

TOWARDS COST-EFFICIENT GRID-CONNECTED PV POWER PLANTS IN NORTHERN SCANDINAVIA

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ABSTRACT: Northern Scandinavia has a yearly insolation that is comparable to Central Europe. This is true for both optimal inclined fixed systems and for two-axis tracking systems. Despite this fact, the installed PV in this region is only a minor fraction compared to Germany, which is one of the world's top PV nations. This paper presents a calculated levelized cost of electricity for Piteå in Northern Sweden on the same level as for Freiburg in Southern Germany. According to these calculations, the system reaches grid parity even without subsidies. These calculations were based on simulations performed for different high efficient PV technologies with both fixed mounting and solar tracking for four locations in Scandinavia and Germany. The results show that the performance of different technologies is dependent on the system design. Since the module area is limited on the relatively expensive two-axis tracking systems, the optimum choices in these calculations were high efficient mono-crystalline modules. The work presented is a part of the installation of a combined commercial and research 20 kWp two-axis tracking system that is currently being installed in Piteå, Sweden.

Keywords: Economic Analysis, Grid-Connected, PV System, Performance, Tracking

1 INTRODUCTION

It is a common misconception that Northern Scandinavia does not receive enough sunlight to make PV installations economically feasible. The available amount of solar radiation in Northern Scandinavia is in fact comparable to that in central Europe. The main limitation in northern latitudes is the large annual variations, where the major share of the solar radiation is received during the long summer days. In combination with the relatively low price of electricity, larger grid-connected PV systems have so far been considered economically unfeasible. However, a system with 360° solar tracking can harvest the valuable summer sun. Simulations show that the energy yield of such a system could be increased with more than 50% in northern Sweden. [1]

The results of the simulations presented here suggest that large-scale PV systems may well be economically feasible in Northern Scandinavia and that grid-parity may be reached in the near future. One of the regions in Northern Scandinavia with the most sun hours per year is the northern coast of the Baltic Sea. The idea of a northern PV system was presented at a conference in 2010 and attracted the interest of the energy company PiteEnergi. It was decided to build a test system at the company premises in Piteå, and at present a 20kWp PV power plant is under construction and will be operational in late 2011. The planned PV power plant will be a commercial system, owned by PiteEnergi, but it will also be used for research purposes.

This paper aims to prove that grid-connected PV systems can be economically feasible in Northern Scandinavia. The planned PV system in Piteå is used as a case study. The system performance is simulated and the levelized cost of electricity (LCOE) is calculated. As a comparison a similar system has been simulated in Germany, the world's leading solar market. As this paper will show, the differences in energy output between the systems are small, suggesting that the feasibility of PV in Northern Scandinavia should be reconsidered.

2 BACKGROUND

2.1 The current status of PV in Sweden

The geographical focus of this paper is Northern Scandinavia, by which we mean the northern parts of Sweden and Norway. So far both countries have a relatively modest installed PV capacity which historically has been dominated by domestic off-grid systems.

Since a capital subsidy was introduced in Sweden in the years 2005-2008 and 2009-2011, the installation of larger grid-connected systems in the country has increased rapidly. By the end of 2010, the installed capacity in Sweden was 11 433 kWp of which 5 395 kWp, or 49.7%, was grid-connected. This is a significant increase from the 194 kWp of grid-connected capacity before the subsidy in 2004. In addition to the subsidy, the rules for installation of small grid-connected systems were simplified in 2010. The installer no longer has to pay a fee to connect to the grid and moreover the distribution system operators have to pay for the necessary electricity meter. This led to 2010 being a record-breaking year with 2 011 kWp of installed PV capacity – four times as much as in 2009. [2]

There are two basic support schemes to promote the use of solar cells in Sweden today: direct capital subsidy and electricity certificates (so-called green certificates). The current direct capital subsidy is valid for installations started after July 1, 2009 and ended before December 31, 2011. The subsidy is available for all types of grid-connected solar cell systems, including hybrid systems. Private installers as well as companies and public organizations are eligible. The subsidy covers 60% of the installation costs (55% for large companies) up to a maximum of 2 MSEK (228 000€) per installation. [3] A similar subsidy was available between 2005 and 2008. This subsidy covered 70% of the costs, but was on the other hand only available for installations on public buildings. [2]

Electricity certificates, also called green certificates, are a market based support tool to promote the cheapest available renewable energy, that is, it does not promote solar energy specifically. The goal is to increase the production of renewable energy by 25 TWh from 2002 to 2020. A producer of renewable electricity receives one

certificate per produced MWh. Electricity suppliers are required to buy a certain number of certificates, which are paid for by the consumers through the electricity price. The system thus leads to an extra income for the producer of renewable energy. [4]

