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Potential and Challenges for Building Integrated Photo-voltaics in the Agder Region

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Summary

In the search for clean and renewable energy sources, photovoltaic or solar electric power generation is a quickly maturing industry that is carving out a significant role as a source of abundant, safe and clean renewable energy. This report will look at the current trends and developments in photovoltaic power production and the potential of building integrated photovoltaics (BIPV) for the Agder region.

The first chapter outlines the goals and research methods employed in this project. The second chapter specifies the technology base, explaining the physical principles for utilization of solar radiation and the state-of-the-art in photovoltaic technology. The third chapter will give some examples of commercial, industrial and domestic use of building integrated PV. This is to demonstrate how products and technologies can be implemented and link them up in order to develop a common vision of what is possible. Chapter four will analyze the policy framework in different European countries for promoting PV products and technologies in order to take advantage of them. Chapter five will then present the regional BIPV products and producers that could be involved in the potential progress of BIPV development.

Chapter six presents a discussion on prospects and potential regional use of BIPV, including barriers and potentials for development. Chapter seven summarizes the report with conclusions and recommendations for further work. The conclusion drawn from this initial evaluation is that there may be opportunities in the medium term, but until PV systems have reached a cost closer to parity with other main sources of energy, there will be a limited volume in Norway for markets closer to the consumer.

The main opportunities in Agder in the near future appear to come from application of advanced competitive technology adapted to the specific needs of the PV industry in the initial part of the value chain. Research and development in regional industries, research institutions and universities is a precondition for following the rapidly advancing technology. Here, the Agder region has a unique opportunity to position itself and take a leading role in terms of solar industry in Norway. This could be a strong case also for including other segments, such as BIPV, in a strategic mid- to long-term plan-

ning process. Two niche areas that could be considered for near-term development is 'plug-in' components that reduce installation costs, and the high-end building market where expensive facade materials can be replaced with BIPV at competitive cost. For opportunities on a larger scale, one should look to the wider European market or wait for government incentives.

In terms of where Agder should go from here, two concrete steps are recommended. The first step is to assemble a team composed of the relevant public and private actors to identify Agder's energy needs and goals within 1-5 year, 5-15 year and 15+ year timeframes. This will lay the groundwork for the development of a regional roadmap. The second step is to define actions, timeframes and deliverables according to the goals and opportunities identified. This will lay a basis for ongoing cooperation and reevaluation of Agder region's concerted efforts to meet the needs of the region and exploit the opportunities up-and-coming energy technologies offer.

Definitions and terms used

List of acronyms

Acronym	**Explanation**
AC	Alternating current
a-Si	Amorphous silicon (a PV material)
BIPV	Building Integrated Photo Voltaic system (forms part of a building)
CdTe	Cadmium telluride (a PV material)
CIGS	Copper, indium, gallium, (di)selenide/(di)sulphide (a PV material)
c-Si	Crystalline silicon (a PV material)
DC	Direct current
EVA	Ethyl vinyl acetate (encapsulation material for PV modules)
GaAs	Gallium arsenide (a PV material)
GW	Gigawatt
GWh	Gigawatt-hours
kW	kilowatt
kWh	kilowatt-hours
MW	Megawatt
MWh	Megawatt-hours
OPV	Organic photovoltaic
PV	Photovoltaic
TW	Terawatt
TWh	Terawatt-hours
W	Watt

Prefixes

Prefix	**Symbol**	**Name**	**10^n**	**Number**
kilo	k	Thousand	10^3	1 000
mega	M	Million	10^6	1 000 000
giga	G	Billion	10^9	1 000 000 000
tera	T	Trillion	10^{12}	1 000 000 000 000

Explanations

Insolation	Refers to <u>in</u>cident <u>sol</u>ar radi<u>ation</u>. Describes the amount of solar energy that strikes a given area over a specific time. The insolation varies with the seasons and geographic location. In this report, units of [kWh/m^2] are used for annual insolation averages and [Wh/m^2] for daily insolation averages.
Irradiation	The amount of solar energy incident on a surface per unit time and per unit area. The most common unit is [W/m^2].
W	One watt equals one joule per second. A solar irradiation of 1 watt per square meter (1 W/m^2) means that an area of one square meter receives one joule per second (1 J/s) from the sun.
kWh	One kilowatt-hour is one thousand watt-hours. It represents the amount of energy when using one kilowatt (1 kW, or 1 kJ/s) over a period of one hour, this equals (1 kJ/s × 3600 s) = 3600 kJ (kilojoules). The average energy consumption in Norway by a family living in a freestanding house is around 20 000 kWh per year. The energy use is lower for apartments.
MWh	One Megawatt-hour is one thousand kWh and is used in connection with larger energy amounts, such as the consumption in factories or smaller generating facilities.
GWh	One Gigawatt-hour is one million kilowatt-hours. This represents sufficient energy to supply about 40 freestanding houses in Norway.
TWh	One Terawatt-hour equals one billion kWh. This is close to the total energy amount used by the city of Drammen over one year. The total (electric) energy consumption in Norway was 125 TWh in 2001 and 135 TWh in 2008.

1 Introduction

The solar energy received annually by the earth is several thousand times larger than the current use of energy by humans and also several times larger than the planet's total unused energy reserves. Solar energy is available all over the earth in principle, but is particularly abundant in a belt within ± 35° around the equator. With over 5 billion residents in this geographical area, this belt happens to coincide with the latitudes where most of the world's population lives.

