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Solar PhotoVoltaics in Norway: a state of the art study

FotoVoltaiske solceller i Norge: en oversiktsstudie

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Preface

This master thesis ends my studies at the Faculty of Science and Technology (REALTEK) at the Norwegian University of Life Sciences (NMBU) spring 2018. The thesis marks the end of a degree in Structural Engineering and Architecture and has a volume of 30 credits.

The thesis presents the situation of solar energy in Norway.

The work related to this thesis has been both rewarding and demanding. I have gained a lot of knowledge about solar energy and the potential of this technology related to buildings and the possible future prospects.

First, I would like to thank my supervisor at NMBU, associate professor Themistoklis Tsalkatidis. Thank you for good discussions and constructive guidance.

Ås, 14. May 2018

Tore Steigen

Abstract

This master thesis aims to present the current situation of for solar energy in Norway. The method used to achieve this goal is to study research literature regarding the topic and to collect data from survey reports.

Solar PhotoVoltaics and their functioning are described in detail and the potential for solar energy in Norway is explained. In addition, theoretical aspects such as the physics behind solar insolation and the selection of solar panel angle are discussed.

The solar market in Norway is explained from the evolvement in the early 2000s and major Norwegian companies are described. Technical building regulations are discussed in detail and possible benefits of applying a PhotoVoltaics system in terms of the energy aspect and as means to achieve near zero emission buildings.

Available support schemes in Norway are thoroughly described and what they provide in subsidies for the consumer. The annual installed effect in Scandinavian countries are compared and analysed.

The conclusion of this thesis is that Building-Attached PhotoVoltaics will be a major contributor to solar energy in Norway for many years in the future. There is also a chance that Building Integrated PhotoVoltaics will expand in use as the building sector continues to realise the benefits of this technology.

At the end, suggestions for further work related to solar PhotoVoltaics is remarked.

Sammendrag

Denne masteroppgaven tar sikte på å presentere den nåværende situasjonen for solenergi i Norge. Metoden som brukes for å nå dette målet er å studere forskningslitteratur om emnet og å samle inn data fra undersøkelsesrapporter.

Solcelle-systemer og deres funksjon er beskrevet i detalj i oppgaven og potensialet for solenergi i Norge forklares grundig. I tillegg er fysikken som ligger bak innstråling og valget av vinkel på solcellepanel forklart.

Markedet for solceller i Norge forklares fra utviklingen i begynnelsen av 2000-tallet, og store norske aktører er beskrevet. Bygningsdirektivet til den Europeiske Union diskuteres i detalj og fordeler ved et solcelle-anlegg når det gjelder energisiden, som middel for å oppnå «plusshus» er drøftet.

Tilgjengelige støtteordninger i Norge er grundig beskrevet og hva det vil gi i utslag som støtte til forbrukeren. Årlig installert effekt i skandinaviske land sammenlignes og analyseres.

Konklusjonen i denne oppgaven er at ettermonterte solceller vil være en stor bidragsyter til solenergi i Norge mange år frem i tid. Det er også en mulighet for at bygningsintegrerte solceller vil øke i andel framover, da fordelene med denne teknologien blir mer velkjente.

Til slutt er mulige forslag til videre oppgaver med solceller nevnt.

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1 Introduction

1.1 Background

Energy is often produced at other places from where it is consumed. This is because the energy resources are located away from major industrial and population areas where the consumption of energy is high. Norway has over time solved this by developing a comprehensive power grid. This grid transports energy from power plants to consumers efficiently.

A relatively new trend in electric power production is to produce more of the energy closer to where it is consumed. This can be done in several ways, but solar photovoltaics is the technology that in recent years have gained popularity and increases in Norway and world-wide.

In Norway the situation for solar technology is still not common to implement in the building envelope. The common approach is to later add the technology and not plan a building from scratch with solar technology in mind. However, with technological advancements and expanded future use, this is expected to increase.

1.2 Issues and objectives

This thesis seeks to explain the current state of solar technology that is used in Norway. It also serves as an introduction to how solar technology works and as a roadmap for future developments.

Achieving this goal is done by studying articles, further explained in the method part, and retrieving data online from acknowledged sites as well as official channels.

1.3 Thesis structure

The structure of this thesis is divided into four parts. The physics of radiation, solar technology, situation in Norway and a part regarding emerging trends.

The physics of insolation is just a brief introduction to the underlying basics of radiation and seeks to explain the potential which lies in solar energy. It also exemplifies important aspects of what are optimal conditions for solar panels.

Solar technology is a part which explains the principle of how a solar cell work and the materials commonly used. It demonstrates key components in a grid-connected system and different ways of applying solar panels to the building envelope. It defines specific terms involving efficiency and the environmental impact of solar technology.

A separate part is devoted to Norway and the current position of the solar market in Norway. It serves as an overview of the present situation and compares Norway to neighbouring countries. The part also lists major solar energy producers throughout the value chain of the Norwegian solar market.

2 Method

To ensure a broad selection of scientific literature, a significant number of on-topic studies was collected by searching three academic databases–Web of Science, Science Direct and NMBUs own library database. The following terms were searched within the title, abstract, or keywords of a study: “solar”, “PV”, “photovoltaic”, “BIPV”, BAPV” and “renewable”. Generally, some variation of the terms PV and solar with the sign “*” at the end and/or in combination with the words constituted the most useful searches.

These searches resulted in many academic articles. To narrow within this base to a more comprehensible sample, the pool of literature was filtered to ensure that only the most relevant and up-to-date articles were used in this thesis. Figure 2-1 shows the selection process and the application of three selection criteria, narrowing the original pool of articles to fifteen. The following subsections explains the steps in the selection process

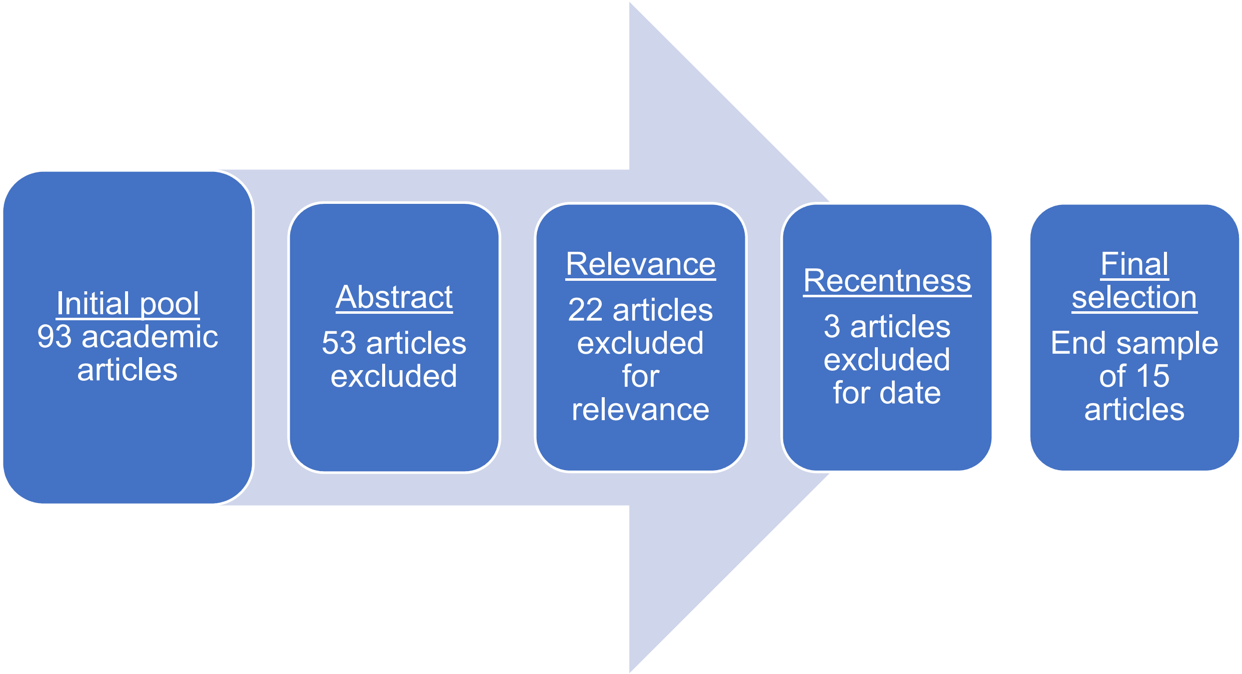

Figure 2-1 Selection process for articles.

2.1 Initial sample

The search process resulted in many thousands of articles. To refine the search, filtration was performed. Articles highly cited in field and a publication limit at 2010 effectively narrowed the results down to a few hundred papers. Furthermore, articles were picked out if the title seemed promising. This resulted in a sample of 93 articles.

2.2 Abstract

The first exclusionary involved reading parts of or the full abstract of the articles. Papers were then further selected if they still were of interest, which caused the removl of 53 articles. This list was intended as an annex but was deleted by mistake during the process of writing this thesis.

2.3 Relevance

Next step in the exclusion process led to removing a total of 22 articles based upon relevance. These studies, shown on the left column in Table 2-1, did not provide necessary information regarding solar photovoltaics or were omitted because another article in terms of readability was selected.

Table 2-1 Studies excluded for relevance.

Source	**Technology**
Bhandari et al. (2015)	Solar PV
Freitas et al. (2015)	Solar
Freitas et al. (2018)	Solar PV
Hagerman et al. (2016)	Solar PV
Hoppmann et al. (2014)	Solar PV
Hosenuzzaman et al. (2015)	Solar PV
Huber et al. (2014)	Solar PV, Wind
Huenteler et al. (2016)	General technology
Jean et al. (2015)	Solar PV
Kaschub et al. (2016)	Solar
Merei et al. (2016)	Solar PV
Michael et al. (2015)	Solar PV/T
Ondraczek et al. (2015)	Solar PV
Peng et al. (2013)	Solar PV
Ramirez et al. (2017)	Solar PV
Sahu (2015)	Solar PV
Turconi et al. (2013)	General technology
Tyagi et al. (2013)	Solar PV
Ueckerdt et al. (2013)	General technology
Wang and Sueyoshi (2017)	Solar PV
Zakeri and Syri (2015)	General technology
Zhang and Gallagher (2016)	Solar PV

2.4 Recentness

The last step in the exclusion process was that of recentness. This is responsible for the omission of the 3 articles shown in Table 2-2. Due to the rapid technological progress that occurs in solar PV and the need for up-to-date information. All articles outside the span of a 5-year publication window were excluded. The articles presented in Table 2-2, applying the 5-year criteria, were omitted because a newer article existed.

Table 2-2 Articles excluded for recentness.

Source	**Technology**
Moosavian et al. (2013)	Solar PV
Reichelstein and Yorston (2013)	Solar PV
Tyagi et al. (2012)	Solar PV/T

A complete list of the articles after the final selection process, is presented in Table 2-3. Most of the articles in this table are related to solar PV, but some are also focused on hybrid systems as well. These are relevant because they contain information regardless whether the thermal part is present.

Table 2-3 Studies used further in thesis.