2.2 The current status of PV in Norway

By the end of 2010, the total installed PV capacity in Norway was 9 062 kWp. The yearly installed capacity has been stable at about 300-400 kWp for the last years. Off-grid systems still dominate completely in Norway and the domestic off-grid systems account for 80%-90% of the market. These systems are typically used to power leisure cabins or boats and a typical size is 80-120 Wp. Since the mid 90's, the professional demand for off-grid PV systems has increased, primarily to power lighthouses along the coast. PV systems with battery banks are in fact used to power lighthouses north of 70° latitude. There have been no support schemes for PV in Norway and the number of grid-connected systems has been very low, although in recent years some larger building integrated systems have been built. [5]

There are no direct support schemes for solar cells in Norway, but in 2012 Norway will most probably join the Swedish electricity certificate market to form a joint market. [6] In addition, Norway is a member of the European Economic Area (EEA) and thereby obliged to fulfil the EU directive on renewable energy. [5]

2.3 Comparison to the situation in Germany

In this paper, the situation in Scandinavia is compared to that in Germany, which is one of the largest markets for PV installations in the world. Germany had an installed PV capacity of 17 320 MWp by the end of 2010, of which the largest part is grid-connected. Yet, as we will soon discuss in more detail, the solar resource in Germany is comparable to that in Northern Scandinavia. The installed PV capacity in Germany is almost 850 times larger than in Sweden and Norway combined, even though the population is only less than six times larger and the land area only half the size. A comparison of the installed capacity in the different countries is shown in Table I. The obvious question is why there is such a small capacity installed in Scandinavia? One of the answers is of course the different economic support schemes in the different countries. While Germany has had a generous feed-in tariff system for small PV installations since a number of years, there is no such system either in Norway or Sweden. [7] This has also helped to develop an industry around PV installations in Germany, which does not exist to the same degree in Scandinavia.

Table I. The table shows a comparison of the installed PV capacity in Sweden, Norway and Germany by the end of 2010. [2] [5] [7]

	Accumulated PV capacity 2010 (MWp)		
	Off-grid	Grid-connected	Total
Sweden	6.0	5.4	11.4
Norway	8.9	0.2	9.1
Germany	50	17 320	17 370

2.4. The solar resource in Scandinavia

As was mentioned in the introduction, it is a misconception that the amount of sunlight in northern regions is the limitation for widespread use of PV. The total solar insolation in Scandinavia is in fact comparable to that in central Europe. In this paper, the conditions for PV systems in four different locations are studied: Piteå in northern Sweden, Narvik in northern Norway and Halle and Freiburg in mid and southern Germany. Piteå is located in one of the sunniest regions in Sweden. Narvik is located on the coast of Northern Norway, a region with considerably lower levels of solar radiation. It is also the location of the research institute Norut Narvik where this paper is written. Halle is a medium irradiation location in Germany, considered here to be a representative location for large parts of Germany, and Freiburg is one of the locations with highest yearly irradiation in Germany.

There are, however, limitations related to the geographic location. The solar resource in northern latitudes is characterized by large annual variations. The major share of the solar radiation is received during the long summer days, while there is very little radiation available during winter. Above the Arctic Circle (66°N) which passes through northern Sweden and Norway, there is a period of midnight sun during summer, meaning that the sun is above the horizon for 24 hours a day. Consequently, there is a period of polar night during winter, meaning that the sun does not rise above the horizon.

The insolation at four locations in Northern Scandinavia and Germany is compared in Table II. Maps of solar radiation commonly show the irradiation on a horizontal surface. As the table shows, this value is larger for the locations in Germany. Yet since it is not common to install a PV system horizontally it can be argued that this value is of less significance. The insolation on an optimally inclined surface exhibits a smaller difference between the locations. Since the summer sun in Northern Scandinavia will shine from all cardinal directions, a fixed PV system will fail to utilize a significant amount of the summer sunlight. A two-axis tracking PV system follows the sun path and can thereby harvest most of the available energy. As Table II shows, the available irradiation on a surface with two-axis tracking is actually higher in Piteå in northern Sweden than in mid Germany.