In this perspective solar energy has the potential to be the single most important source of renewable energy for the future. The utilization of solar energy is based on sustainable and environmentally friendly solutions. The technology is well documented, and the utilization of solar energy is now a considerable international market in rapid growth.

1.1 Utilization of solar energy

For building integrated purposes, there are two main categories of solar energy applications. *Solar thermal collectors* are typically used for heating water, whereas *photovoltaic modules* (solar cells) produce electricity directly from the sun. In this report we will focus on the photovoltaic (PV) industry for reasons mentioned below (see 1.4).

The value chain of the PV industry is characterized by several large actors producing for the global market. They cover all production steps from raw material to modules. Downstream activities like installation and maintenance are best performed by local enterprises. Installed systems can be both standard solutions designed by global actors as well as tailor-made solutions provided by local companies. For crystalline silicon technology, which currently represents the majority of the world PV market, the value chain is presented in Figure 1.

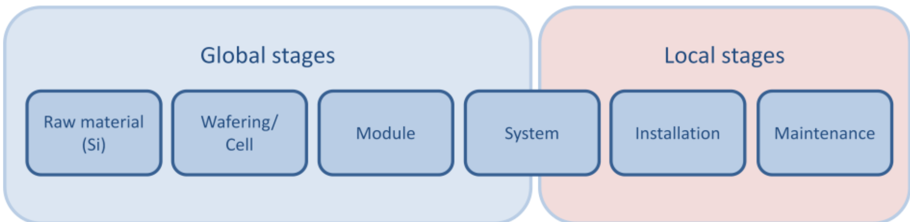


Figure 1: Value chain for the crystalline silicon PV industry.

In the Nordic countries, the use of PV panels for electricity production has up till now primarily been found in remote vacation cottages, especially in Norway, Sweden and Finland. Enova estimates that over 60,000 vacation cottages in Norway have installed PV modules. The combination of large distances to the existing electricity grid and a small annual energy demand makes such solutions an economical alternative.

The amount of energy delivered by these cottage systems is small, mainly providing lighting and other low power applications for a few weeks per year. PV is also used on a more continuous basis to power technical measuring instruments in remote areas, and more than 2000 lighthouses at sea are powered by photovoltaics.

In Norway, the accumulated installed capacity of PV power was 8.6 MW at the end of 2009 [IEA, 2009d]. Of this capacity, 93 % is domestic stand alone systems, 5 % is non-domestic stand alone systems, and only 1.5 % is grid-connected PV systems. This is completely opposite to the rest of the world, where almost all installed PV capacity is grid-connected [IEA, 2009e]. As will be discussed later, this difference is significant and not accidental.

1.2 Goal of this project

The goal of this project is to look at the relevance and potential for photovoltaic power development in the Agder region. Specifically, this report will highlight the current products and trends in building integrated photovoltaic (BIPV) applications, and place these developments in a regional context focusing on potential gaps in the value chain for both local producers and consumers.

The purpose is to lay the foundation for exploiting new opportunities, especially in the deployment of practical and efficient solar electric technologies. The result of this review will be an evaluation of the potential for solar energy use in southern Norway, the identification of significant actors along the value chain, and a proposal for how to move forward in order to develop a plan that specifies the activities, roles and relevant time frames for taking a more active position and profile for the actors in this field, which include the government, local industry and research institutions.

The history of commercial photovoltaic power generation is a relatively recent one that is rooted in an environment defined by technology-push combined with political leadership. Although at first glance the potential energy that can be harnessed is limitless given the ubiquitous sun, the practical application has often fallen short of its promise because of the fundamental challenge of concentrating a diffuse source of energy into a cost-effective and usable form.

This characteristic is in stark contrast to the historic development and use of most common sources of power such as wood, coal, oil, gas and nuclear power, where the primary challenge is a controlled release of energy from a concentrated source of potential energy. In spite of this hurdle, there are three main driving forces that continue to fuel the increasing global investment in, and development of, photovoltaic technologies.

The first impetus for developing photovoltaic power is the simple calculus of dramatically increasing demand for energy combined with a leveling off or even fall in the traditionally cheaper or more readily available sources. The rapid industrialization of countries such as China, India and Brazil together with steadily increasing demand in more developed economies has created a situation that cannot be sustained in the long run without the development of new sources of power.

Because of this dynamic, some of the more robust technologies that are not necessarily cost efficient for production today will more than likely be profitable in the near future. In classic economic terms, the growth in the demand for energy is outstripping the growth in the supply, driving prices higher and creating a demand for alternate sources of energy.

The second impetus for developing alternative sources of power is the rising norm of efficient and environmentally friendly energy consumption. Although the existing, primary sources of energy are becoming more efficient and cleaner in terms of per unit energy production, the sheer scale in the size and growth in demand means that they are pumping out ever higher total levels of contaminants.

New standards, such as the ISO 14000 environmental management standards and the ISO 50001 energy management standard have been sanctioned [ISO, 2011]. These standards will establish a framework for industrial plants, commercial facilities and entire organizations to manage energy[1]) and will increase the necessity for investing in and deploying clean energy systems. Even hydro-power, long recognized as a clean and renewable source of energy, is facing limits both of exploitability and a willingness to accept the cost of its environmental impact.

The third impetus for change is energy security. Diversification of energy supplies helps to prevent an overdependence on potentially insecure providers or declining resources. A lack of redundancy and a failure to multiply energy sources can leave an economy open to ruinous, uncontrolled external events or leave firms on the outside looking in regarding significant technological developments.