Source	**Technology**
Armaroli and Balzani (2016)	Solar
Campoccia et al. (2014)	Solar PV
Castillo et al. (2016)	Solar
Fan and Xia (2017)	Solar PV
Hagos et al. (2014)	Solar PV/T
Jelle (2016)	BIPV
Mahela and Shaik (2017)	Solar PV
Makki et al. (2015)	Hybrid PV
Nugent and Sovacool (2014)	Solar PV, Wind
Pandey et al. (2016)	Solar PV
Rodrigues et al. (2017)	Solar PV
Rodrigues et al. (2016)	Solar PV
Sharma and Chandel (2013)	Solar PV
Singh (2013)	Solar PV
Thorud (2016)	Solar PV

2.5 Other sources

In addition, other sources of information were evaluated. These were mainly reports with data of installed PV capacity and prices. Information from online sources, websites and alike, was attempted to be kept at a minimum due to possible inaccuracies and unreliable sources. Data is mainly gathered from official reports and agencies. Such examples as, the International Energy Agency (IEA) and Fraunhofer Institute for Solar Energy Systems ISE (Fraunhofer ISE).

3 Physics of insolation

3.1 Sun to atmosphere

According to Chen (Chen, 2011), the emitted effect from the sun is 63.1 MW/m^2. The difference in size and distance between sun and earth however means that the power emitted from the sun is reduced along the way. The radiated effect from the sun reaching earth is often referred to as the solar constant and is set to around 1365 W/m^2 (Chen, 2011). The variation in this constant is so small over time that it is informally viewed as a physical constant. According to Chen (Chen, 2011), this has not changed more than 0.1 percent over the past 100 years. One day has 86,400 seconds, one year has 365.24 days and the earth's radius is 3671 km (Williams, 2015). This gives a total yearly radiant energy of about 5.46 10^{24} J. Comparing this with the total energy consumption in the world in the period 2005-2010 represents approximately 0.01 percent of this (Chen, 2011). In Figure 3-1 the energy available in the world is graphically presented using blocks. The figure also presents several of the world sources of energy. Notice the vast amount available from the sun compared to the annual need.

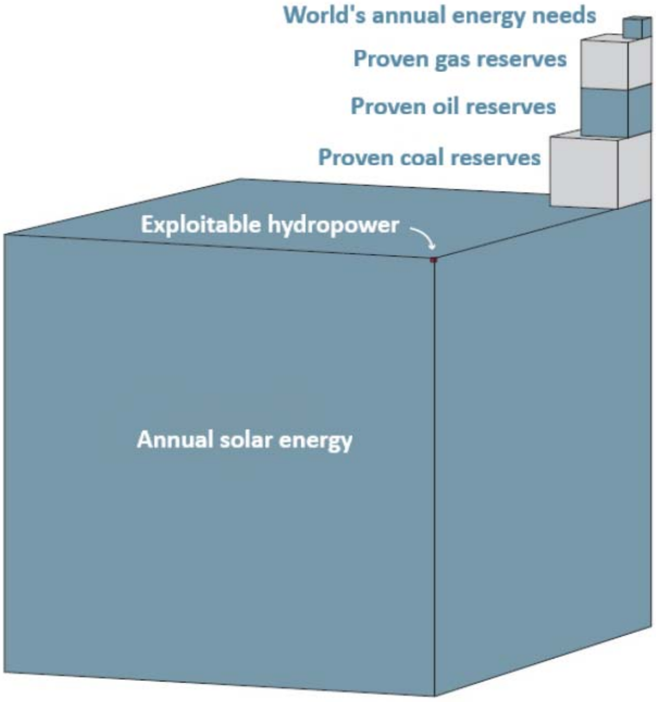

Figure 3-1 Energy of the sun. Modified from fornybar.no.

3.2 Atmosphere to earth’s surface

During the journey through the atmosphere, some of the radiation from the sun is absorbed by clouds and gases while others are reflected on earth’s surface area. This causes the radiated power at the ground level of earth to be lower than the solar constant. The connection between radiation, absorption and reflection is often discussed among climatologists. This task does not address this type of climate-related discussion, but rather presents the most important aspects.

By Chen the distribution is summarized throughout the atmosphere to be the following (Chen, 2011):

- About 30% of the radiation is reflected or spread back to space
  - 20% is reflected by clouds
  - 6% is spread by the air
  - 4% is reflected by the earth's surface
- About 20% of the radiation is absorbed by the atmosphere
  - 16% absorbed by water vapor, ozone, dust, and more
  - 4% absorbed by clouds
- About 50% is absorbed by the earth's surface

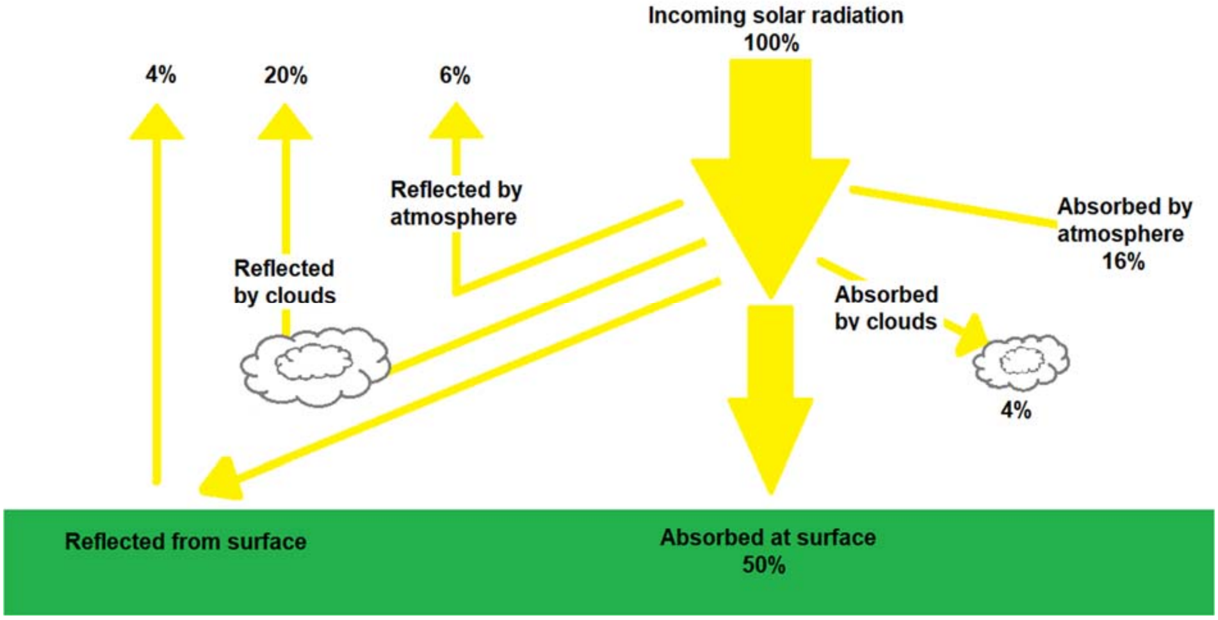

Figure 3-2 Radiation through the atmosphere.

The total radiation energy the earth receives from the sun is thus around 70 percent of the solar constant. Radiated power throughout the atmosphere is illustrated in Figure 3-2 Radiation through the atmosphere.Figure 3-2.

3.3 On earth's surface

To achieve maximum output from a solar cell module it is of great importance to make use of as much of the incoming radiation as possible. The specific effect on a given surface area however depends on more than the radiated effect. It is assumed that the incoming radiation falls perpendicular to the solar module. In most cases, this means that the modules must be placed at an angle relative to the cardinal direction. In addition, the optimal angle for the solar cell module changes throughout the year and the time of day due to the sun's displacement relative to the ground. To discuss this further, some key concepts must be further explained, see Table 3-1.

Table 3-1 Definitions regarding insolation. The table lists the most important definitions regarding the suns movement.

Term	Description	Symbol
Azimuth	The cardinal direction of the sun at a given time. South, West and East are 0 °, -90 ° and 90 ° respectively, giving the sun is moving in positive direction.	A
Declination angle	Angle between the origin of the equator plane and a straight line to the centre of the sun. Occurs because of the Earth's rotation about its own axis. The maximum effect of this occurs 21 June and 22 December at 23.5 ° and -23.5 °.	δ
Altitude angle	The angle between radiation and a horizontal surface.	α
Zenith angle	Angle between radiation and a vertical line perpendicular to a horizontal surface.	λ

The most beneficial angle to orientate a solar panel to achieve maximum output varies with sun height, α, which again depends on the current latitude, the declination angle and the time. A high solar elevation (altitude angle) will cause the sunlight to travel a shorter path through the atmosphere. Figure 3-3 illustrates the relationship between the most important concepts in relation to radiation. The illustration only applies to areas north of equator, as the sun's position is southern.

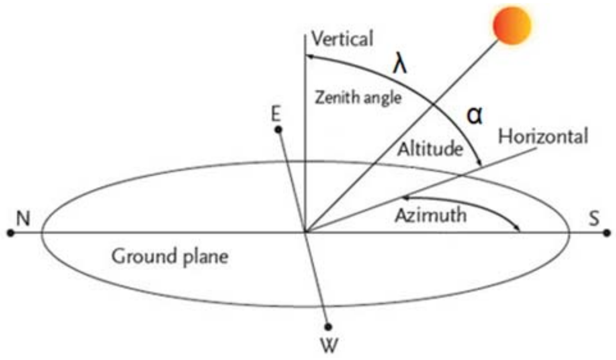

Figure 3-3 Relationship between radiation and a surface. Modified from cibsejournal.com

The desirable angle of a solar cell module also varies according with use. Some might prefer, or need, steady production of electricity throughout the year rather than a high production peak during the summer. Thus, the modules must be oriented accordingly to fulfil desired needs and use of electricity. Figure 3-4 shows that the potential for solar energy in Europe. Notice on the map that Norway is comparable in potential with large parts of Germany. The importance of this is further explained in part 5.1.

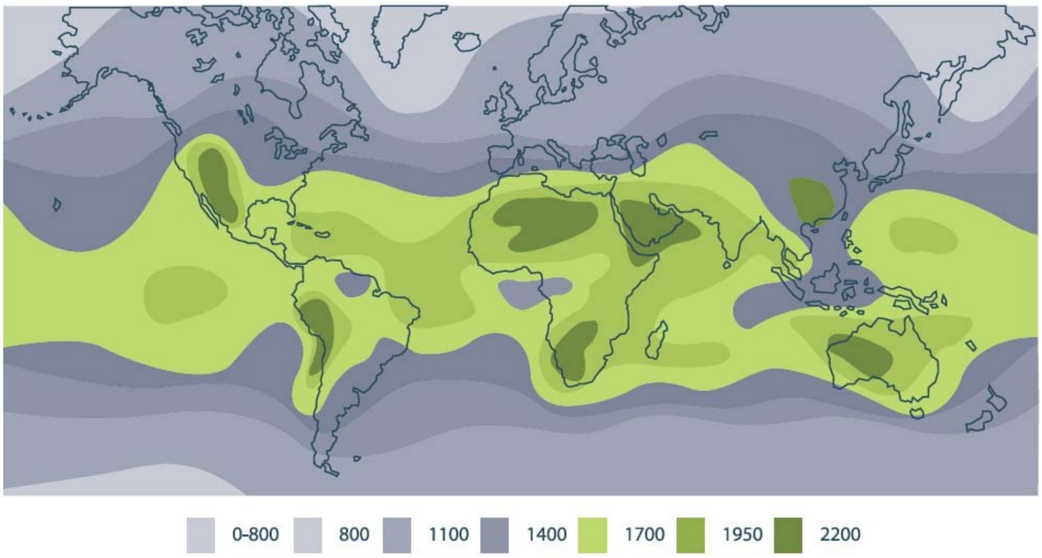

Figure 3-4 Annual solar radiation against optimum angled surface (average kWh/m^2 and year). Source: NASA. Illustration: Kim Brantenberg

3.4 Standard test conditions

To define standard test conditions (STC) relative to radiation, the term Air Mass (AM) is introduced. An air mass of 1 (AM1) describes sunlight that falls perpendicular to a surface, giving $\alpha = 90$ ° and $\lambda = 0$ °. Standard test conditions for solar cell modules dictates that AM1.5 is preferable. An air mass of 1.5 means that the solar radiation travels one and a half times as far through the atmosphere when compared to perpendicular rays of sunlight to a surface. This occurs when the sun height α is little and the zenith angle λ is greater. The longer path for the sunlight through the atmosphere causes the radiated effect to be weakened relative to optimal conditions. AM1.5 is often called one sun and corresponds to a radiated power of 1000 W/m^2. The sun constant of 1365 W/m^2 has a reference point outside the atmosphere, where the air mass has a value of 0 (AM0).