Since the system is always directed at an optimal angle towards the sun, sunshine duration data can be used to find areas with good potential for two-axis tracking PV systems, as measurements of solar irradiation other than horizontal are rare. Figure 1 shows three maps of sunshine duration in Sweden for a whole year and for the months June and December for a normal year in the period 1961 to 1990. It is evident that the larger difference during the whole year is not between the north and the south, but rather between the coastal areas and the inland. On a yearly basis, the northern coast of the Baltic Sea is in fact one of the sunniest regions in Sweden. It is also evident that most of solar energy will be harvested during the summer.

Table II. The table shows a comparison of the yearly irradiation in the four locations in Scandinavia and Germany. The simulations are performed in PVsyst with NASA-SSE 6 data and with an estimated horizon line.

Yearly insolation (kWh/m ²)				
	Narvik	Piteå	Halle	Freiburg
Horizontal	740	900	990	1150
Fixed, vertical south-facing	640	920	810	860
Fixed, optimal inclination	870	1160	1130	1290
Horizontal one-axis tracking	950	1270	1190	1350
Inclined one-axis tracking	1160	1590	1350	1590
Vertical one-axis tracking	1200	1610	1370	1590
Two-axis tracking	1210	1640	1400	1630

As can be seen in Table II, the advantages of installing a tracking system in Piteå are obvious. The insolation on a two-axis tracking surface is 41% higher than on an optimally inclined fixed surface. For Freiburg, the same increase is 26%. In absolute numbers, a system in Piteå will actually receive a similar amount of solar energy as a system in Freiburg. In addition, a two-axis tracking system in Piteå receives 27% more insolation than a fixed system of similar size in Freiburg. As the example above shows, the solar resource in Germany is comparable to that in Scandinavia for an optimally inclined system. If two-axis tracking is used, the simulations suggest that parts of Northern Scandinavia have a better resource than large parts of Germany.

2.5 Other climate factors

There are of course other factors than the total yearly insolation that influence the output and efficiency of a PV system. One such factor is the large seasonal variations in Scandinavia. The largest part of the insolation in Northern Scandinavia is received during the summer months, while there is little or no solar irradiation during the winter, which can clearly be seen in Figure 1. For a residential system this may lead to a load mismatch, especially if electricity is used for heating. If net metering is used, owners of a residential system can deliver energy to the grid when production is high and take electricity from the grid when their demand is high, and only pay for the net electricity use. In addition, studies have shown that a substantial expansion in the number of residential PV systems is possible without any negative consequences on the energy grid. [8] For a commercial PV plant, this mismatch issue does not have to be a problem if there are other energy sources to balance or regulate it, such as wind and hydro power.

The yield of a PV system is also dependent on the efficiency of its different components. Here, the colder climate in Northern Scandinavia may be an advantage. As a general rule, the efficiency of solar cells decreases with increasing temperature. This means that in a colder climate, the efficiency will generally be higher than in a warmer climate. However, the temperature coefficient for a PV module given on the product data sheet comes from measurements close to STC, and therefore care should be

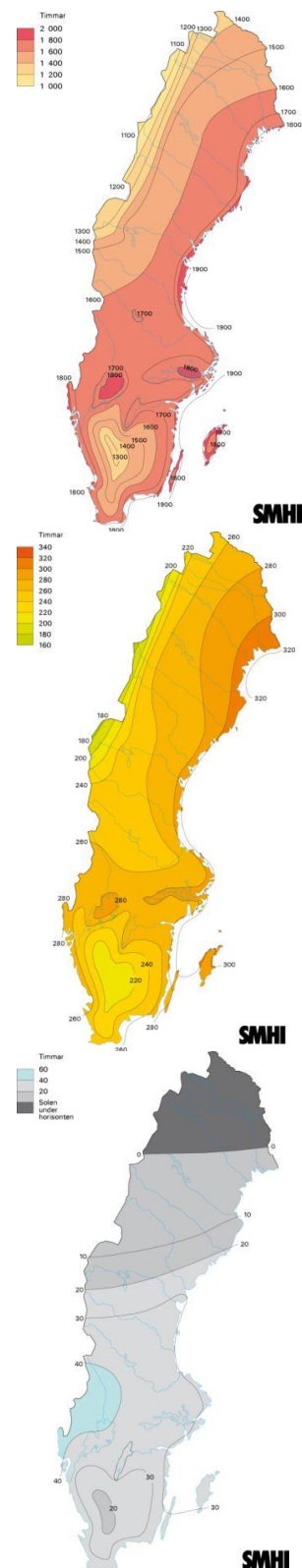


Figure 1. The sunshine duration in sun hours in Sweden for one year (top), the month of June (middle) and the month of December (bottom) for a normal year in the period 1961 to 1990. The sunshine duration is the amount of time when the direct irradiation exceeds 120 W/m². The dark area in the bottom image indicates the area above the Arctic Circle. [9]

taken before extrapolating to for example subzero temperatures.

