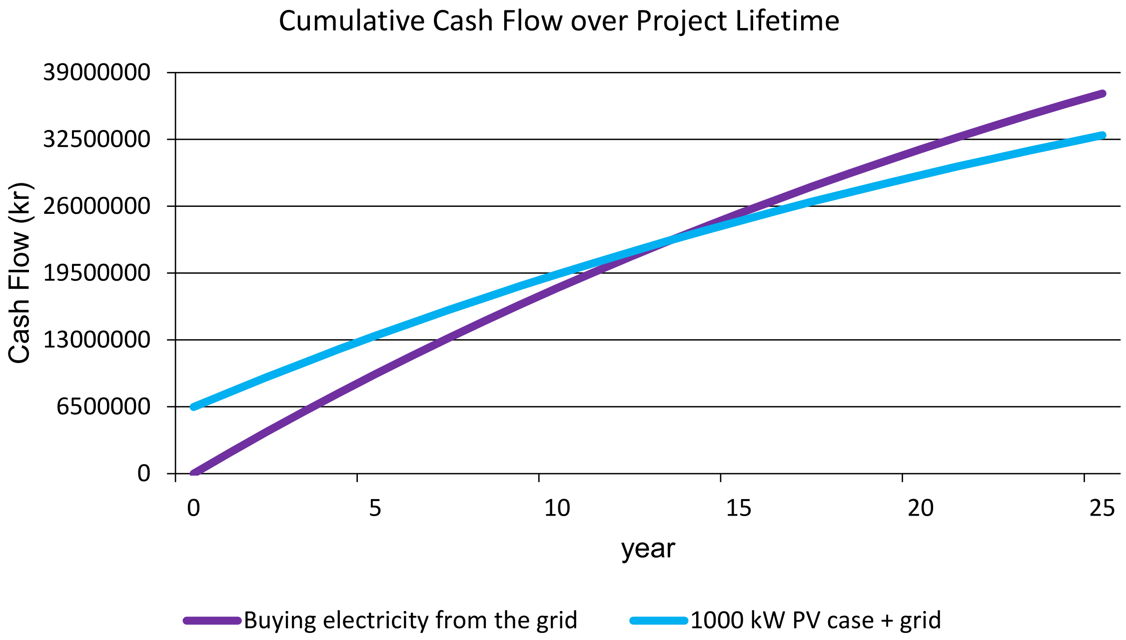


Figure 14 Cash Flow over the project lifetime. The solar energy case has a higher upfront cost, but over time it pays off.