The purpose of the test conditions is to create realistic conditions for solar cells, which the cell can be subjected to throughout its service life. According to Chen, STC for measuring efficiency and delivered power for solar cells is 25 ° C room temperature, one sun equivalent to 1000 W/m^2 and a traveling distance for the sunlight corresponding to AM 1.5. Formula (2-1) shows how the zenith angle can be calculated by a given air mass (Chen, 2011).

$$\lambda_{AM1.5} = \cos^{-1}\left(\frac{1}{1,5}\right) = 48{,}19° \qquad (2\text{-}1)$$

Where $\lambda_{AM1.5}$ is the zenith angle at AM1.5. From this it can be calculated that the angle a solar panel should have in relation to the horizontal plane should be about 42 ° to achieve maximum average production.

3.5 Angle of the solar panel

Solar panels facing south will produce significantly greater output in electric power when compared to panels oriented in a northern direction. The optimal angle for a solar panel will wary depending on geographic position, see Figure 3-3. In addition, the desired production profile needs to be considered.

A house only used during summer time will probably need the greatest utilization of the solar module during this period. Then a lower angle of the panel will be optimal, since it provides almost a perpendicular angle of the incoming radiation throughout the summer. However, it will come in expense to utilization during winter time. When looking at a residence used more on a regular schedule. The angle should be greater to utilize more of the solar energy during the year. This will cause the peak-values during warm months to be lower, but the annual production of electricity will be higher. Besides, angle of solar panels depends on the individual consumption profiles of electricity, and how far north the solar installation is located.

Norway is located from 57 ° north latitude in the south, to 71 ° north. In a report from Multiconsult it is stated that the optimal angle for annual production in Norway varies from 38 ° in Kristiansand to 47 ° in Tromsø (Multiconsult, 2013). Radiated power varies from around 700 kWh/m^2/year farthest up north of Norway, to around 1000 kWh/m^2/year in the southernmost areas (Fornybar, 2018b). In addition it should be noted that the differences between north and south is bout 4000-5000 Wh/m^2 monthly average (Hagos et al., 2014).

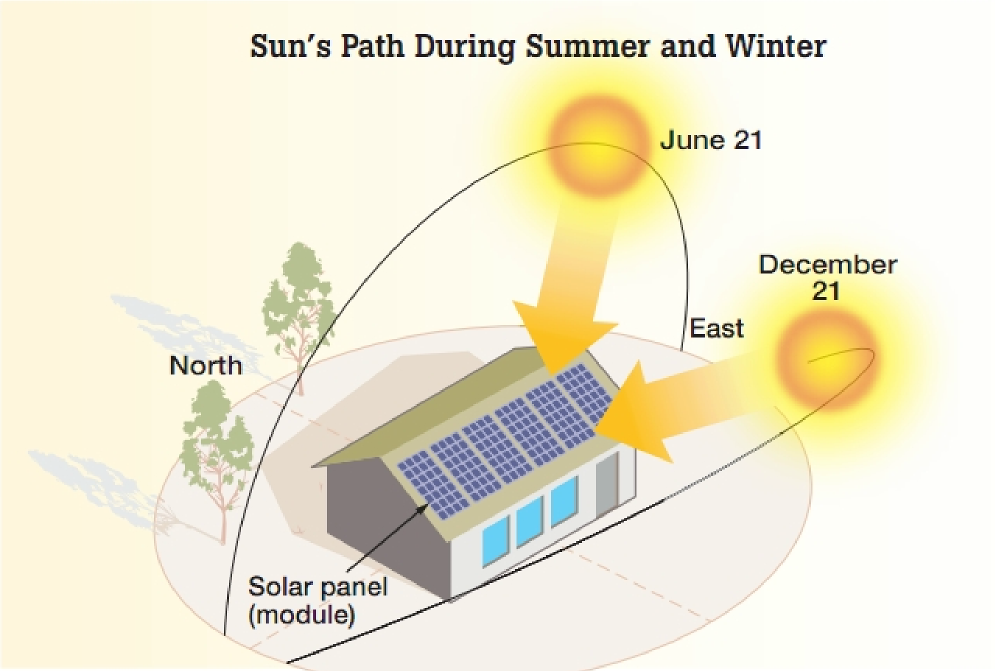

Figure 3-5 Optimal angle of solar panels in northern hemisphere. Source: solartribune.com.

4 Solar technology

Electric energy has been produced in several ways over the history, even in a large industrial scale. The most popular of these methods is electromagnetic induction, based on Michael Faradays (1791-1867) theories from 1831. Since the start of the 19th century, large generators based on these principles have been common throughout the whole world. Unlike generators, solar cells have no moveable parts and the incoming electromagnetic radiation from the sun is transformed into electric energy.

4.1 The solar cell

The photoelectric effect makes it possible to convert solar energy into electric energy. This effect absorbs energy from photons in the light, when matter is being illuminated and electrons move from one substance to another. A solar cell, or photovoltaic cell, consists of a semi-conductor where the front and backside are treated, normally making the frontside in surplus of free electrons while the backside has a deficit. Another way to achieve the same result is to do the process backwards. In the boundary layer between the two areas, an electric field is created, driving the electrons towards the front side of the cell. Bound electrons in the solar cell can absorb a photon and become free (unbound). Most of these electrons will be trapped inside an electric field in the boundary layer and be transported to the face of the cell. When the front- and backside are combined with an electric circuit, the electrons can do useful work, powering an electric motor, lightbulb or charge a battery. When this effect is used in a solar cell, it is called the photovoltaic effect, and this is abbreviated as PV (PhotoVoltaic).

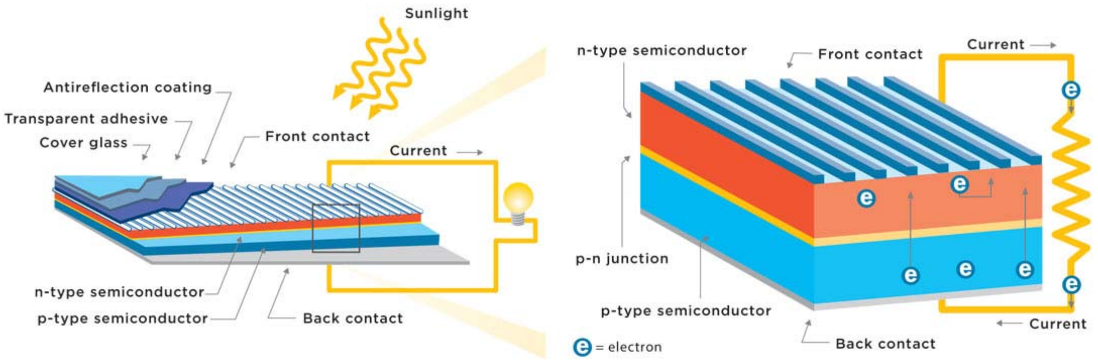

Figure 4-1 Principle of a solar cell. Source: Aaron Thomason/srpnet.com

Figure 4-1 illustrates a solar cell composed of two layers of semiconductor material with opposite charges. Sunlight shines on the cell surface freeing electrons, which then travel through a circuit from one layer to the other, providing a flow of electricity

4.2 Efficiency

The efficiency level of a photovoltaic cell is the ratio between insolation and electric power. This level varies with many factors. Efficiency level will vary during the day and the year and is dependent on the amount of insolation and surface temperature. Studies have shown an increase in efficiency for decreasing surrounding temperature (Makki et al., 2015). When producing electric power using PV-panels, it is common to differentiate between three different types of efficiency levels; cell- module-, and system-efficiency.

4.2.1 Cell efficiency

The instantaneous efficiency of a solar cell system varies throughout the day and during the year, as it relies on several factors, such as the amount of radiation and surface temperature. For a silicon cell, the efficiency decreases with increased surface temperature. This means that the efficiency of a solar module is reduced as it heats up from the sunlight when compared to a cooled state. Luque and Hegedus (2011) describes a linear reduction in voltage for silicon to be about -2.3 mV/°C at 300 K.

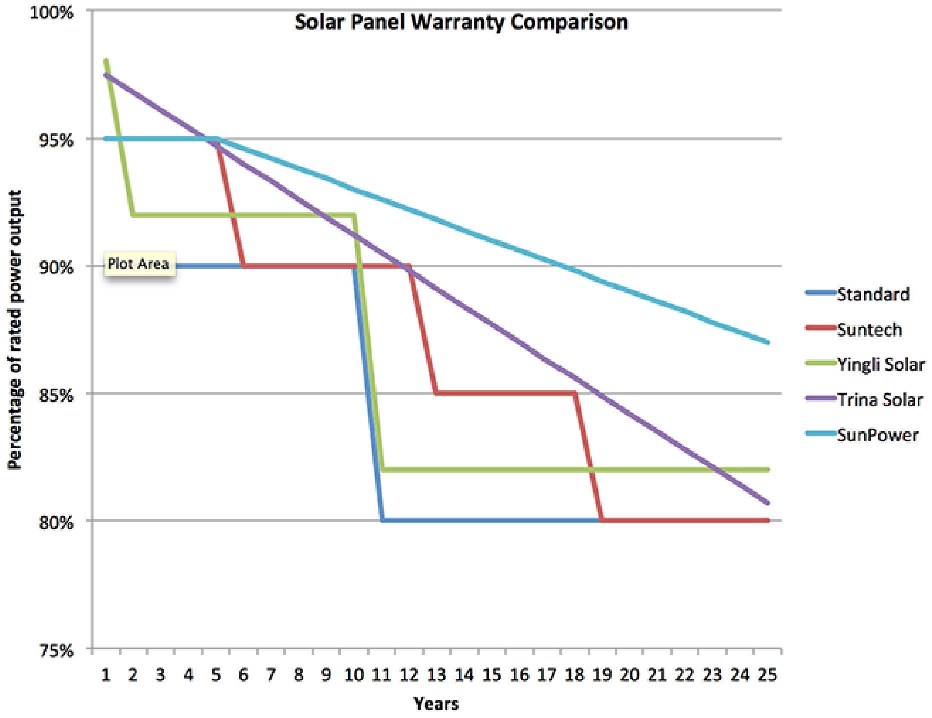

Figure 4-2 Performance of solar panels. Source: Maehlum/energyinformative.org

When solar cell manufacturers state the efficiency of the solar cells and when the solar energy efficiency levels are compared, the maximum amount of energy that the solar cells can produce under STC are compared. The same assumptions are based when manufacturers state the maximum performance of the solar cell, the term used is Watt peak (Wp). The efficiency will be somewhat lower after many years of operation, and most of the solar panel manufacturers guarantee that the power output of the panels does not drop below 80 percent after 25 years of service, see Figure 4-2.