Both Piteå and Narvik have snow for several months each winter. When the ground is covered with snow, more sunlight is reflected onto the PV modules (albedo increases). Simulations show that this can increase the insolation available for the PV system by 0.8% for a fixed, optimally inclined system and by 1.2% for a two-axis tracking system. Snow on the modules, on the other hand, both leads to shading and physical strain on module, frame and mounting system. Icing and snow load can also lead to problems with the moving parts of a solar tracking system, and the low temperature might cause problems with the tracking motor and hydraulic parts. Therefore cold climate puts higher demands on the robustness of a PV system than would be the case in warmer climates.

3 DESCRIPTION OF THE SYSTEM IN PITEÅ

The planned installation in Piteå will be a commercial system, that is, it will be owned by PiteEnergi and deliver electricity to the power grid. At the same time it will be a research system that provides the research partners with valuable data about system performance, quality of electricity etc.

Features for the PV power plant in Piteå:

- 20kWp of PV modules.
- CIGS, mono-Si and poly-Si modules for comparison between different technologies.
- Individual performance monitoring and logging of each module.
- Two different types of 2-axis solar tracking systems, approx. 80 m² each.
- Astronomical vs optical solar tracking.
- Monitoring of the quality and impact of the produced energy on the grid.

4 METHOD

The aim of this study has been to investigate the economic feasibility of a PV system in Piteå in northern Sweden. To do this, we have studied six different systems setups at the four locations. Although the proposed system (described in the previous section) will be a commercial installation, it will be partly used for research and is therefore not primarily designed to be cost-efficient. To achieve a more generalized result, the system setups studied in this paper have been simplified.

An evaluation is performed by calculating and comparing the levelized cost of electricity (LCOE) [10] for each of the systems. The payback times of the systems are calculated based on the local price of electricity and its expected increase. We have also studied if the systems reach grid parity in the four locations.

The different factors that influence the calculations are discussed in the following sections. It is obvious that the calculated values depend on a large number of different assumptions. One should therefore be careful to apply too much significance to the exact values, but rather understand them as estimations that are useful for comparing different alternatives.

4.1 System setup for simulations

The proposed system in Piteå will be mounted on a two-axis solar tracker and include three different cell technologies: mono-Si, multi-Si and CIGS. To include these aspects in the simulations we have considered six different system setups; a two axis tracking system and a fixed optimally inclined system for each of the three technologies.

The proposed system in Piteå will be mounted on two solar trackers with 80 m² available module area each. We have used this size, i.e. 160 m² of module area, as the basic limitation of the simulated systems. This gives us a 26 kWp mono-Si system, a 24 kWp multi-Si system and a 20 kWp CIGS system.

The performance of the three systems is simulated in PVsyst for the following four locations: Piteå in Northern Sweden, Narvik in Northern Norway and Halle and Freiburg in Germany.

The calculated cost of installing a PV system with two-axis tracking is based on real data from the project in Piteå in combination with market prices. The cost of operation and maintenance is set to approximately 3% of the installation costs. The installation cost of a fixed PV system is assumed to be 2.40 €/W, based on average price on the German market in 2010. [11]. As the cost of PV installations is steadily decreasing, this is considered to be a conservative assumption and the real cost will probably be lower. Then again, the cost is estimated for larger scale systems and since the systems in question are moderate in size, the cost of installation may actually be a bit higher. The assumed cost is a general estimation and the same values in €/W has been used regardless of cell technology.

High efficiency modules are chosen for the simulations (15.2-16.2% efficiency for the Si modules and 12.7% for the CIGS modules). Since the module area is limited by the size of the tracking system, the PV modules must have relatively high efficiency to make the system cost effective. The module and inverter prices are taken from the spot price of modules and inverters on the German market in July 2011 [12]. Since the price drop in PV modules is expected to continue, this too is considered to be a conservative assumption, i.e. the electricity price will probably be lower than calculated.