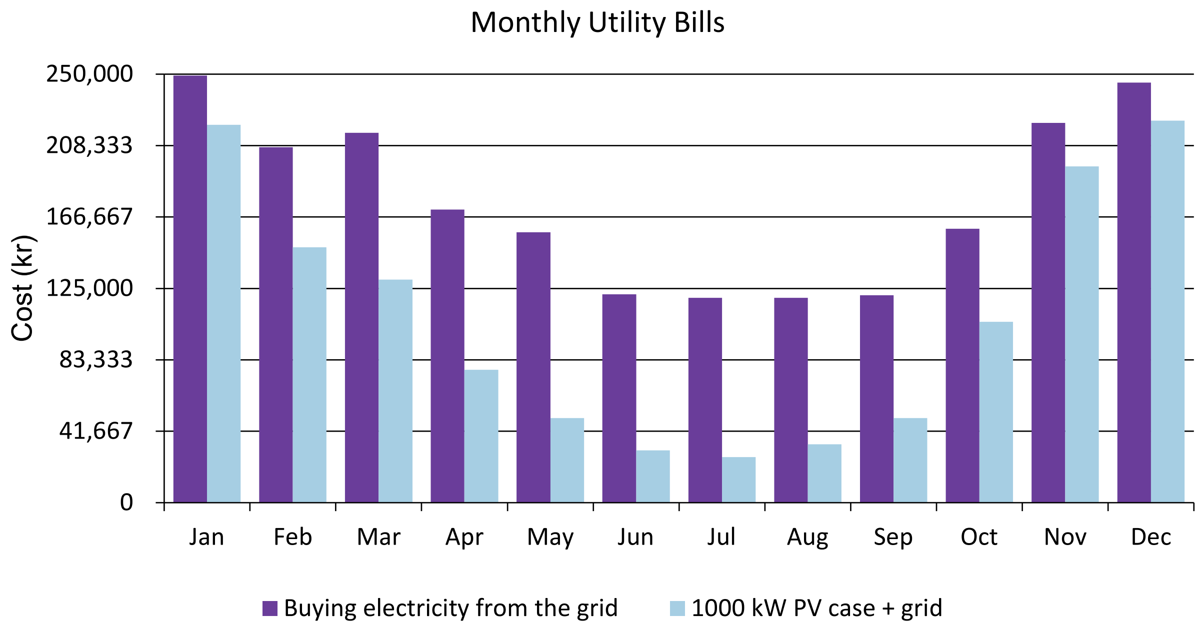


Figure 15 Monthly utility bills for the two systems

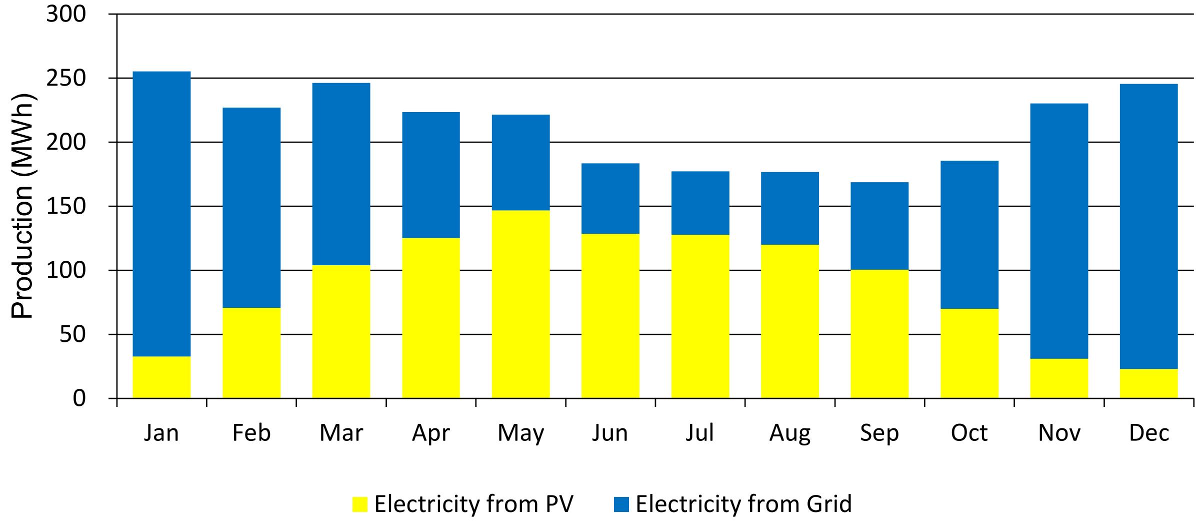


Figure 16 Energy provided to the building per month by Grid and Solar

Rated Capacity	1,080 kW	Total Production	1,079,879 kWh
Capital Cost	kr6.48M	Maintenance Cost	216,075 kr/yr
Specific Yield	1,000 kWh/kW		

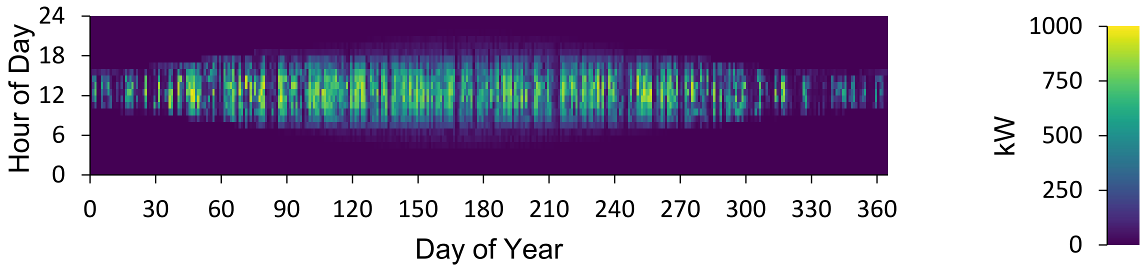


Figure 17 Energy production from PV throughout the year for our system

PV-System

The suggested PV System could be placed on the roof if there is 6000 m^2 available space, as shown by the calculation in the table below.