4.2.2 Module efficiency

The modulus of efficiency considers the losses over the complete module area and it is therefore always lower than the efficiency of the solar cells themselves. This is mainly because of the space between the solar cells cannot be fully exploited.

4.2.3 System efficiency

System efficiency is the designation of the complete system, including the network connection. The transmission of power to the network and the conversion of the solar produced current to AC power is associated with a certain loss. When calculating the cost of energy produced an estimation for the system efficiency is important.

4.3 Crystalline solar cells and thin film technologies

The most important photovoltaic technologies are crystalline photovoltaic and thin-film solar cell. The crystalline solar cells are made of silicon wafers, and there are two main types: monocrystalline and multi-crystalline. The difference lies in the crystal structure. The silicon wafer in the monocrystalline solar cell consists of a single crystal with a homogeneous crystal grid, while the multi-crystalline silicon wafer consists of many small crystals.

4.3.1 Mono- and multi-crystalline technologies

Monocrystalline cells can convert more of the sunlight to electricity than multi-crystalline or thin film solar cells. The production process, however, is more demanding than and more energy is required for production. The efficiency of commercially available monocrystalline solar cells is about 25 percent.

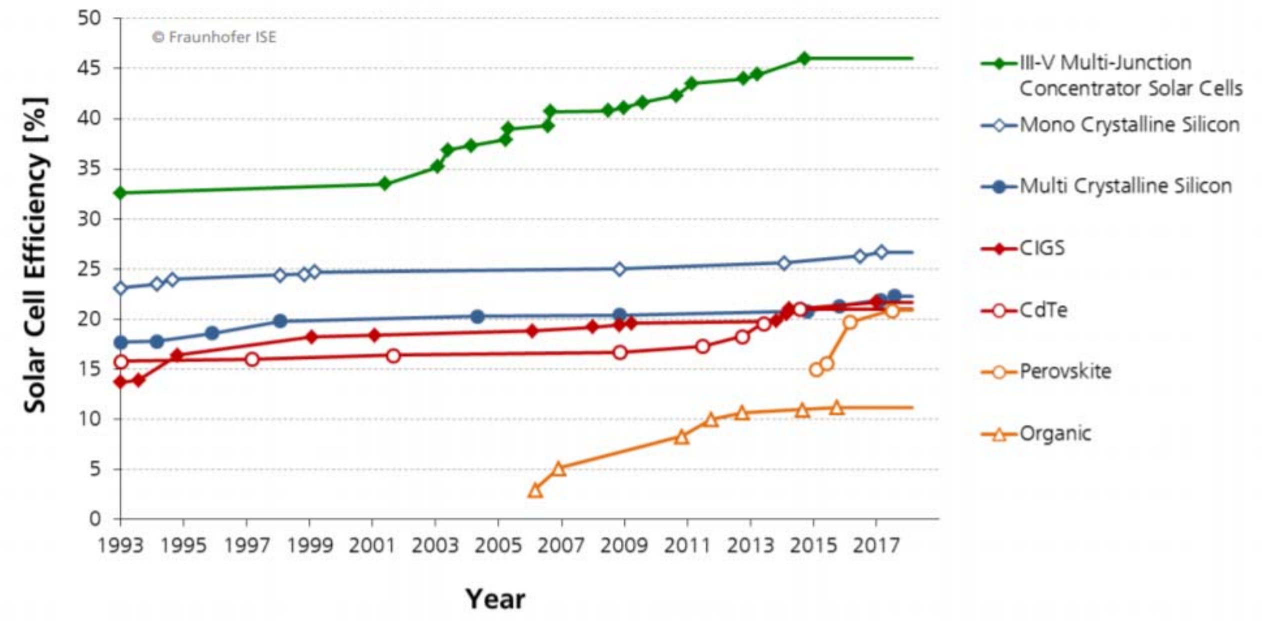

Figure 4-3 Solar cell efficiency. Source: Fraunhofer ISE 2018.

Figure 4-3 shows the maximum efficiencies achieved in laboratories for different solar power cell technologies.

Multi-crystalline solar cells are somewhat less expensive in production than monocrystalline solar cells, but the efficiency is somewhat lower, approximately 20 percent.

4.3.2 Thin-film technologies

There are several different thin film technologies. The first commercialized technology was amorphous silicon cells (a-Si). The amorphous silicon cells have a lower efficiency (about 7-9 percent) compared to crystalline solar cells, a slightly greater reduction in efficiency must be considered. The main advantage is that they only need 1 – 5 percent of the raw material in comparison to a crystalline cell.

The other commercial thin film technologies are Cadmium Telluride cells (CdTe) and Copper-Indium-Gallium Selenide cells (CIGS). Thin-film cells are usually made on glass or steel substrates, but plastic is also used. The modules can then be made flexible. The efficiency varies somewhat between different manufacturers and qualities, but representative values are 14 percent cell efficiency for α-Si, 21 percent for CdTe and 21.7 percent for CIGS. Although thin film technologies have been available for a while, it is just recently that commercial production have managed to recreate the efficiency attained in lab. Figure 4-4 shows the best lab cells versus the best lab modules.

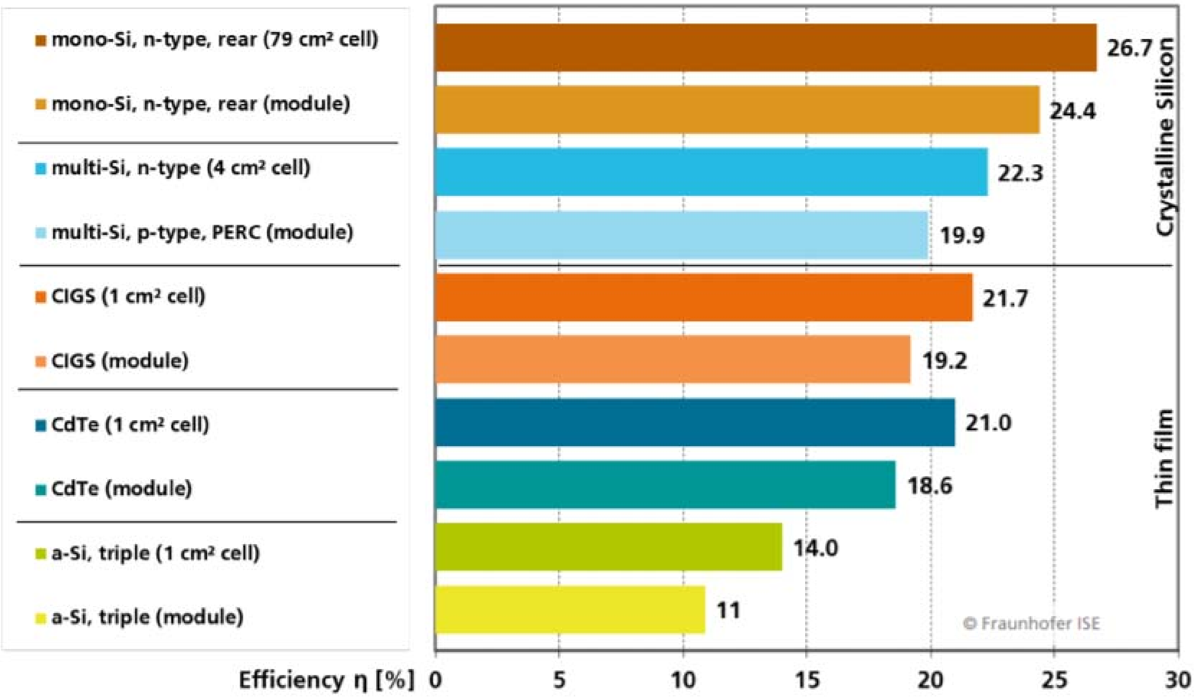

Figure 4-4 Efficiency of solar technologies. Source: Fraunhofer ISE 2018.

The main advantage of thin film technology relative to crystalline silicon cells is less use of raw materials in the production process. Another advantage is that it is possible to make large surfaces in one operation, which allows for a more rational production process. Furthermore, the surfaces can be manufactured to be able to bend and, for example, be laid over arcuate ceilings. Although the stated efficiency is below the efficiency of crystalline cells, the annual production of electricity does not have to be comparatively low. As mentioned above, the industry uses maximum electricity production under ideal conditions as a basis for the stated efficiency. Under real life conditions, such as diffuse radiation, thin film systems may in some cases produce more electricity than the crystalline, which are more dependent on direct radiation.

To get a clearer picture of the different solar technologies an overview is shown in Figure 4-5. The figure also mentions new technologies, like organic based PV (OPV), concentrated solar power (CSP) and perovskites.

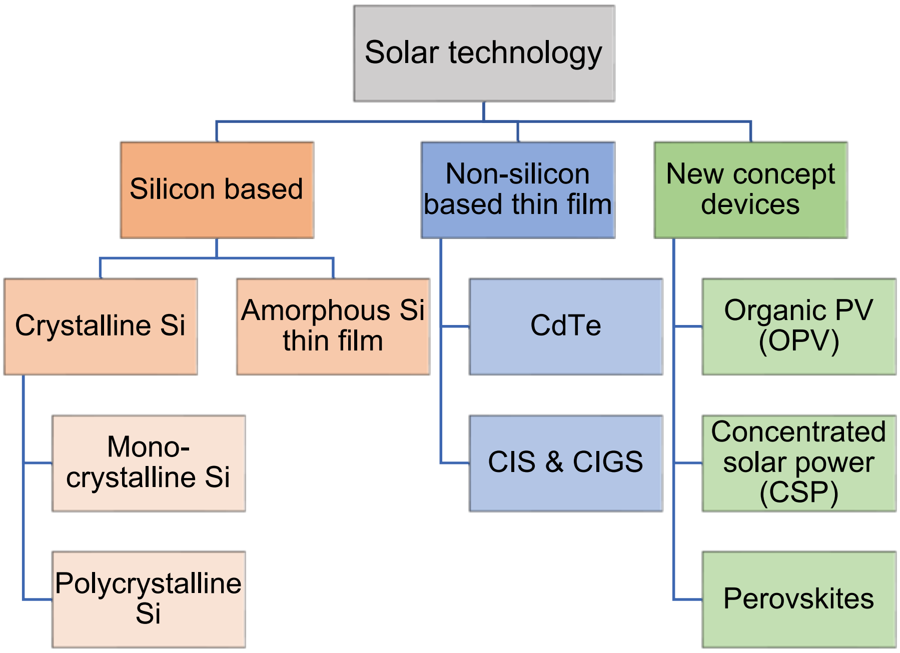

Figure 4-5 Flowchart of PV-technology. Inspired from Pandey et al. (2016).