4.2 Levelized cost of electricity

To compare the cost-efficiency of the different systems, the levelized cost of electricity (LCOE) is used. The LCOE in €/kWh is the price that has to be assigned to every kWh produced by the system in order for it to pay back its own total life-cycle cost (TLCC) [10]. An advantage of LCOE is that it is expressed in €/kWh – not €/W – which makes it easier to compare the results to other energy installations. [11]

The LCOE is calculated according to Equation 1. In addition to the total life-cycle cost of the system, the input parameters are the annual energy production from the system, and the discount rate.

$$LCOE = \frac{TLCC}{\sum_{n=0}^N \frac{Q_n}{(1+d)^n}} \quad (1)$$

Equation 1. LCOE is the levelized cost of electricity, TLCC is the total life-cycle cost, Q_n is the energy output or saved energy in year n, N is the system lifetime in years and d the discount rate. [10]

If the annual produced energy from the system is equal, as assumed here, the formula can be simplified to the expressions in Equation 2.1 and Equation 2.2.

$$LCOE = \frac{TLCC}{Q} UCRF \quad (2.1)$$

$$UCRF = \frac{d(1+d)^N}{(1+d)^N - 1} \quad (2.2)$$

Equation 2. In eq. 2.1 LCOE is the levelized cost of electricity, TLCC the total life cycle cost, Q is the annual energy output or saved energy and UCRF is the uniform capital recovery factor. In eq. 2.2, N the system lifetime in years and d is the discount rate.

To calculate total life-cycle cost, the expenditures of each year are added and discounted back to the present year with present value analysis, as shown in Equation 3.

$$TLCC = \sum_{n=0}^N \frac{C_n}{(1+d)^n} \quad (3)$$

Equation 3. TLCC is the total life-cycle cost, C_n the annual cost, N is the analysis period in years and d is the discount rate. [10]

It should be noted that the LCOE is useful for comparing different alternatives, but it should not be taken as an exact value. It is useful for comparing different system setups or alternative installations, because it gives a more intuitive value than the €/W. Still, the calculation includes several assumptions and it cannot be directly compared to other calculated values of LCOE.

The calculation of LCOE depends on several factors, including (but not limited to) the simulated energy yield, the cost of the system in €/Wp, the estimated cost of operation, the discount rate and the expected lifetime of the PV system. Based on earlier estimations for similar calculations performed in Sweden, the discount rate is set to 6%. [13] We have estimated a system lifetime of 25 years of the PV system, in accordance with the consensus view in the industry. However, the estimated lifetime is expected to increase in the coming years as improved system components are developed.

4.3 Payback time

The payback time of the system has been calculated with the net present value method (NPV) [10]. The expected costs of the PV system and the expected income from sold (or saved) energy are calculated on a yearly basis and discounted back to a base year. The payback time is taken as the number of years of operation before the NPV is positive.

The net present value of the installation in Piteå is calculated with and without subsidies. For the calculations with subsidies we have included the Swedish subsidy of 55% of the installation costs and green certificates to the revenues from the sold electricity. Based on current data we have set the value of these to 0.029 €/kWh. (In reality, one certificate is received for each MWh produced by the system and the sold at marked price, but for the sake of simplicity we have applied a value for each kWh.)

As in the case of the LCOE, the payback time

depends on a number of assumptions. The estimated income from the produced or saved energy is based on the price of electricity and its expected increase. Electricity that is sold to the grid will be valued lower than saved electricity, since the consumer will pay the spot price with added taxes and fees. The sold electricity will be worth the selling price, i.e. the spot price on the energy market. Saved energy, as in case of a residential system with net metering, will be worth the buying price of electricity. In addition, if the electricity is sold to the grid, the payback time depends on whether subsidies such as green certificates or feed-in tariffs are accounted for.

In this paper, the payback time of a system with no subsidies, as well as a subsidized system is estimated for Piteå in Sweden. The subsidized system includes the capital subsidy of 55% of the investment costs as well as an income from green certificates.

4.4 Grid parity

According to the European Photovoltaic Industry Association (EPIA), grid parity is defined as the point in time when the revenues generated by the energy output (sold or saved) from a PV system equals the total lifetime costs of the PV system. [14] To estimate the grid parity, we have calculated the NPV of the costs and revenues of a system over its lifetime. A NPV of zero or above indicates that the system costs and revenues are equal, that is, that it has reached grid parity. Consequently, a negative NPV indicates that grid parity is not reached.

As in the case of the LCOE, this depends on assumptions about the lifetime costs of the system. In addition, it depends on the assumptions on the price of electricity, as in the case of the payback time.