Description	Value	Unit
Rated capacity	1080	kW
Capacity per PV panel	360	Wp
Total Numbers of PV panels	3000	
Size per panel	1.7	m^2
PV area	5100	m^2
Total area (25% extra space)	**6120**	**m^2**

Table 1 Space required for the proposed PV system

To illustrate how this would look in practice, we could compare this system to one built by Norgesgruppen in 2016, which is approximately the same size:

Figure 18 UNILs warehouse at Våler, owned by Norgesgruppen. This system has a rated capacity of approximately 1000kW, similar to the proposed solar energy system for the building at Forus [10].

Roof vs walls vs PV-field

There have been enormous discussions concerning PV fields and roof-mounted PV solutions in the last decade. When it comes to the potential of the facades, in locations with a high latitude such as

Norway, the potential of facades increases significantly. For example, the solar potential of the south façade in Norway is almost equal to the solar potential of the roof (flat mounted). Utilising the significant potential of facades has several advantages:

- The possibility to achieve zero energy buildings (ZEB) or even plus energy building goals
- spreading the energy production throughout the day and when the demand exists
- The system's contribution to enhancing the energy performance of the envelopes

Moreover, using façade-mounted PV solutions doesn't have issues such as snowfall on the PV cells. Still, such a condition will increase the reflection radiation and result in a higher electricity production rate by the PV system in winter.

Figure 19 Oljedirektoratet in Stavanger is an example of a building with roof and wall integrated PV panels. Both the grey and black panels on the wall are PV panels [11].

Degradation rate per year of solar panels

Regardless of the environment solar cells of the Building Integrated Photo Voltaic (BIPV) system are in, they naturally degrade over time which is called the BIPV degradation rate. Depending on the material and technology, the BIPV degradation rate can vary. For the silicon-based PV cells, it is generally between 0.3% and 0.5%. This factor is also crucial to calculating the lifetime of the system. For example, when it is said that the degradation rate of BIPV technology with Silicon material is 0.5%, it means that the system's effectiveness after 30 years would be: $(1 - 0.005)^{30}= 0.8603$. This number means that the efficiency of the BIPV panel after 30 years due to the degradation rate will be 86 % of its nominal efficiency.

A study led by Jordan and Kurtz gathered nearly 2000 degradation rates, measured on individual modules or entire systems from the literature and found that the median degradation rate is 0.5% per year [12]. Another study done by Niccolò Aste et al. dealt with a PV system after 13 years of operation, and the results obtained showed that the analysed BIPV degradation rate is equal to 0.37%/year [13].

Orientation

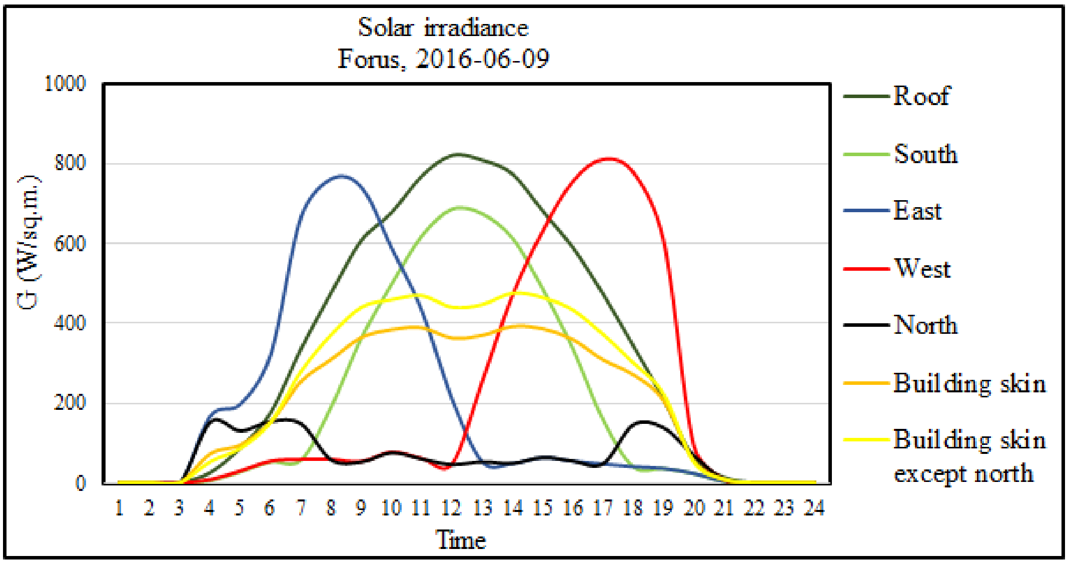


Figure 20 Solar radiation on different orientations on a sunny day in Forus

Returning to the graph presented earlier, we can see that the direction the PV panels are oriented impacts when and how much power is produced. A general rule for optimal annual energy production is to set the solar panel tilt angle equal to the geographical latitude. For example, if the solar array location is at 50 degrees latitude, the optimal tilt angle is also 50 degrees towards the south [14].