4.4 Module prices

Since 2008, the price of crystalline silicon solar modules produced in China has decreased about 90 percent, see Figure 4-6. Thin film technologies have thus lost their main obvious advantage over crystalline solar cells. The future of thin film technologies will depend on the possibilities of exploiting the flexibility in shape and size, as well as the advantage that it provides the opportunity to produce lighter solar panels than crystalline technology does.

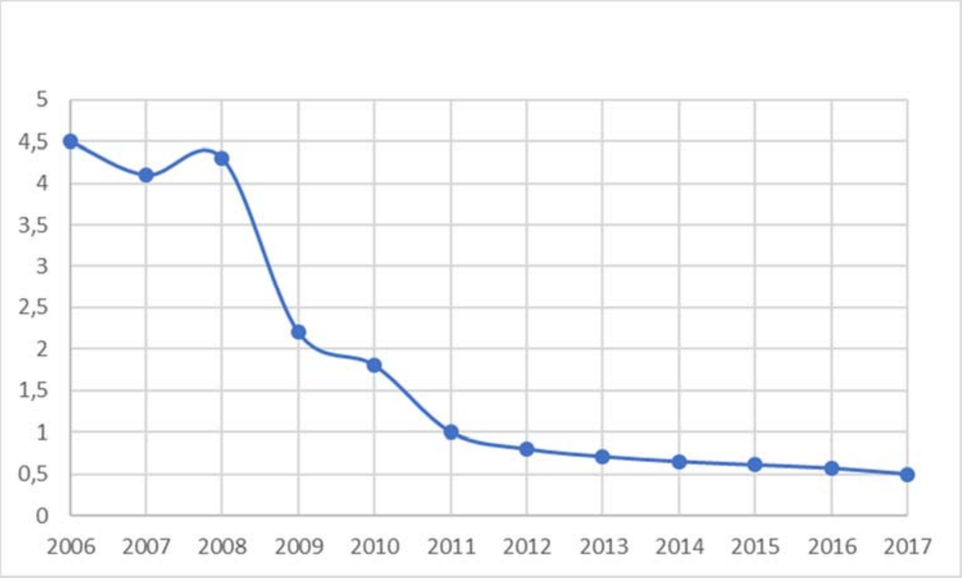

Figure 4-6 Price for crystalline solar modules produced in China in (US$/Wp). Source: IEA PVPS

4.5 The PV-system

The effect delivered from a single solar cell is limited, and thus several of these are connected in a solar module to reach a higher effect. A module consists of many solar cells connected in parallel, series or a combination of these. The cumulative sum of voltage over the cells is the voltage of the string. The individual cells are then connected to obtain the preferred current and voltage. Strings can be joined in a series or parallel, depending on what is desired between a high voltage or a high electric current. For example, two equal strings put in a parallel circuit will not alter the total voltage but will double the electric current. Two equal strings placed in a series circuit will deliver the same amount of electric current but double the voltage. The connection of strings is called an array, and in a complete PV-system, all the elements mentioned is included to deliver electric current to a battery or an inverter.

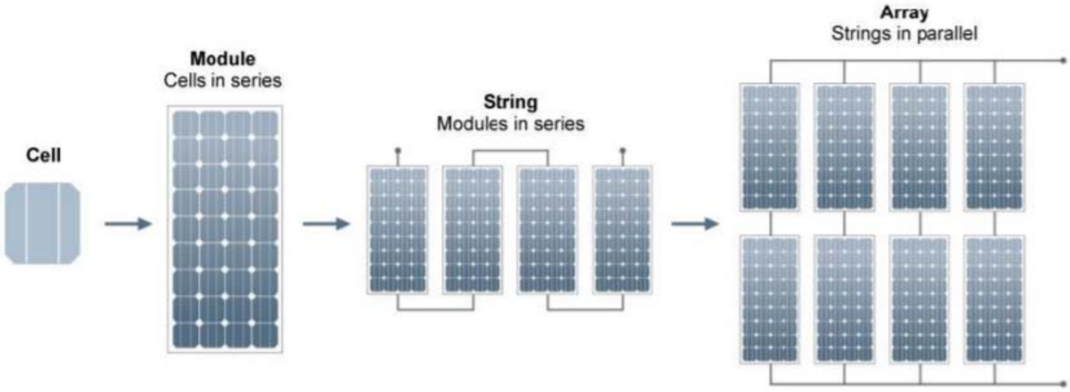

Figure 4-7 Structure of a PV-system. From cell, module string and array. Source: yourhome.gov.au

4.6 Deficiencies

To utilize most of the solar PV-system it is important to know about some of the losses that occur. Some deficiencies are preventable and not harmful while others, like shading, can cause devastating consequences for the materials in a solar cell. The climate in Norway causes shading to be a major factor, especially regarding snow during winter months. Deficiencies and their significance are mentioned below and described in the following subsections:

- Shading
  - Reflection decrease
  - Soiling
- Inverter
- Thermal
- Ohmic
- Mismatch
- Degradation
- Light Induced Degradation (LID)

4.6.1 Shading

Shading of a solar cell module occurs if one or more of the solar cells are not irradiated as much as the rest of the solar cells in the module. This limits the photovoltaic effect of the solar cells, which again causes the supplied power from a module to be limited.

As previously mentioned, two identical solar cells in series supply the same voltage as one cell but doubles the amount of voltage. By partial shading of one cell, the electric current through both will be limited. The serial connection will force the electric current to be equal, even when the radiation is different and the voltage over the non-shaded cells to increase.

By fully shading one cell in a series circuit with non-shaded cells, the current in the cell and hence the entire circuit, will be zero. Since there is no electric current flowing through the solar cell. The voltage from the non-shaded cells will fall opposite way compared to the ones that are shaded. If the reverse voltage is high enough the reverse voltage is deposited as heat development in the shaded solar cell. This is called Hot Spot Heating. Unless designed for this, the cell will break down and destroy. Several solar cells in a series leads to higher potential of reverse voltages and increases the potential of cell breakdown and material damage.

Today's solar modules are usually designed to avoid problems with reverse voltages. This is done by connecting a bypass diode in parallel over a solar cell. The diode has opposite direction relative to the cell which it is connected, sending the reverse voltage of the breakdown point around the shaded solar cell. Thus, power generation in the non-shaded solar cells will continue unaffected. In practice, one bypass diode is connected per string in an array. In relation to snow, it is favourable that each row of a module is connected to the same bypass diode. Since snow tends to lie down on sloping surfaces, only the bottom rows of solar cells will be affected.

There are two factors that can lead to shadow loss; reflection loss and soiling.

Reflection loss is mainly about reflection of incident radiation. The antireflective coating on a solar cell is not ideal, so a certain number of photons do not permeate through the n-material. This leads to some of the radiated effect not being absorbed in the depletion layer. In addition, the reflection increases with the angle of the incident radiation, relative to the surface. This can be regarded as lost energy.

Soiling is described as the amount of energy from incident radiation that is not absorbed due to contamination of the solar cell module surface. Contamination is a mixture of dust and particles, and wear and tear because of wind and weather. This loss depends largely on location and climate. Solar panels in a dry climate is exposed to more dust and particles. Precipitation leads to some form of cleansing of the modules. Snow and ice leads to more wear and tear and have a limiting effect on energy production. In a country like Norway, layers of snow on solar panels can be very limiting, regarding the overall production of a PV-system.

4.6.2 Other deficiencies

In addition to shading, there are several factors that limit the efficiency of a PV-system. The performance of the solar module is by itself limited, and energy is lost throughout the transport in modules, cables, inverters and transformers.

Inverter loss occurs when the electrical signal changes from DC to AC to be connected to the power grid. All inverters have different efficiencies relative to this, but generally set to 2-5 percent.

The thermal losses in a PV-system occurs because the delivered power is temperature dependent. The efficiency of solar cells increases at decreasing operating temperature (Multiconsult, 2013; Sharma & Chandel, 2013).

All electric conductors have a resistance. This causes some development of heat in the conductor when electricity is moving through the conductor. This loss is known as ohmic loss and occurs in all parts of the PV-system.

In the same way partial shading of solar cells limits their effectivity, a string of solar cells with different properties is limited by the weakest panel. All solar cells are different and have different electrical properties. In a series connected string of solar cells, the current in the circuit will be limited by the weakest solar cell. Consequently, this leads to the stronger cells deliver less current. This is known as a mismatch loss. Even though no solar cells are identical, it is still favourable to put almost identical solar cells together to reduce this loss.

Over time, the materials in a solar cell module will degenerate. This happens because the materials are broken down by ultraviolet (UV) radiation during a long period of time. The losses from this degeneration are called module quality loss.

In addition, there is a short-term degeneration called Light Induced Degradation. This is losses due to degradation in the silicon structure during the first days the module is exposed to radiation. The degradation is due to chemical reactions between impurities in the grid structure of silicon and doping agents. This applies only to boron-doped silicon sols.

4.7 Grid-connected solar PV

During the past in Norway, small solar PV-systems were installed mainly in Norwegian houses used during a few weeks throughout the year (“hytte”) and often with no more than one or two panels. These houses were not connected to the power grid and the electric energy was stored in batteries for later consumption, powering light and appliances requiring little electricity. In recent years PV-systems have expanded in size and with the ability of connection to the power grid because of changes in the legal systems and the fact that more electric companies now provide this as an alternative when signing contracts.

4.7.1 Components

In addition to solar modules, a network-connected PV-system consists of several components. Most of the main components are mentioned in Figure 4-8 and explained below:

- Inverter
- Couplings
- Maximum Power Point Tracker (MPPT)
- Transformer
- Conductor
- Mounting
- Power supply connection