4.5 Energy price

Any assumptions about the energy price will influence both the estimated payback time and the grid parity evaluation. The energy price in the Nordic countries is set on the Nordpool, the Nordic power market. The assumptions on energy price and energy price increase in this paper are based on current and historical data from Nordpool. [15] The energy price used to estimate the payback time and the grid parity is set to 0.060 €/kWh for energy sold to the grid and 0.10 €/kWh for bought energy. The estimated annual price increase is set to 9%. (An annual increase of 9% might seem high but Sweden has in fact had a more than 20% increase annually during the last ten years.)

5 RESULTS

The calculated installation costs in €/W of the different systems are presented in Table III. In this study, the system with CIGS modules was the most expensive per installed Wp even though it was the least expensive, in regard to the total system. This is due to that lower total power in Wp can be fitted to the same area than for the Silicon modules.

Table III. The estimated cost of installation for the different systems in €/W.

	Mono-Si	Multi-Si	CIGS
Estimated installation cost for PV system with two-axis tracking (€/W)	3.17	3.31	3.52
Cost with Swedish subsidy (€/W)	1.43	1.49	1.58

The cost distribution of the different systems is shown in Figure 2. The systems with crystalline Silicon modules are dominated by the module cost, while the CIGS system is dominated by the cost of the tracker.

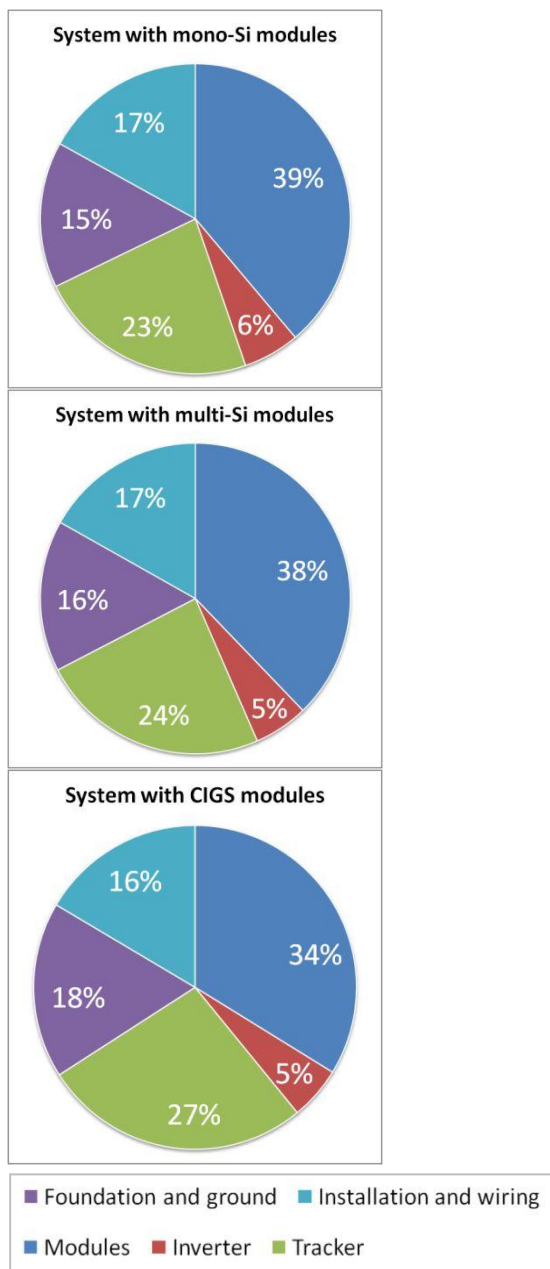


Figure 2. The three pie charts show how the installation costs are distributed on the studied PV system with two-axis tracking and mono-Si modules (top), multi-Si modules (middle) and CIGS modules (bottom).

The simulated values of the annual yield, in kWh/kWp installed, are presented together with the calculated levelized cost of electricity in €/kWh. The values are given for unsubsidized systems if not otherwise stated. The values for fixed and two-axis tracking systems are presented for each location and technology (mono-Si, multi-Si and CIGS).

The annual yield in kWh/kWp of the different systems in the four locations is shown in Table IV. The annual yield for a two-axis tracking system is highest in Piteå, while the annual yield for a fixed system is generally highest in Freiburg. The annual yield is higher in Piteå than in Halle for all the system setups.

Table IV. The table shows the annual yield for the PV system with different cell technologies in the four different locations. The values for the two-axis tracking system as well as the fixed system with optimal inclination are shown. (Round numbers are used.)