However, optimising for maximum annual production is unlikely to match the seasonal and daily power requirements. Therefore, it can make more sense to match the orientation to the power requirement of the given building or area. For example, if most of the energy demand occurs in the evening, the panels should be oriented west.

Figure 21 Solar tracking provides the maximum possible power produced, but it comes at a higher investment and maintenance cost [15]

The optimal solution could be to place the PV panels on trackers that follow the sun throughout the day. Doing this ensures significantly higher power production throughout the day. However, the cost is higher.

Discussion

4. Additional factors

Regulations, incentives and energy cost

The electricity price in Norway can be broken down into three main components, which constitutes about 30% of the cost each:

1. Power Price (Strømpris)
2. Taxes (Avgifter)
3. Grid fee (Nettleie)

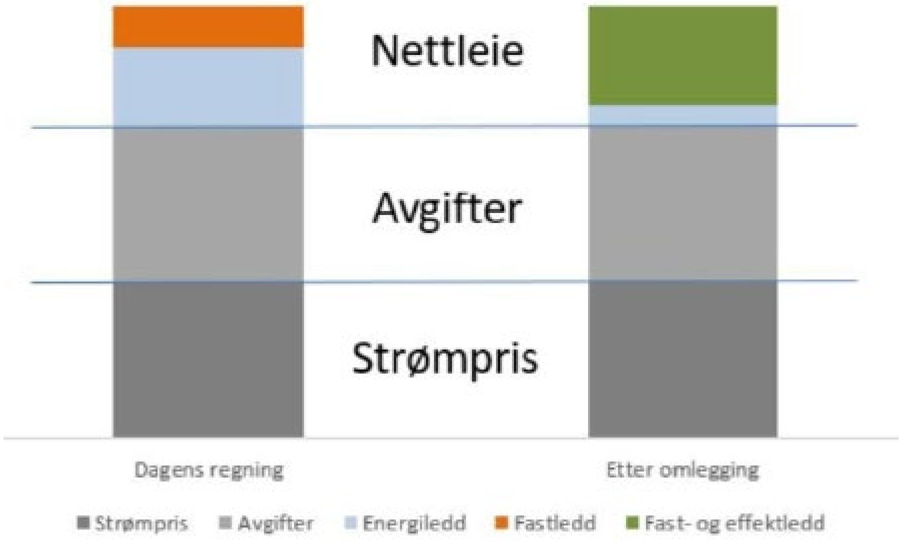


Figure 22 Breakdown of the total price paid for electricity in Norway [16].

When buying power from the grid, each of these cost components is paid. However, if a consumer wants to sell her excess energy back to the grid, she can get a "plusskunde" deal, which lets her sell up to 100kW back to the grid without registering for a power trading license or register as a grid company. However, she will only be paid the power price, and grid companies are not required to buy back power from consumers [17].

The main issue arises when a cluster of buildings want to produce power locally. To illustrate this, we can consider two buildings with different owners across the street from one another; we will call them building A and building B.

Building A has a lot of roof area available for PV panels. Still, because it is a simple warehouse without cooling and heating needs, there is not much need for energy when the power production from solar is at its highest.

On the other hand, Building B houses a heavy industry company that can use all the energy produced by the PV panels on the roof of building A, with more needed. However, the building is much smaller than the warehouse, so they can not produce their power from PV.

If building A want to sell their excess power to building B, they will be able to sell their electricity for a third of what building B pays for it. They will be paid so little because two-thirds of the cost will go towards grid fee and taxes, even though only a few meters of the grid is used.

Here lays the critical challenge to solve, there is a need for a more flexible way to transfer and sell electricity locally between consumers and producers, without redundant costs [18].