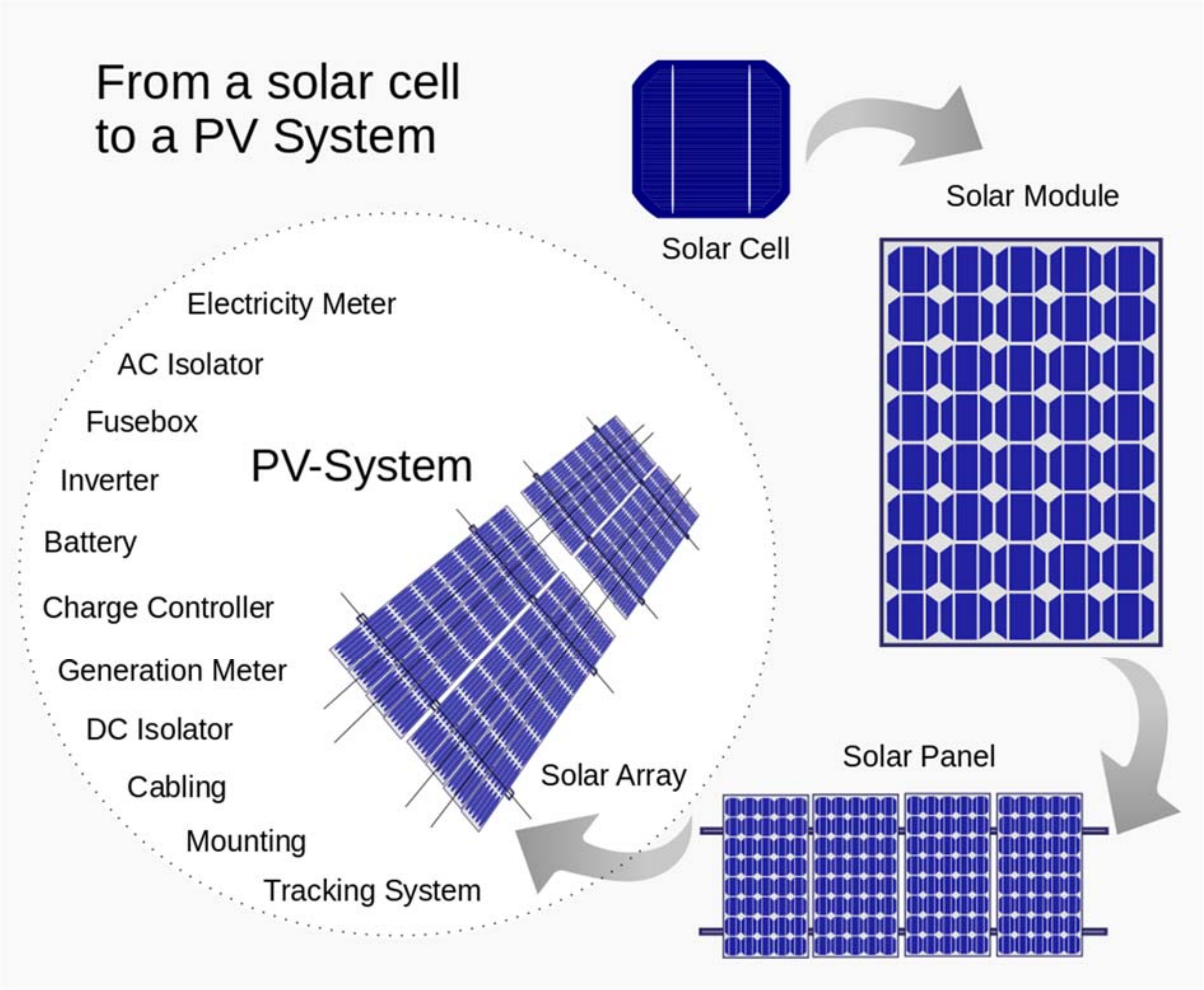

Figure 4-8 The PV-System. Diagram of the possible components of a photovoltaic system. Source: Wikipedia. Illustration: Rfassbind.

Inverters convert DC-signals (direct current) from the PV-system for AC-signals (alternating current), so that power can be fed into the network. There are three types of inverters:

- Micro-inverter
- String inverter
- Central inverter

With the use of micro-inverters, each module has its own inverter. This minimizes shadow loss since only shaded modules are affected.

Using string-inverters, an entire string of PV modules connects to one inverter. These are designed to withstand higher voltages than microcontrollers. Here, shadow loss in some modules will affect entire strings. String switches usually have built-in monitoring equipment for measuring power output, as well as a display for retrieving data. This is the most common inverter for small scale solar systems.

If all PV modules in a system are connected to the same inverter, this is called a central switch. This is like a string inverter but withstands significantly higher voltage.

Fuse boxes are located on the backside of all modules. They act as a junction for modules and bypass diodes. In addition, there is a larger fuse box that connects all the strings of a PV-system.

The Maximum Power Point Tracker (MPPT) ensures that the inverter operates at MPP. This allows the PV-system to work in optimal condition, thus delivering the most energy. This component is usually part of the inverter construction.

A transformer in a grid-connected PV-system has the task of transforming the voltage from the inverter into a voltage that harmonizes with the grid. This component is often built into the inverter construct.

The electrical conductors in a PV-system consists of two parts. There are DC-conductors on the DC side of the system. These connects the modules in strings, strings in array and array to the inverter. The AC conductors, on the AC side of the system connects the inverter to the transformer if it is not built-into the inverter and connects the entire system to the network.

Photovoltaic mounting systems, also known as solar module racking, are used to attach solar panels to surfaces like the ground, facades or roofs. It is also possible with mounting systems that adjusts the solar panel in orientation and tilt. This tracking system increases the power production of the solar panels as it will adjust according to the suns movement across the sky.

4.7.2 Building Applied Photovoltaics

One of the most common PV applications for modern buildings today is called building-attached or building-applied photovoltaics (BAPV). This means to retrofit structures with PV modules, without any major changes to the existing building envelope. All functions remain intact despite the attachment, and the system is easy and quick to install, requiring only 2-3 days for a middle sized residential house.

Figure 4-9 BAPV at Evenstad. Photo: Thor Christian Tuv (Fusen AS)

Figure 4-9 shows a solar PV-system from the college at Evenstad built in november 2013 and with a module area of 455 m^2. The system consists of 276 multi-crystalline silicon modules from REC Solar with a module efficiency of 255 Wp. System efficiency is 70 kWp. Figure 4-10 shows a smaller PV-system in Oslo of 18 solar panels. With a system efficiency of about 4.6 kWp

Figure 4-10 BAPV installed on the roof of a residence. Photo: Hege Westskog (Cicero.no)

4.7.3 Building Integrated Photovoltaics

Integration of PV in the building envelope is called building-integrated photovoltaics (BIPV). This means replacing conventional building materials for roof and façade. The clear advantage over non-integrated systems, is not only saving cost for materials, but also the labour of the construction that the BIPV modules replace. This makes BIPV one of the fastest growing segments in the photovoltaic industry.

Figure 4-11 BIPV on a tilted roof. Source: bipvno.no

Figure 4-11 shows PhotoVoltaics integrated in a tilted roof of a single-family house at Skarpnes outside Arendal. In Figure 4-12 the PV facade of Oseana Art and Culture Center at Os outside Bergen is seen.

Figure 4-12 BIPV in façade. Source: Getek / fornybar.no

4.8 Energy

Producing materials used in a solar PV system has an energy cost. This cost is also known as Energy Return on Investment (EROI). A simple formula for calculating the EROI is presented in Armaroli & Balzani; EROI = E_{out}/E_{in}. Furthermore, it should be mentioned that EROI is typically used when comparing energy from equal sources and not for example solar PV to oil (Armaroli & Balzani, 2016).

Another important term when looking at energy is the Energy PayBack Time (EPBT). EPBT is the time required for an energy production system to produce the same amount of energy that was used to manufacture it. This parameter is related to EROI by the equation EPBT = lifetime/EROI.

Table 4-1 PV systems EROI and EPBT. Source: (Armaroli & Balzani, 2016).

PV system	EROI	EPBT
sc-Si	8.7	4.1
poly-Si	11.6	3.1
a-Si	14.5	2.3
CIGS	19.9	1.7
CdTe	34.2	1.0

4.9 Environmental impact

Effects concerning the environment is of grave relevance as it will affect the future climate on planet earth. A common way to compare different technologies is to set up the lifecycle analysis (LCA) of greenhouse gases per unit of energy produced. Greenhouse gases are measured in gram carbon-di-oxide (CO_2) equivalents and energy in kilo-Watt-hours (kWh). Data for solar PV were calculated in a meta-survey, examining 153 studies, to be about 50 g CO_2-eq/kWh (Nugent & Sovacool, 2014). This is in no way able to challenge hydroelectric power which is calculated to be as low as 10 CO_2-eq/kWh, but far better than non-renewables like coal (1000 CO_2-eq/kWh), gas (500 CO_2-eq/kWh) and oil (800 CO_2-eq/kWh).

When looking at PV material input in Table 4-2 it is quite clear that thin-film technologies are far better than mono-, multi- and poly-crystalline technologies regarding equivalents of greenhouse gas emission. Note that the basis of these digits comes from a relatively small sample of studies.

Table 4-2 Greenhouse gas intensity for solar PV material inputs. Source: (Nugent & Sovacool, 2014).

PV Technology	**Mean value CO_2-eq/kWh**	**Studies**
Mono-Si	79.5	6
Multi-Si	44.3	17
Poly-Si	78.7	2
a-Si	20.5	7
CIGS	26.5	2
CdTe	19.4	2

4.10 Dictionary of main terms regarding solar technology

Table 4-3 is a list of main terms and definition in solar technology.

Table 4-3 Definitions regarding solar technology.

Term	**Definition**
BAPV	Building Applied PhotoVoltaics System retrofitted to the building-envelope
BIPV	Building Integrated PhotoVoltaics Use of PhotoVoltaic building materials
Efficiency	
- Cell	Efficiency of a single solar cell
- Module	Performance of a solar panel
- System	Total energy from the system in its entirety
Inverter	Converts electric power from DC to AC
MPPT	Maximum Power Point Tracker
PV	PhotoVoltaics Conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect
PV-System	
Thin-film	PV-material that can be made flexible
Wp	Watt-peak Maximum effect of PV devices

5 Solar landscape in Norway

Solar PV technology became commercially available early in the 1980s but remained almost at a status quo for nearly two decades before a significant increase in installation capacity was observed. The first major increase in solar PV came because of strong support mechanisms in Germany and other European countries. This combined with cheaper technology costs, rising electricity prices and increase in consumer engagement, started the first wave of demand that put a spark in global solar PV industry. From 2013-2014 the growth in installed solar PV capacity, gradually shifted from Europe to China, Japan and the US. The solar product market is expected to reach a worldwide capacity of about 700 GW installed by the year 2020.

5.1 The insolation myth

Norway was long considered unsuitable for solar PV, due to having a short summer period and a geographic location close to the northern part of the hemisphere, giving a lower solar insolation and thus resulting in a lower solar potential. However, the solar resources of southern and eastern Norway are comparable to the resources of central European countries. A milder climate compensates the lower solar insolation, thus increasing the solar PV-system efficiency. The electricity production potential in Oslo is comparable to Berlin, and the potential of Kristiansand to that of Munich. This is illustrated in Figure 5-1 which shows Oslo and Kristiansand having a slightly larger potential than Berlin and Munich respectively.

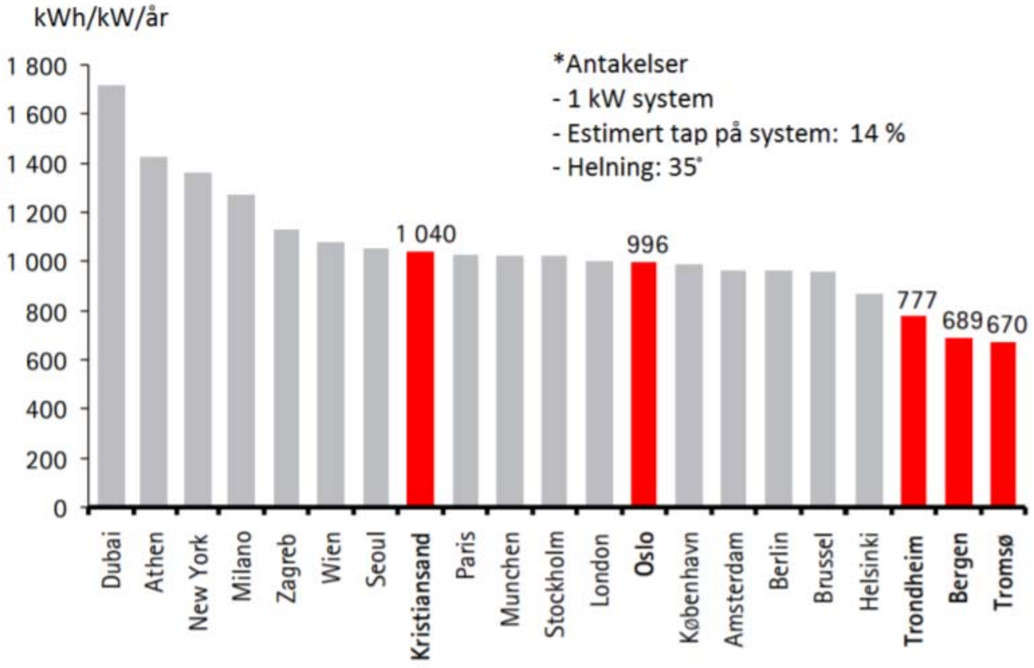

Figure 5-1 Insolation data for Norwegian and international cities. Source: Accenture/WWF.