	Annual yield (kWh/kWp)			
	Narvik	Halle	Piteå	Freiburg
Two-axis tracking				
Mono-Si	1070	1210	1440	1410
Multi-Si	1040	1170	1400	1360
CIGS	1050	1240	1480	1480
Fixed, optimal inclination				
Mono-Si	750	950	990	1090
Multi-Si	740	930	970	1060
CIGS	700	940	970	1100

The LCOE for the systems with two-axis tracking is shown in Figure 3. The LCOE is comparable for the systems in Piteå and Freiburg, 0.23-0.25 €/kWh, and slightly higher for the system in Halle, 0.27-0.30 €/kWh. The system in Narvik has a LCOE of 0.30-0.36 €/kWh.

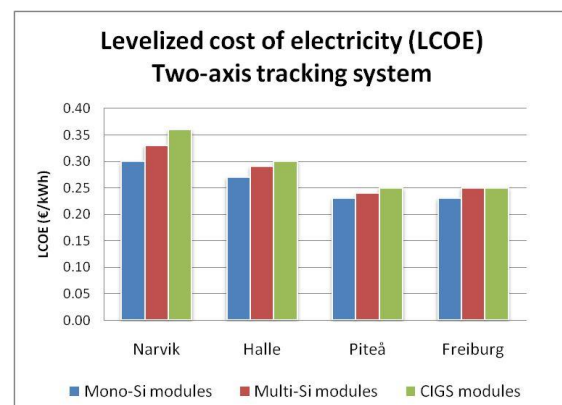


Figure 3. The figure shows the levelized cost of electricity for the system with two-axis tracking in the four locations and for the different cell technologies.

The LCOE for the fixed systems are shown in Figure 4. In this case, the LCOE in Freiburg are lower than for the other locations with 0.24-0.26 €/kWh. The LCOE for the system in Piteå, 0.27-0.30 €/kWh, is still lower than in Halle, with 0.28-0.31 €/kWh. The LCOE in

Narvik is still the highest with 0.36-0.41 €/kWh. It should be noted that the same installation cost in €/W have been used for all three technologies for the fixed system, and it is therefore only the difference in yield for the different locations that influence the LCOE.

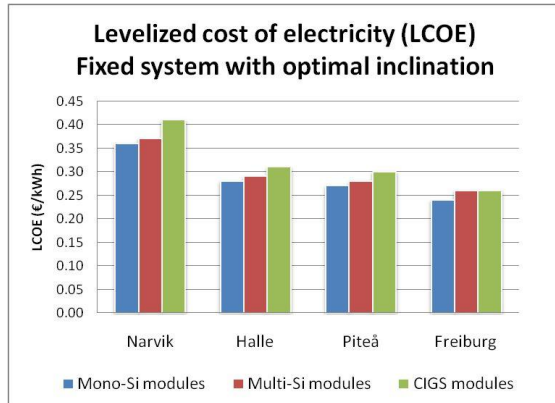


Figure 4. The figure shows the levelized cost of electricity for the fixed system with optimal inclination in the four locations and for the different cell technologies.

It is worth noting that the LCOE for a fixed system in Germany is higher than for a two-axis tracking system in Sweden. That is, the calculations suggest that it is more cost-effective to install a PV system with two-tracking system in Piteå than to install a fixed system in Germany.

The net present value (NPV) and the payback time in years are estimated for the systems in Piteå. The values are presented for a system where the energy is sold – and therefore worth the lower selling price – and where energy is saved – and therefore worth the higher buying price. The values for an unsubsidized system are shown in Table V.

Table V. The table shows the net present value of the different systems in Piteå without any subsidies. (Values in brackets are negative and round numbers are used.)

System in Piteå, no subsidies			
Two-axis tracking			
	Mono-Si	Multi-Si	CIGS
NPV if energy is sold (€)	(25,140)	(30,660)	(30,750)
Payback time (years)	-	-	-
NPV if energy is saved (€)	29,360	18,310	12,600
Payback time (years)	21	22	23
Fixed, optimal inclination			
	Mono-Si	Multi-Si	CIGS
NPV if energy is sold (€)	(30,949)	(31,771)	(30,840)
Payback time (years)	-	-	-
NPV if energy is saved (€)	6,620	2,150	(2,410)
Payback time (years)	24	25	-

The values for the system with subsidies have been calculated with the 55% capital subsidy on the investment costs and the green certificates for the produced energy. The calculated values are shown in Table VI.

Table VI. The table shows the net present value of the different systems in Piteå with subsidies. (Values in brackets are negative and round numbers are used.)