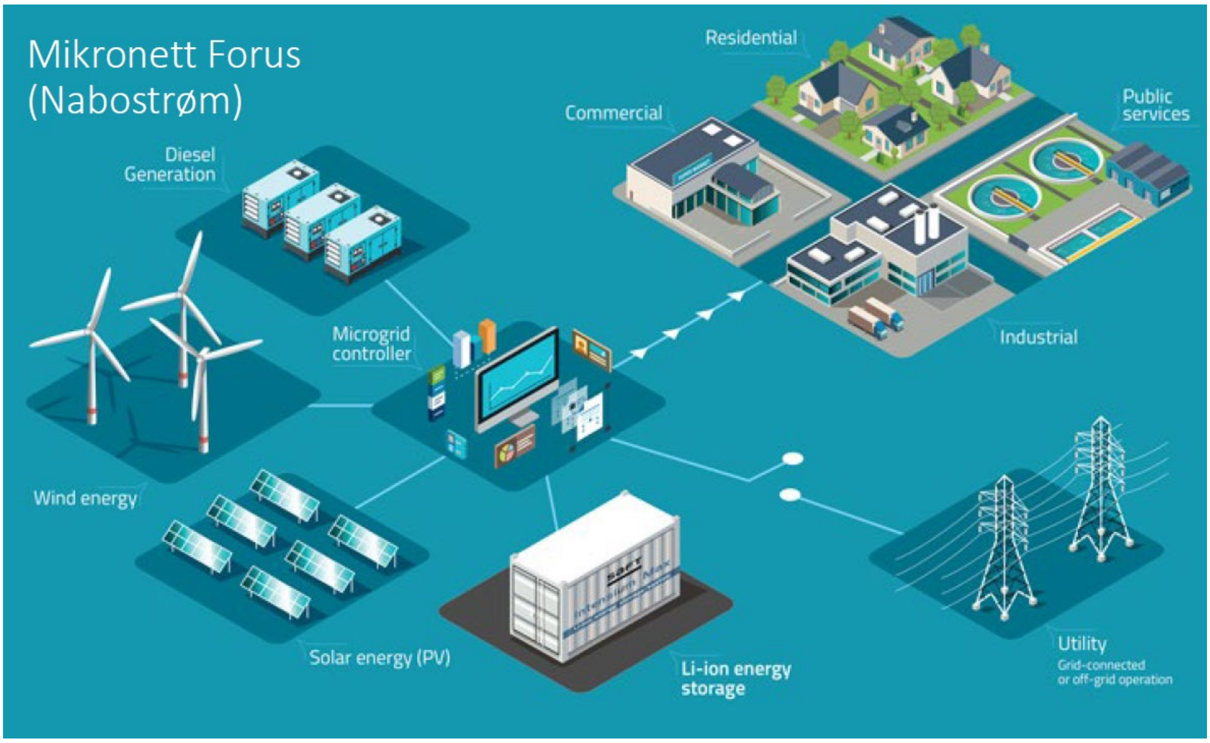


Figure 23 Illustrates how Forus Næringspark AS envisions a concept where they combine local generation with a grid connection. They argue this will provide a more flexible energy system, with less need for grid upgrades, due to lower peak demand [18, 19].

Multi-use of land

PV panels are flexible when it comes to placement, compared to other renewable energy sources, like wind and hydro. You can place the panels in racks on the ground, integrate them into the walls of the buildings, put them on the roof, and even incorporate them into the pavement. Nevertheless, each of these alternatives comes with advantages and disadvantages.

Figure 24 A flock of sheep grazing in between PV panels [20]

Figure 24 shows an example of combining PV panels with livestock. The advantage of this is that land utilisation is higher than doing each of the activities separately. In warm regions, this combination could prove exceptionally well suited as the PV panels would provide shading for the animals. In Norway, warm weather is not the main problem, but wind and rain could be a challenge for the animals, especially in the late autumn. Therefore, placing PV panels in a field where livestock is grazing could provide the animals with some shelter without impacting the growth of the grass used for animal feed.

Figure 25 PV panels used as roofing over a parking space represents another form of multi-use of land [21]

One alternative is to place the PV panels over parking lots, as is shown in figure 24. By making the parking lots into energy-producing areas, multi-use of land is achieved. This has the added benefit of providing shade and shelter from the rain for the cars.