The US dependence on the Middle East for oil, Europe's dependence on Russia for gas, the limited sources for supplies of nuclear fuel, these are examples of potentially damaging energy security exposures that can only be mitigated by diversification and flexibility.

1.3 Methodology and constraints

In this report we use a combination of sources including textbooks and web pages, official projections, published technology roadmaps, country studies and selected market scanning. In addition, we have spoken to a cross-section of relevant Norwegian actors within and outside the region including potential producers, consumers and suppliers. There is a fierce competition and the need to protect competitive advantages results in limitations in access to such information. On the other hand, producers in the value chain are eager to have their products capture market share and are hence willing to provide some useful and actionable information.

[1] http://www.iso.org/iso/pressrelease.htm?refid=Ref1337

1.4 Scope of the report

We have chosen to limit the scope of this initial review exclusively to *photovoltaic electric power generation* and its inclusion in building design. The main reasons for this are as follows:

a) The Agder region is strong on the production side of solar cell technology for electric energy generation but insignificant within the solar water heating segment. Paradoxically the region has an almost nonexistent record in solar power deployment. This gap is largely the result of the extensive clean, relatively cheap and renewable hydropower resources that have been expanded over the years. However, it is also a result of a lack of prioritization from the central government to harness the solar energy directly.

b) Developments are moving towards more energy-efficient house standards where there will be less demand for heating but a continuing need for renewable based electricity.

c) Southern Norway is the optimal location for utilization of solar energy in our country due to its having the highest levels of irradiation, similar to levels in Northern Germany.

d) PV is a technology in rapid growth across the world, with continuous technological improvements and large investments that are bringing it closer to grid parity - it seems wise to be part of this development.

e) Increased public awareness is demanding a focus on new renewable energy and members of the public would like to be able to choose grid-connected PV as an alternative for their houses. As of today, this is not a straight-forward process.

f) Distributed PV power production and intelligent energy management could help to shave off energy peaks and reduce the traffic on the main grid.

g) For solar thermal applications there are already established Norwegian producers of modules particularly aimed at building integration (for instance the company AventaSolar), whereas this is less the case for BIPV in Norway (some companies, like Schüco, offer various facade solutions including BIPV options). The stated goal of presenting Agder's profile as a clean energy and technology region dictates that the quickly maturing PV technology and the globally increasing market application be evaluated in terms of exploitability and competence requirements.

2 PV technology – existing and developing

2.1 The solar energy resource

Solar energy is in principle available all over the earth, but is particularly abundant in a belt within ± 35° around the equator. With over 5 billion residents, this belt happens to coincide with the latitudes where most of the world's population lives. The solar energy received by the earth annually is several thousand times larger than the current use of energy by humans and several times larger than the planet's total usable energy reserves.

Numerical examples:

Annual solar radiation received by the Earth*	7.81×10^{17} kWh
Total annual global energy use (TPES) [IEA, 2009a]	1.40×10^{14} kWh

The solar energy received by the earth is more than 5500 times larger than the global use of primary energy.

Annual solar radiation received in Norway**	2.91×10^{14} kWh
Total energy use (TPES) in Norway [IEA, 2009a]	3.12×10^{11} kWh

The solar energy received in Norway is more than 900 times larger than the total primary energy use.

*Based on Earth's energy budget http://en.wikipedia.org/wiki/Earth's_energy_budget
**The estimate assumes an average annual insolation of 900 kWh/m^2.

In this perspective, solar energy has the potential to become the most important source of renewable energy. The utilization of solar energy is based on sustainable and environmentally friendly solutions. The technology is well documented, and can show a considerable international market in rapid growth.

The term *insolation* refers to incident solar radiation. It describes the amount of solar energy that strikes a given area over a specific time. The insolation varies with the seasons and geographic location, and is typically given in units of kWh/m^2 (annual insolation averages) or Wh/m^2 (daily insolation averages). The term *irradiation* describes the amount of solar energy incident on a surface per unit time and per unit area, commonly given in units of W/m^2.

2.1.1 The solar constant

As a consequence of the earth's elliptical orbit around the sun, the distance between the sun and the earth is not constant – it changes throughout the year. The irradiation in the outer atmosphere thus varies between 1321 W/m^2, on or around 4th of July, and 1412 W/m^2, on or around 3rd of January. The mean irradiation value in the outer atmosphere is 1367 W/m^2. This number is referred to as *the solar constant*.

In addition to the ± 3 % variation due to the elliptical orbit, another 1-2 % variation is observed due to variations in the solar activity. The 23.5 degree inclination of the earth, shown in Figure 2 also causes seasonal variation in insolation. In the northern hemisphere this counteracts the variation due to the elliptic orbit and makes the winter time, when the insolation is lowest, occur during the months around December to February.

Some radiation is reflected by the earth's atmosphere and some is absorbed by gases in the atmosphere, mainly water vapor, oxygen, ozone and carbon dioxide. Together with light scattered by dust, aerosols and molecules, these factors reduce the amount of energy that reaches the surface of the earth.