Figure 5-2 shows the insolation data for a horizontal surface in Norway; January and July respectively. Significant reduction in power, Watthours (Wh), is expected during wintertime, but this is somewhat compensated by cooler ambient air temperatures and in some cases supplemental insolation, reflecting off snow.

Figure 5-2 Insolation data for January and July respectively. Source: fornybar.no. Illustration: Endre Barstad

5.2 The PV-market

The PV market in Norway was driven mainly by stand-alone applications until 2014. However, this was taken over by grid-connected segmentation when it increased ten-times from 0,1 MW in 2013 to 1,4 MW at the end of 2014. The following year (2015) the market saw an insignificant growth in commercial business installations, but this was offset with the growth coming from household systems. Therefore, the grid-connected segment increased modestly to 1,5 MW in 2015. In 2016 the grid-connected segment dominated the market completely with 10 MW installed: installations were split between commercial (7,4 MW) and residential (3 MW) installations (Forskningsrådet, 2017).

Overall, the total installed capacity reached 27 MW at the end of 2016, Figure 5-3. The data for 2017 is not yet available, but the estimation indicates further market growth despite unchanged incentives and low electricity-prices.

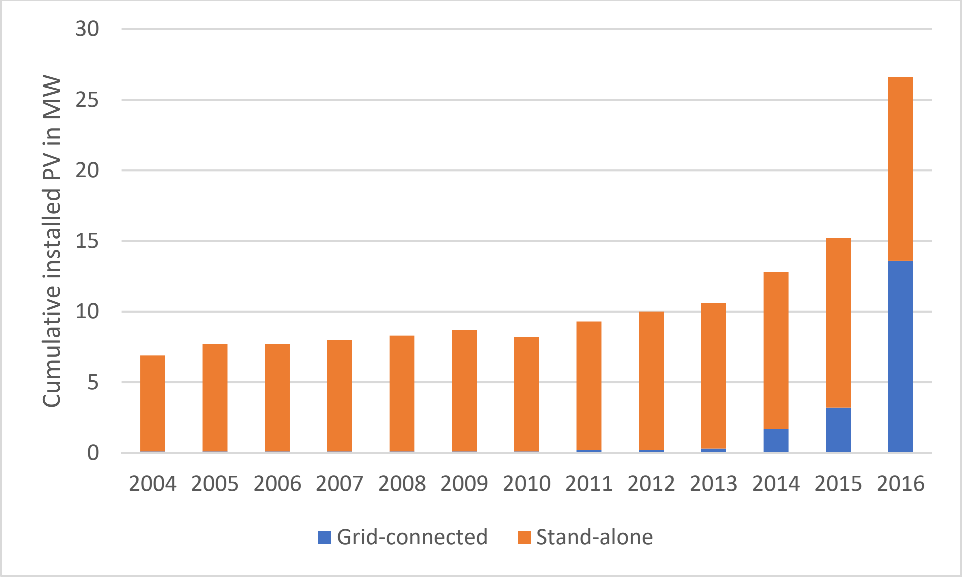

Figure 5-3 Accumulated solar capacity in Norway. Source: iea-pvps.org

The stand-alone market refers to both the leisure market (cabins, leisure boats) and the professional market (primarily lighthouses/lanterns along the coast and telecommunication systems). This segment is growing because of an increasing number of larger hybrid systems with higher battery-capacities, diesel or petrol back-up generators and electrical conversion from the PV-system to 230 Volt AC.

During 2015, self-consumption for large PV-systems were under discussion to be eligible for el-certificate (renewable energy certificates, RECS) market which created uncertainty for investors, but from 2016 PV-plants receive el-certificates for the total annual production for 15 years.

With a low density of population, a Nordic cold climate (which fits perfectly the use of PV) and an extremely high share (96-99 percent) of cheap (0,20-0,50 NOK/kWh in the summer), hydro-based renewable energy in the electricity mix, Norway is not expected to become a key player in the PV market. However, it represents an interesting example of PV possibilities, especially in combination with the increasing popularity and share in electric vehicles.

Table 5-1 Top ten solar PV-systems in Norway. Source: Multiconsult.

Nr.	Name	kW_p	Year
1	Asko Vestby	3 380	2017
2	Asko Vest	2 000	2017
3	Asko Midt	1 406	2017
4	UNIL Våler	1 322	2016
5	Asko Kalbakken	1 147	2016
6	Asko Sør	720	2016
7	Posten-Bring Trondheim	670	2016
8	Asko Hedmark	537	2017
9	CC Vest	363	2017
10	Powerhouse Kjørbo	312	2014

Table 5-1 lists the top ten solar installations in Norway with production capability and year of construction.

A study done by the university of Oslo have identified the following driving factors for the private housing market (Thorud, 2016):

- own production of power for electric cars
- increased independence from power companies
- environment
- positive experience with solar cells in the cabin
- reduced expenses

The private market has also seen greater competition among the providers and new business models that make solar power more attractive and accessible, among leasing arrangements and other things.

5.3 Building regulations

While previous building technology regulations (TEK) have had an increasing focus on reducing thermal energy needs and better climate scale (TEK97 - TEK17), now focuses on the total need for energy delivered. Among other things at "near zero energy building" (nZEB) or plus houses, one will increasingly depend on local renewable energy production to meet the energy requirements.

It is expected that building technical regulations by year 2030, because of the EU Building Directive (EPBD) (EU, 2018), will adapt nZEB or Plusshus level into future revisions of TEK. This will result in an increased need for locally produced electricity. With today's technology trends it is likely that this will mainly be done by means of solar cells.

As an example of incentive for increased use of solar cells in TEK17, an increase in net energy needs is allowed at 10 kWh/m^2 BRA/year, assuming renewable electricity generation from the building of at least 20 kWh/m^2 per year heated BRA.

This means that installation of solar cells contributes to complying with technical regulations, and thus giving greater flexibility for builders in how technical regulations can be achieved. As well, solar cells constitute an opportunity when alternative measures are expensive. This incentive already stimulates today’s installations of local solar systems.

5.4 Companies

This section lists some of the major current companies on the Norwegian solar market. It will not mention previous companies that are no longer active.

Table 5-2 Major companies on the Norwegian solar market.

Company	Area
Norsun	Manufacture
REC Solar Norway	Manufacture, Assembly
Norwegian Crystals	Manufacture
Otovo	Seller
Fusen	Seller, Installation

Norsun was established back in 2005 and manufactures high performance mono-crystalline silicon ingots and wafers in Årdal.

REC Solar Norway, previously Elkem solar, produces solar cell silicon based on own technology developed in Kristiansand. It is active in all parts of the solar energy chain, and produces silicon in USA, wafers in Herøya, Porsgrunn and Singapore, and solar panel production in Singapore.

Norwegian Crystals re-established in REC's old production facilities in Glomfjord in 2013 and produces monocrystalline ingots and blocks.

The energy company Otovo started up in January 2016 and sells solar PV-systems to private residents. Their website offers help in calculating size and annual production capacity of the solar PV panel suited for a property.

The leading supplier in Norway Fusen, delivers solar installations for roof and facades. They have installed over 100.000 square meters of solar panels with major contributor to this number being the ASKO facility in Vestby.

Figure 5-4 Solar PV at ASKO, Vestby. Source: Fusen.no

5.5 Economy

Here is some of the main current support schemes available on the Norwegian market.

Enova is a state-owned enterprise (SOE), which seeks to increase the share of environmental friendly energy production and consumption. This is done by giving economic grants to projects. The enterprise is financed indirectly by the consumers through the "Energy-fund", through an additive in the tariff, but also by transfers in the government budget (Statsbudsjettet, 2018).

From January 2016, owners of small PV-systems that are below 15 kWp are eligible for a financial investment support provided by Enova, a public agency owned by the Ministry of Petroleum and energy. Enova also offers financial supports for "building with High-energy Performance" where the energy performance goes beyond the normal technical norms. Environmental qualities are an increasingly important market parameter for stakeholders in the Norwegian building and construction sector. Enova has a strong focus on energy efficient buildings and supports innovative technologies and solutions. Building Integrated PhotoVoltaics integrated with storing energy in batteries, and smart control is emerging along with new companies with innovative business models. The support covers up to 35 percent of total costs (VAT included) and is calculated like this: 10 000 kr + (1 250 kr per kWp).

In 2014, the municipality of Oslo launched a capital subsidy for PV-systems on residential buildings covering a maximum of 40 percent of the investment cost. The program was run by their climate and energy fund, financial aid for private residents, who wishes to invest in solar energy. The main purpose this was to increase the expansion of PV-systems in the Oslo area and long-term reduction in the system price. The aid stopped in September 2017, and will not be brought back again (Borgersrud, 2017).

Self-consumption for grid-connected systems is allowed under the 'Pro-customer scheme' ("Plusskunde-ordningen") provided that the customer is a net customer of grid-electricity on a yearly basis and limits the maximum feed-in power to 100 kW. A prosumer possesses their own production unit and uses this to partially meet their own energy demands. When production is less then what is needed, the remaining portion is bought from the electricity supplier. In periods with low energy demand and a surplus of generated energy, the surplus electricity is bought from the user and fed into the electric power distribution network (NVE, 2018).

As a pro-customer, it is also possible to join the green certificate scheme. This is best suited for systems producing 16,000kWh or above since there is a cost of joining the scheme. A large plant can be eligible for reclamation in between 0.15-0.25 NOK per kW. This is measured and settled by the inverter, so it is the total output and not just the surplus electric current that counts. Power-plants must be in operation within the end of 2020 to be part of the RECS support program. (fornybar, 2018a; irenewables., 2018).

5.6 Comparison with Scandinavian countries

Sweden is the country which is the most comparable to the Norwegian market. Not only because of location on a northern latitude, but also as a result of similar financial incentives. Sweden has experienced steady growth in the market, largely characterized by predictable support schemes and framework conditions from authorities. A country like Denmark is seen as less natural to compare with, as government regulations have struck Danish market since 2012. In 2012, radical support schemes for solar power were introduced, which led to one explosion in the market with 406 MW installed power (IEA, 2016). Since then, the Danish market has experienced a downward curve.