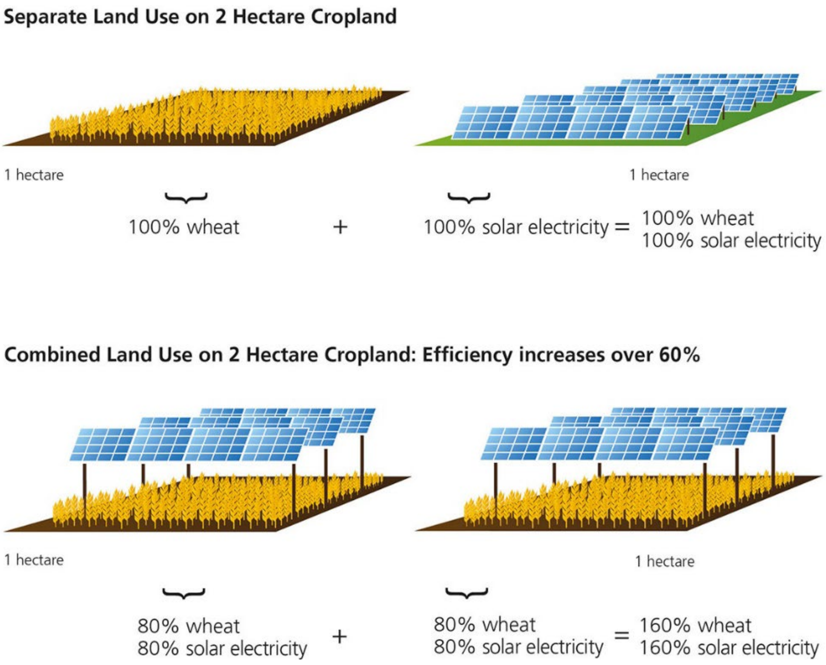


Figure 26 Combining agriculture with photovoltaic panels is called "Agrivoltaic" [20].

It is also possible to combine PV panels with farming, as is shown in figure 26. By combining the two, both the farm yield and PV yield will decrease by about 20% compared to doing each activity independently. However, because they are combined, this decrease will be cancelled out by the overall increase. There could be some challenges and extra cost associated with this method. One aspect is that "agrivoltaic" could be better suited in areas with a lot of direct sunlight, where shading is required. The panels need to be placed relatively high up and spaced apart to allow enough sun to reach the crops and farming equipment like tractors to have access.

Figure 27 Using PV panels as the facade and roof material is a perfect example of highly efficient multi-use of land. Incorporating solar into the building materials could make them pay for themselves during the building's lifetime. Also, the panels take up no additional space. The picture is of the building "Solsmaragden" in Drammen [22].

The last variation of multi-use of land that we want to highlight in this report is Building Integrated Photovoltaics (BIPV). In an area like Forus, there are hundreds of buildings already taking up a large land area. Using PV panels as the facade and roof material is a perfect example of highly efficient multi-use of land. Incorporating PV panels into the building materials could make them pay for themselves during the building's lifetime. Also, the panels take up no additional space.

Conclusion

We have summarised the main findings of this pre-project below:

- **Solar energy in the form of PV Panels could be economically feasible and well suited at Forus.**
- **There is a lot of uncertainty regarding future electricity prices (including grid tariffs), which is a vital factor for the economic feasibility of this project.**
- **Our case study shows that if one can sell electricity for a yearly average of 0,40NOK/kWh to the grid and buy for 1NOK/kWh, a 1000kWp PV system would have a payback of 10.78 years for the office building investigated.**
- **If the price one gets for selling electricity to the grid is low, one could orient the panels in another direction than a 60degree tilt south. The PV panel orientation should be based on the daily and seasonal power requirement for the given building/area.**
- **Having to pay the full grid tariff for transferring power to a neighbouring building is a challenge for the profitability of solar energy projects.**
- **The high grid tariff for short energy transfers is an obstacle that can be solved, for example, by creating a virtual grid with more flexible pricing based on the power transfer distance.**
- **The best multi-use of the land area is to utilise roofs and facades of existing or new buildings to produce solar energy.**
- **However, PV panels placed on the ground are likely to yield a lower installation cost than integrating PV panels onto buildings.**
- **Multi-use of land is possible to achieve with the panels placed on the ground. Livestock or farming underneath the PV panels is one example. It is also possible to use the panels as parking lot coverage.**
- **A Limitation in the case study is that we used a yearly average price for buying and selling electricity. The cost of electricity fluctuates, which will make the system profitability dependent on that.**
- **In Norway, the lowest electricity costs are generally in the middle of the summer, when power production from solar is highest. Thus, one should aim to use most of the power locally, as the grid fee is the main cost driver in this period.**
- **The partners should investigate the potential for solar energy at Forus further.**
- **It is necessary to go into dialogue with the grid companies and the energy directorate, as the challenges of making solar energy profitable at Forus is more a matter of regulatory issues than technical challenges.**

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