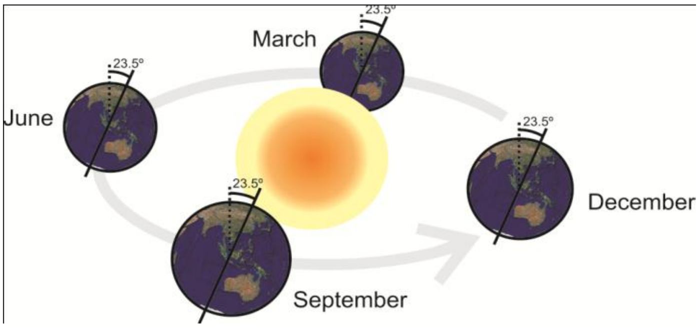


Figure 2: The earth's inclination angle of 23.5 degrees causes seasonal local variations in the insolation.

Around noon on a clear day and in a plane perpendicular to the direction of the sunlight, the irradiation will typically be around 1000 W/m^2. This is a peak value which is relatively independent of location. Values as high as 1400 W/m^2 can be observed, however, in short periods when clouds are reflecting light towards a particular location [DGS, 2008].

2.1.2 Global variations in the insolation

The annual average insolation varies geographically as seen in Figure 3 - Figure 5. Close to the equator insolation values as high as 2300 kWh/m^2 per year can be found. Southern Europe receives up to 1700 kWh/m^2 per year, while the mean value for Germany is 1040 kWh/m^2 per year [DGS, 2008].

Europe experiences large seasonal variations, with the largest amplitudes in northern Europe. North of the Arctic Circle you will find the extreme case where the midnight sun provides solar radiation 24 hours per day in the summer, and no sunlight is received during the darkest winter days when the sun never rises above the horizon.

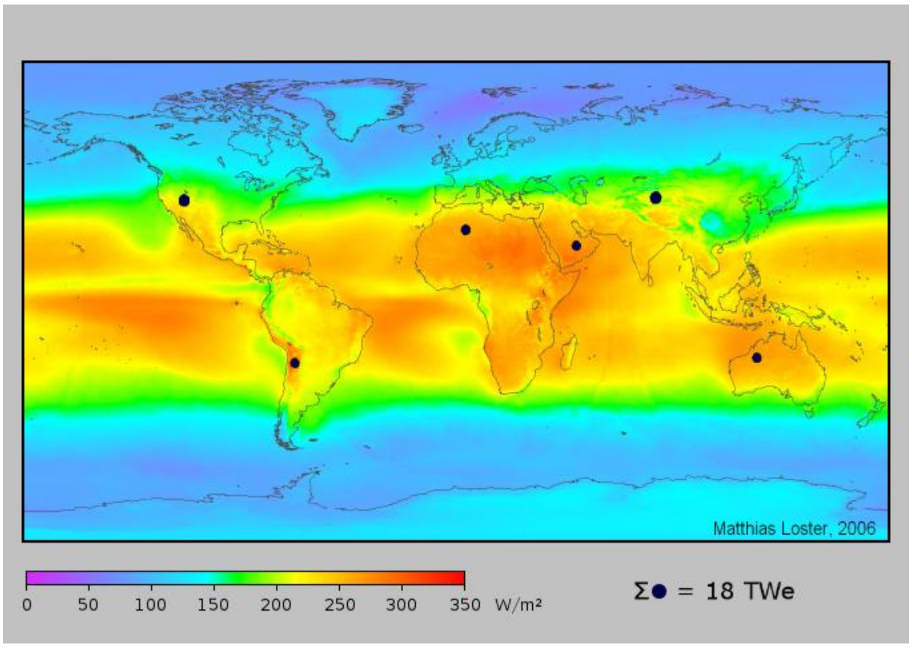


Figure 3: Average solar irradiation (based on data from 1991 to 1993) across the globe, in units of [W/m^2]. PV installed at the six indicated locations would produce on average 18 TW electric, equivalent to the current total power from all primary energy sources. Most people receive from 150 to 300 W/m^2 or an insolation of 3.5 to 7.0 kWh/m^2/day. Source: [Loster, 2006].

Figure 3 is the work of [Loster, 2006], who argues that sunlight could power the whole world. If installed in areas marked by the six discs in the map, solar cells with a conversion efficiency of only 8 % would produce, on average, 18 TW electrical power. That is more than the total power currently available from all our primary energy sources, including coal, oil, gas, nuclear, and hydro. The colors show the distribution of solar irradiance across the surface of the globe, in units of watts per square metre, based on a three-year average of satellite data (including nights and cloud coverage).