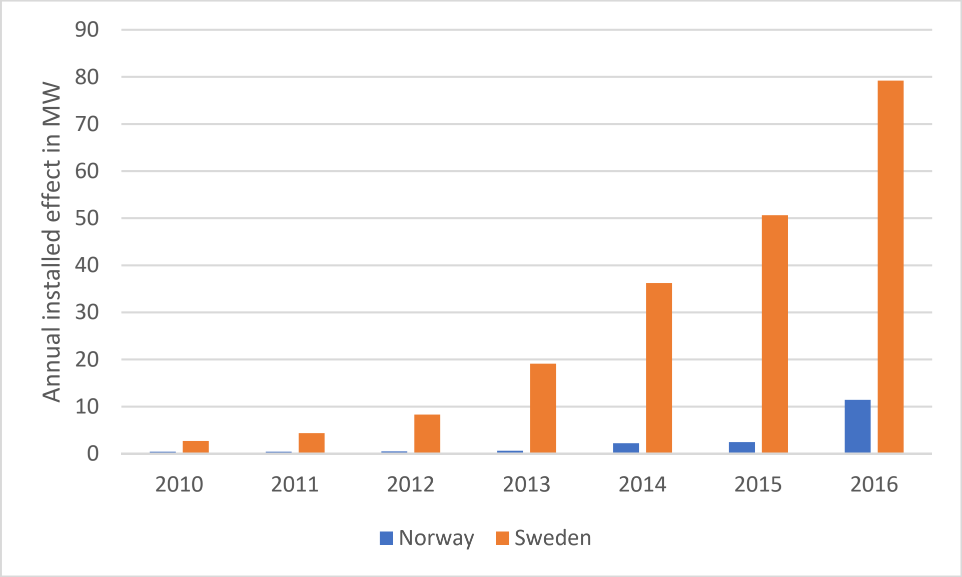

Figure 5-5 Annual installed effect in MW for Norway and Sweden. Source: iea-pvps.org

The annual installed effect in MW for Norway and Sweden from 2010 to 2016 is shown in Figure 5-5. Denmark is excluded since it distorts the representation with a significantly higher installed effect. Data from the period 2006-2016 can be found in the annex for Norway, Sweden and Denmark.

6 Discussion

Many believe the electric car will speed up the long-foreseen end of the fossil fuel era. This is quite possible and with the great increase in renewable energy and falling prices, it is not unlikely that renewable energy sources in only a period of 10-15 years will be preferable in price to energy coming from fossil sources. According to an article in NRK (Hedvig, 2018) recent calculations predict that in only seven years' time the majority of cars sold will be electric and phase out the ones reliant on diesel.

As mentioned earlier, the access to cheap renewable waterpower in Norway is one of the most limiting factors of rapid expansion of solar power in Norway. This will most likely continue, since it is unlikely this will change dramatically in the nearest future. However, since Norway begins to become more attached to the rest of the European energy market through the European Economic Area (EEA) and large investments in the power-grid is forthcoming. The prices are expected to increase in years ahead.

With experience over time and as usage of solar PV increases, it is not unlikely that this becomes more of a standard building material. When considering the materials for a building a lot of things can be considered and whether we emphasize the cost, energy or environmental impact. The usage of BIPV will see an increase as it will pay back the extra costs and require low maintenance. Building-applied PhotoVoltaics will still be the major contributor to solar power in Norway for many years since this can be easily retrofitted unto the building envelope.

7 Further work

When this assignment was written, Norway was in the installation phase of Automatic Metering System (AMS). Estimated to be completely installed nationwide within 2019. Energy providers will soon be able to price electricity from consumption peaks to balance out the spikes in energy consumption. An interesting study could be how this affects households with solar PV systems.

Batteries to store electric energy for solar PV is not discussed in this thesis. An interesting idea would be to look at battery storage in case of e.g. an emergency where the power is gone. Inclusion of a battery pack is also relevant with the instalment of AMS.

Hybrid systems in the context of solar PV refers to system also harvesting thermal energy from the sun. An interesting topic to study further is the potential for cooling the solar cells in warm periods while reversing it to melt of snow and ice during winter.

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9 Annex

Annex A Evolution of actual module production and production capacities in MW

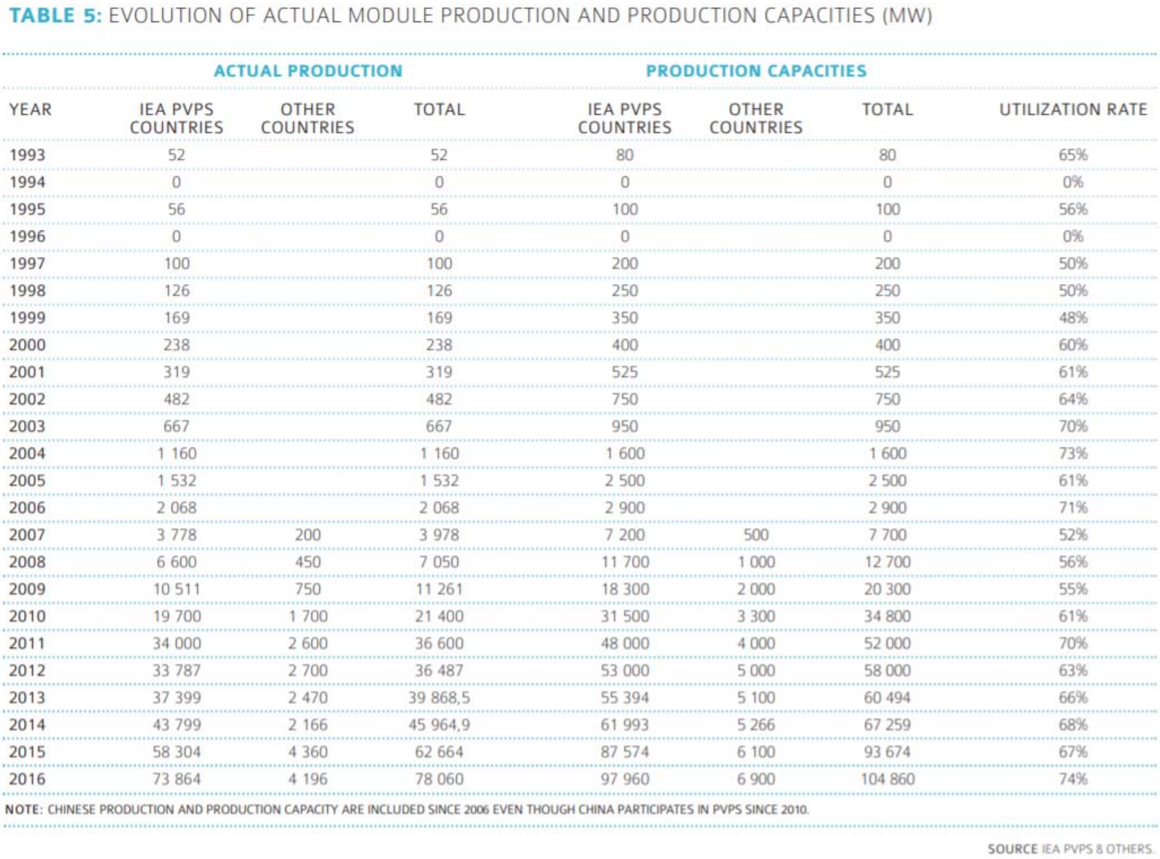


TABLE 5: EVOLUTION OF ACTUAL MODULE PRODUCTION AND PRODUCTION CAPACITIES (MW)

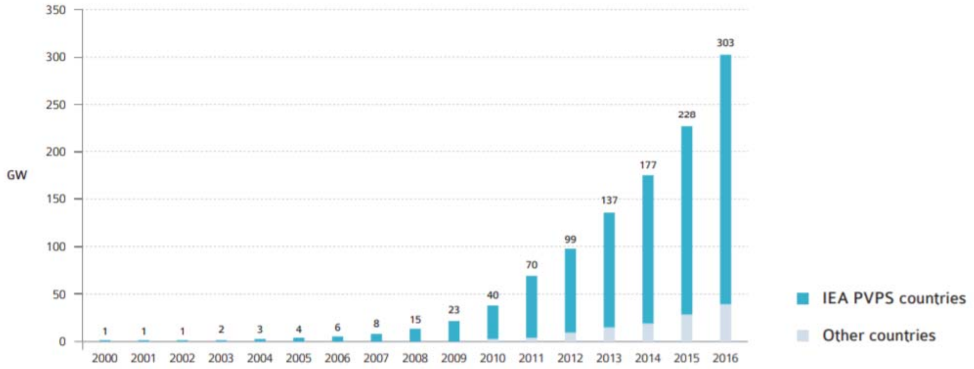
	ACTUAL PRODUCTION			PRODUCTION CAPACITIES			
YEAR	IEA PVPS COUNTRIES	OTHER COUNTRIES	TOTAL	IEA PVPS COUNTRIES	OTHER COUNTRIES	TOTAL	UTILIZATION RATE
1993	52		52	80		80	65%
1994	0		0	0		0	0%
1995	56		56	100		100	56%
1996	0		0	0		0	0%
1997	100		100	200		200	50%
1998	126		126	250		250	50%
1999	169		169	350		350	48%
2000	238		238	400		400	60%
2001	319		319	525		525	61%
2002	482		482	750		750	64%
2003	667		667	950		950	70%
2004	1 160		1 160	1 600		1 600	73%
2005	1 532		1 532	2 500		2 500	61%
2006	2 068		2 068	2 900		2 900	71%
2007	3 778	200	3 978	7 200	500	7 700	52%
2008	6 600	450	7 050	11 700	1 000	12 700	56%
2009	10 511	750	11 261	18 300	2 000	20 300	55%
2010	19 700	1 700	21 400	31 500	3 300	34 800	61%
2011	34 000	2 600	36 600	48 000	4 000	52 000	70%
2012	33 787	2 700	36 487	53 000	5 000	58 000	63%
2013	37 399	2 470	39 868,5	55 394	5 100	60 494	66%
2014	43 799	2 166	45 964,9	61 993	5 266	67 259	68%
2015	58 304	4 360	62 664	87 574	6 100	93 674	67%
2016	73 864	4 196	78 060	97 960	6 900	104 860	74%

NOTE: CHINESE PRODUCTION AND PRODUCTION CAPACITY ARE INCLUDED SINCE 2006 EVEN THOUGH CHINA PARTICIPATES IN PVPS SINCE 2010.

SOURCE IEA PVPS & OTHERS.

Annex B Evolution of cumulative PV installations in GW

FIGURE 1: EVOLUTION OF CUMULATIVE PV INSTALLATIONS (GW)



SOURCE IEA PVPS & OTHERS.

Annex C Comparison of annual installed MW in Nordic countries. Source: iea-pvps.org

	Norway	Sweden	Denmark
2006	0,416	0,61	0,2
2007	0,324	1,39	0,2
2008	0,35	1,67	0,19
2009	0,32	0,85	1,3
2010	0,4	2,69	2,5
2011	0,42	4,35	9
2012	0,47	8,28	316
2013	0,62	19,1	248
2014	2,2	36,22	39,4
2015	2,45	50,64	183
2016	11,4	79,2	70

* all numbers in MW

Annex D Accumulated solar capacity in Norway. Source: iea-pvps.org.

	GRID-CONNECTED	STAND-ALONE
2004	0,1	6,8
2005	0,1	7,6
2006	0,1	7,6
2007	0,1	7,9
2008	0,1	8,2
2009	0,1	8,6
2010	0,1	8,1
2011	0,2	9,1
2012	0,2	9,8
2013	0,3	10,3
2014	1,7	11,1
2015	3,2	12
2016	13,6	13

* all numbers in MW

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