System in Piteå, with subsidies			
Two-axis tracking			
	Mono-Si	Multi-Si	CIGS
NPV if energy is sold (€)	32,490	24,120	18,110
Payback time (years)	17	18	20
NPV if energy is saved (€)	86,990	73,090	61,460
Payback time (years)	11	12	12
Fixed, optimal inclination			
	Mono-Si	Multi-Si	CIGS
NPV in energy is sold (€)	8,757	4,740	(208)
Payback time (years)	22	24	-
NPV if energy is saved (€)	46,330	38,660	28,230
Payback time (years)	14	15	16

As the tables show, the net present value is positive for the subsidized systems, except for the fixed system with CIGS modules where the energy is sold. If the energy is counted as saved, all systems have positive NPV, except for the unsubsidized fixed system with CIGS modules. A positive NPV means that the systems have reached grid-parity.

6 DISCUSSION

It should be remembered that the presented results in this article rely strongly on simulation data from PVsyst and is hence sensitive to uncertainties in these. By definition, a simulation is not the real case. The simulated values depend on a large number of factors such as weather data, choice of modules and inverters, string layout and the horizon. PV simulation programs normally use a 1-diode model to predict module performance depending on STC values, temperature and irradiance. It has been found that averaging irradiance over longer time intervals will shift the irradiance profile towards lower values, and since the module efficiency varies with irradiance the quality of the simulations is therefore highly dependent on the quality of the input weather data. Inconsistencies have also been found between the modeled module efficiency vs. irradiance and temperature for PV simulation programs and the efficiency parameters from the PV module manufacturer,

indicating that the 1-diode model does not simulate the PV module perfectly. [16] [17]

The economic evaluations presented in this paper are based on a large number of assumptions and varying one or more of the parameters will inevitably lead to changes in the results. The discount rate has a significant influence on the results and the results presented here can therefore not be directly compared to results where another discount rate is used. The assumptions on energy price and its increase over time will of course also influence the results. This means that the NPV and payback time will be different for the same system in different countries. It will not, however, influence the LCOE calculations as they are performed without regard to a specific location.

7 CONCLUSION

The calculated values show that there is little difference between the LCOE for the PV systems in Germany and Sweden. This is both for fixed systems and tracking systems. The calculated LCOE is always lower in Piteå than in Halle. For a system with two-axis tracking, the LCOE is more or less the same for Piteå and Freiburg, even considering a fixed system, while it is slightly higher in the case of the fixed system. The LCOE for the system in Norway is generally higher, because of the lower insolation.

The calculations of NPV show that all of the systems setups except one will pay back their own cost if the energy is valued as saved energy, i.e. if it is used locally by the producer. This applies to the fixed systems as well to those with two-axis tracking, and it should be noted that it also applies to the system without subsidies. According to the EPIA definition the systems have reached grid-parity, since the total revenues from the systems are larger than the total costs. All of the subsidized systems with two axis tracking will be paid back within 11 to 12 years if energy is valued as saved or within 17 to 20 years if it is sold to the grid.

As mentioned earlier, the calculated values should not be taken as exact numbers, but can be used to compare alternatives. The conclusion that can be drawn from the calculations of LCOE is that there is little difference in cost-efficiency between the systems in Germany and the systems in Piteå. In addition, the calculations suggest that it is more cost-efficient to install a two-axis tracking system in Piteå than a fixed system in Germany. From the NPV estimations, it can be concluded that it is possible to install a system that reaches grid-parity in Northern Scandinavia.

The results that are put forward in this paper show that PV systems in Northern Scandinavia can be economically feasible. Indeed, the economic evaluation show that it can be as cost-effective to install a system on the Baltic Sea coast in northern Sweden as in one of the sunniest regions in Germany and even more cost-effective than in some of the less sunny parts. So why is the installed capacity in Germany 850 times larger than in Sweden and Norway combined? A simple answer is naturally the economic situation, where Germany has had a generous feed-in tariff system for several years. Importantly, the feed-in tariff system in Germany has had a very positive effect on the publicity and information for solar energy as an advantageous option for households and industries. It has also led to a well-developed

industry around PV installations. At the same time, PV installations have not enjoyed any kind of subsidies in Sweden until very recently, and there is still no economic support system in Norway. Policy makers, politicians and the general public in Scandinavia are simply not aware of the large solar resource in Scandinavia and that the Baltic Sea region does in fact out-compete large regions of Central Europe. If this information would be more widespread in Scandinavia it is likely that the Baltic Sea region would experience a large increase in PV system installations, especially as we have proved that it is possible, already today, to reach grid-parity in this region.

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