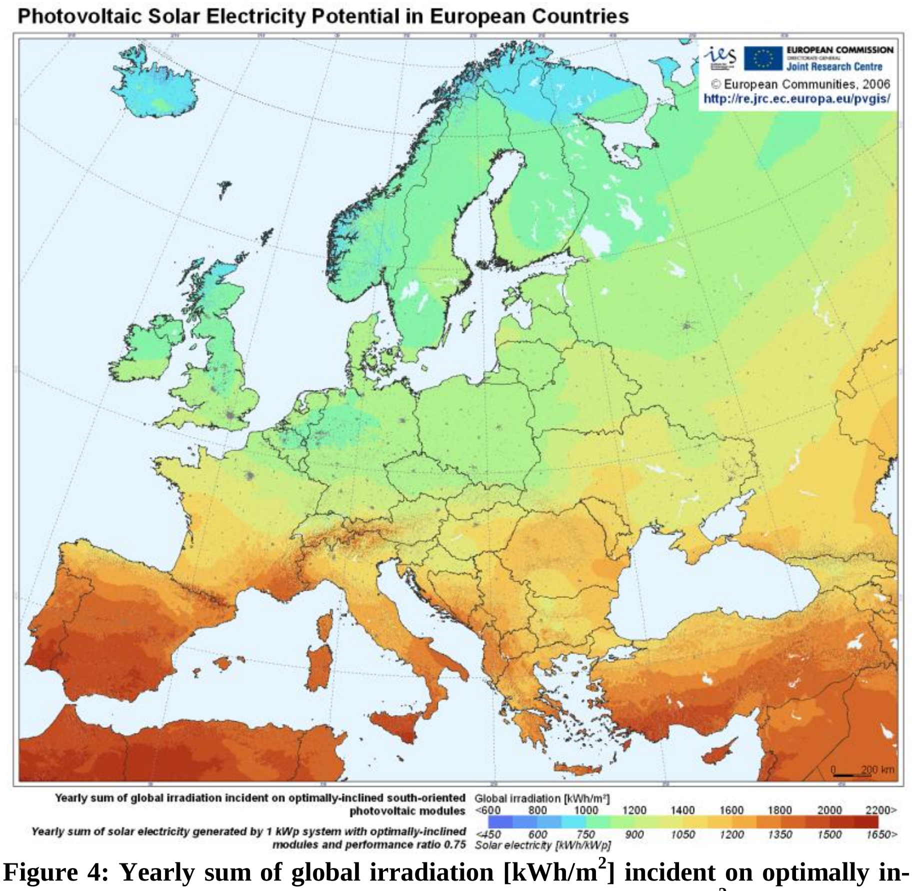


Figure 4: Yearly sum of global irradiation [kWh/m^2] incident on optimally inclined PV modules. The scale goes from blue (<600 kWh/m^2) to red (>2200 kWh/m^2). Source: [PVGIS, 2010].

In northern areas, the typical position of the sun is closer to the horizon than in areas close to the equator. Therefore, most of the light hitting the ground in Norway has passed through more atmosphere than light hitting the ground in for instance Tanzania. In addition to the fact that more light is absorbed and scattered by the atmosphere in Norway, the larger incidence angles reduce the energy intensity as the light hits the ground. Together this leads to the observed differences in insolation seen in maps such as Figure 3.

2.1.3 Insolation in Norway

The daily mean insolation in Norway in January and July is shown in Figure 5. The annual insolation varies from about 700 kWh/m^2 in the north to 1100 kWh/m^2 in the south. This corresponds to 30-50 % of the values around the equator. The large seasonal variations represent a challenge, where a clear summer day can yield up to 8500 Wh/m^2, while an overcast winter day might yield only 20 Wh/m^2 [NSEF, 2010]. The variation is not in phase with the energy demand, which peaks in the cold and dark winter months.

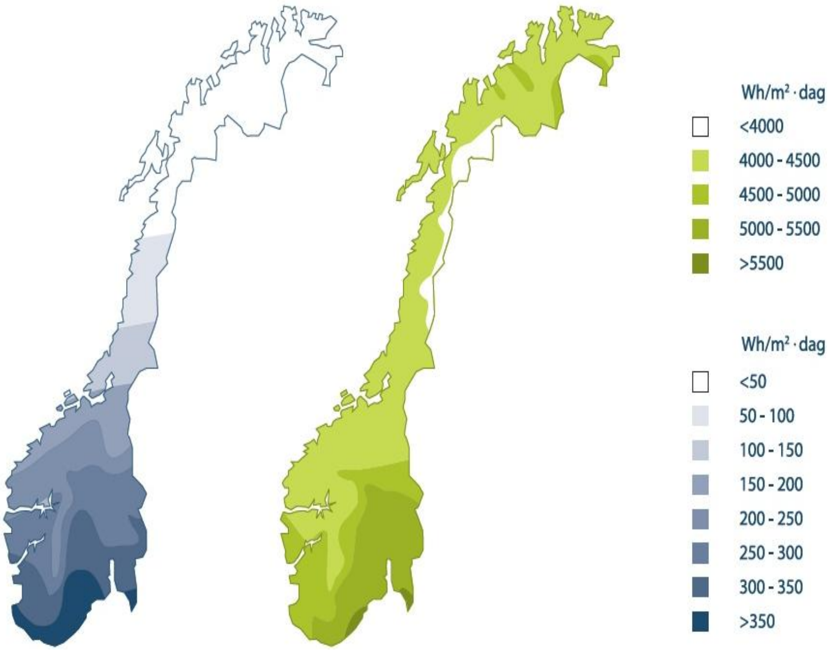


Figure 5: Daily mean solar energy received by a horizontal surface in Norway, in January (left) and in July (right). In Agder, values of around 300-400 Wh/m^2 per day are expected in mid-winter, and 5000-6000 Wh/m^2 per day in mid-summer. Illustration by Endre Barstad [Fornybar Energi, 2007].

2.1.4 **Numerical example**

For southern Norway we can assume an average insolation of 1100 kWh/m^2 per year. Table 1 shows the corresponding area that must be covered by solar panels to produce various amounts of electricity. Please note these are only indicative values to get an idea of the approximate areas required for a given production.

Table 1: Size of solar panel necessary for four cases of PV system efficiency (indicative values only, assuming 1100 kWh/m^2 annual global insolation).

System Efficiency	PV production			
	1,000 kWh/year	10,000 kWh/year	20,000 kWh/year	100,000 kWh/year
5 %	18 m^2	182 m^2	360 m^2	1818 m^2
10 %	9 m^2	91 m^2	182 m^2	909 m^2
15 %	6 m^2	61 m^2	121 m^2	606 m^2
20 %	4.5 m^2	45 m^2	91 m^2	455 m^2

The average household energy consumption in Norway is 20 000 kWh per year, which would indicate a required area of around 121 m2 of PV modules according to Table 1, assuming 15 % system efficiency. However, an estimated 70 % of the energy consumption in households is used for heating purposes [NVE, 2009], where the preferred solution should be thermally based (e.g., solar thermal collectors, bioenergy, energy efficiency measures). The required PV area would then be reduced to around one-third, targeting the remaining electrical energy demand such as electrical appliances, pumps, control systems and lighting. This would still represent a relatively large investment.

2.2 The characteristics of solar radiation

2.2.1 Direct and diffuse radiation

The solar radiation can be decomposed into a direct and a diffuse component (Figure 7). Direct sunlight comes from the part of the sky that is covered by the sun. This component makes objects cast distinct shadows. The diffuse light comes from the part of the sky that is not covered by the sun. This light consists mainly of solar light that has been scattered by molecules and particles in the atmosphere. The diffuse light from the sky and reflected by objects on the ground makes it possible to see objects in places where the direct light makes shadows. The direct component is the most important component on clear days, while the proportion of diffuse light dominates on overcast days. Figure 6 shows typical insolation values for various degrees of cloud coverage.

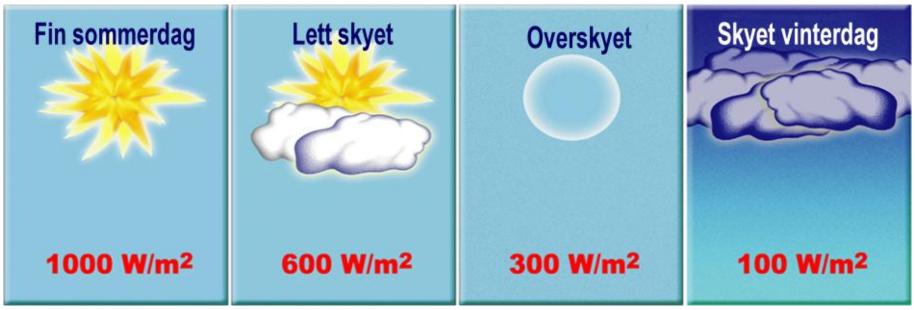


Figure 6: Illustration showing how the insolation is affected by the clouds. From left to right: Clear summer day, partially clouded day, overcast day and overcast winter day. Source: [Knudsen, 2008].

Solar water heaters and photovoltaic panels can harvest both the direct and the diffuse sunlight. The proportion of direct and diffuse light is geographically dependent and varies with local climate, pollution etc. In Germany 60 % of the light is diffuse [DGS, 2008], taken as an annual mean. In sunny areas the proportion of diffuse light is less.

2.2.2 Albedo

When determining the insolation at a surface it is also useful to include reflections from the ground and the surroundings. This is particularly important for tilted surfaces. The reflection coefficient of the ground is called albedo and can vary from 0 (all light is absorbed) to 1 (all light is reflected). A typical value of the albedo is around 0.2, but surfaces like fresh snow can have an albedo up to 0.9. Table 2 shows some examples of various albedos.

In general the albedo refers to diffuse radiation that results from light being reflected from (multiple) rough surfaces. Plain surfaces, on the other hand, can give very strong 'mirror-like' reflection of direct radiation. Facades facing water can experience a 50 % increase in the insolation due to reflection off the water surface when the sun is close to the horizon [DGS, 2008].

Table 2: Examples of albedo values for various surfaces. Source: [DGS, 2008].

Surface	Albedo
Grass (July, August)	0.25
Lawn	0.18 - 0.23
Dry grass	0.28 - 0.32
Soil	0.17
Gravel	0.18
Fresh/clean concrete	0.30
Old/dirty concrete	0.20
Cement	0.55
Asphalt	0.15
Forrest	0.05-0.18
Sand	0.10-0.25
Water	0.05 - 0.22
Fresh snow	0.80-0.90
Old snow	0.45-0.70

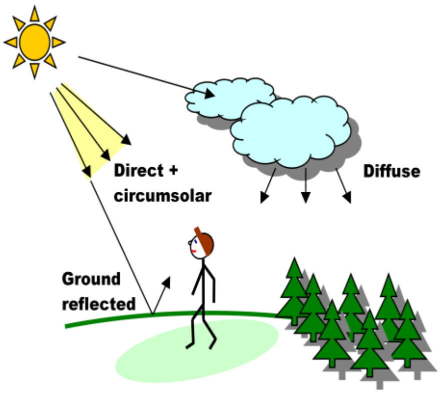


Figure 7: Solar radiation can be characterised in terms of direct radiation, diffuse radiation from the sky, and ground reflected radiation.

2.2.3 Orientation of solar panels

The position of the sun at any time can be described by two angles, the azimuth angle and the zenith angle. The azimuth angle tells us the position along the horizontal line, where 0 degrees is south, 90 degrees is west and -90 degrees is east. The zenith angle is the angle between zenith (directly overhead), the observer and the sun. This angle is zero when the sun is 'in zenith', that means straight above (this happens at mid-day on equinox at the equator), and 90 degrees when the sun is at the horizon.

One obviously wants a PV panel to collect as much energy as possible. While the diffuse part of the light is more evenly distributed angularly, the collection of direct light is highly dependent on the angle of incidence on the panel. The angle of incidence is determined by the azimuth and zenith angle of the sun and the orientation of the panel. The dependency between the angle of incidence and energy collection is illustrated in Figure 8. If a panel collects 1000 W of direct sunlight when the angle of incidence is 0 degrees, this is reduced to 707 W if the angle is increased to 45 degrees. When the angle of incidence goes towards 90 degrees, the collected direct radiation goes towards 0. Note that these numbers represent best case values. It is common that the reflectivity of solar panels increases by the angle of incidence. This further enhances the loss-effect of tilting.

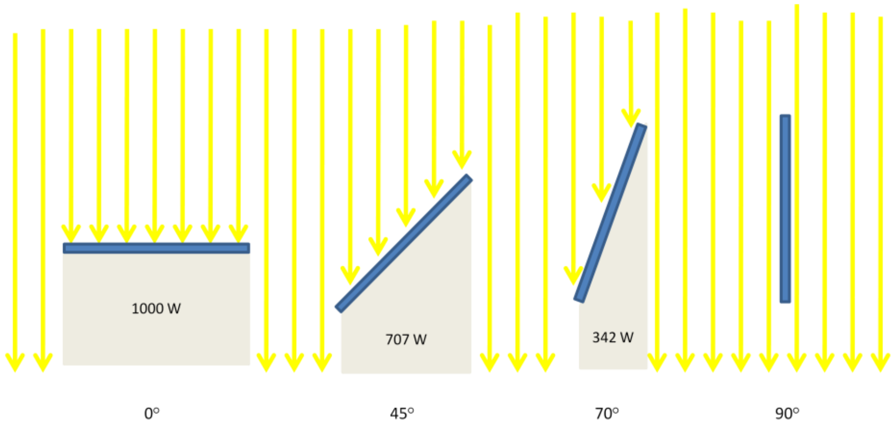


Figure 8: The energy from direct radiation collected by a solar panel decrease with increasing angle of incidence, as indicated by the width of the shaded areas. A panel tilted 90 degrees from the direction of the sunlight cannot collect any of the direct radiation.

Unless the panels are mounted on solar trackers, the angle of incidence will change throughout the day and also have seasonal variations. To maximize the collection of direct radiation, the solar panel should be oriented to minimize the angle of incidence in the middle of the day, when the irradiation reaches its maximum.

Figure 9 shows how much solar energy PV panels with various orientations can receive in Kristiansand. It should be noted that the simulation does not include reflection or shading from surrounding objects. If a panel is located next to a water surface or on locations where snow reflects light onto the panel, the numbers could be different. The x-axis used in the figure is the tilt angle of the panel, and data is plotted for azimuth angles of 0, 45 and 90 degrees, which corresponds to panels oriented towards south, southwest and west, respectively. With an optimal orientation the panel will receive 1040 kWh/m^2 per year. A panel mounted horizontally will receive around 900 kWh/m^2 per year. Panels mounted on vertical south facing or east facing walls will receive 760 and 560 kWh/m^2 per year, respectively.

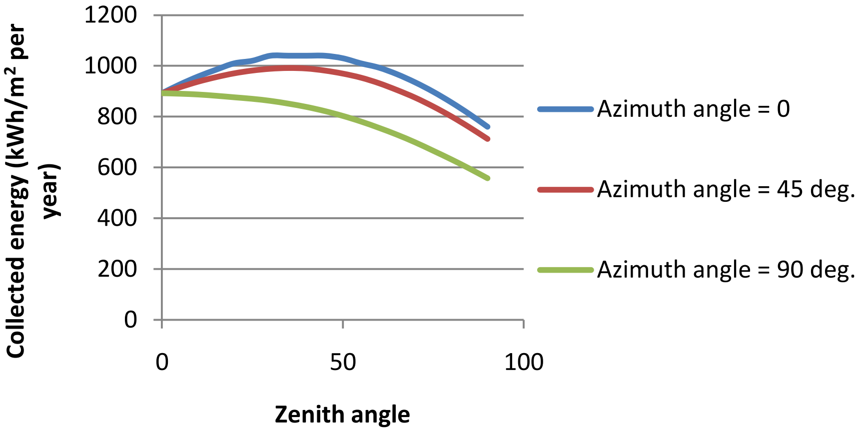


Figure 9: Upper limits for energy collected by solar panels with various orientations in Kristiansand. The data is found using the simulation tool PV GIS [PVGIS, 2010].

2.2.4 Air Mass and the solar spectrum

Air mass (AM) is an important concept in solar engineering. This quantity refers to how much air (atmosphere) the light has passed through before it reaches the surface of the earth, see illustration in Figure 10. The higher the air mass, the more light is scattered or absorbed by the atmosphere. An air mass of 1 (AM1.0) means that the light has passed through air corresponding to 1 atmosphere. This is the case for sunlight that strikes the earth's surface at the equator at noon at the equinox (i.e., sun in zenith). Air mass zero (AM0) describes solar irradiance in space, where it is unaffected by the atmosphere.

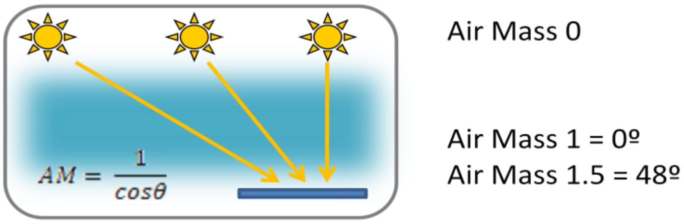


Figure 10: Illustration of the angle of incidence and the connection to the definition of air mass (AM).

For most of the time and at most locations on the globe, sunlight passes through more than one air mass before reaching the earth's surface. As the solar zenith angle increases, so does the air mass. Mathematically this relationship is described by AM=1/cosθ, where θ is the solar zenith angle. When the zenith angle is 48 °, the air mass is 1.5 (AM1.5). This is commonly used as a reference value for characterizing solar cells, and coincides with the annual average conditions for the United States without Hawaii and Alaska.

Solar radiation consists of photons, or little 'energy-packets', of different wavelengths. The distribution of the radiated solar energy as a function of wavelength is called the solar spectrum. This spectrum covers the ultraviolet, visible and infrared wavelength range. As the light travels through the atmosphere, some wavelengths are more affected by absorption and scattering than others. The result can be seen in Figure 11, where the 'dips' in the curve correspond to absorption by particular gases and water in the atmosphere. The total reduction in irradiance is obvious, comparing the spectrum hitting the outer atmosphere (in yellow) with that hitting the ground (in red).

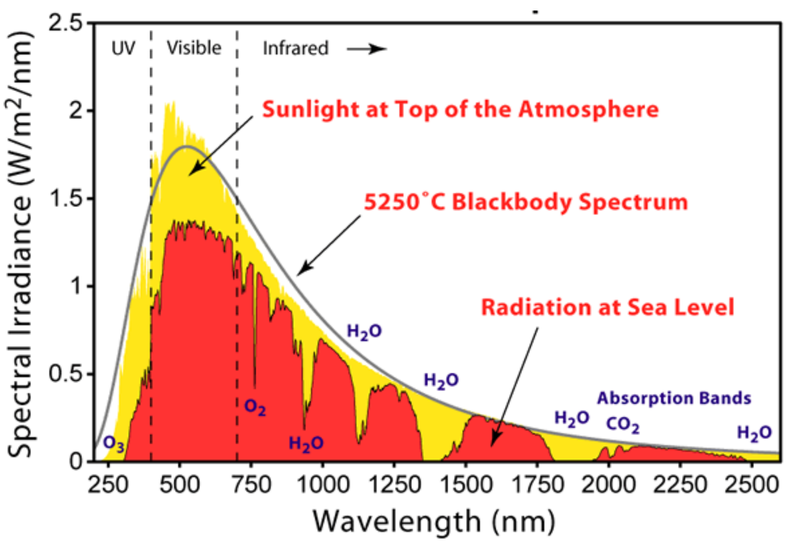


Figure 11: Solar radiation spectrum, illustrating the effect of the atmosphere on the distribution of wavelengths and the total solar energy received at the earth. Source: [SolarBook, 2011].

In Lindesnes, the southern tip of Norway, the minimum zenith angle (when the sun is at its highest point in the sky) is 34.6 ° around June 21st. This corresponds to air mass 1.2. Around December 21st the minimum zenith angle is 81.5 °, which corresponds to AM 6.8. Table 3 shows examples of corresponding air mass and zenith angle values.

Table 3: The relationship between the zenith angle and the air mass.

Air mass (AM)	**Zenith Angle (θ)**	**Comments**
AM 0	-	Experienced by satellites outside the atmosphere.
AM 1	0 °	The sun is in zenith
AM 1.1	24.6 °	
AM 1.5	**48.2 °**	**Standard reference for solar cells**
AM 2	60.0 °	
AM 4	75.5 °	
AM 8	82.8 °	The air mass concept becomes less applicable for large zenith angles. Light from the upper and lower part of the sun will experience different air masses.

Solar cell characteristics are generally specified at the AM1.5 global spectrum normalized to 1000 W/m^2 (also referred to as 1 sun) at 25 °C. The reference spectrum is defined in the international standard ISO 9845-1, 1992 (and known as the ASTM G-173-03 standard). The sunlight then traverses the atmosphere at an angle of 48.2 ° with a path length 1.5 times the 'thickness' of the atmosphere (sun at zenith).

2.2.5 Measuring the insolation

Measurements of the insolation can be very important for estimating the yield from a photovoltaic system. Simulation tools are easily available and can give reasonably good results, but will never be as accurate as direct measurements since local conditions always vary.

Measurements over a longer period of time give the best basis for the dimensioning of solar systems. Post-installation measurements are also useful since they allow the user to verify that the system performs according to its specifications. It also allows for further optimization of systems and components.

Irradiation is measured either directly by pyranometers or reference cells (Figure 13), or indirectly by analysis of satellite data. Pyranometers are scientific instruments that measure irradiation with a high degree of accuracy. The error is typically less than 1 % [DGS, 2008]. A typical pyranometer consists of two hemispheres of glass that protect a black metal plate, which is effectively absorbing solar radiation. The temperature of this black absorber varies with the irradiation level, which is determined by comparing the absorber's temperature to the temperature of the ambient air. This temperature difference is measured with thermocouples.

A pyranometer can be equipped with a shadowing ring that blocks the direct component of the radiation for measurements of the diffuse radiation (see right-most photo in Figure 13). Such a band needs to be regularly adjusted to account for the variation in the solar path. Direct radiation is measured by a slightly different instrument called a pyrheliometer, which needs to be mounted on a solar tracker in order to always point directly towards the solar disc. Figure 12 shows an example of solar measurements made with pyranometers (global and diffuse light) and a pyrheliometer (direct light).

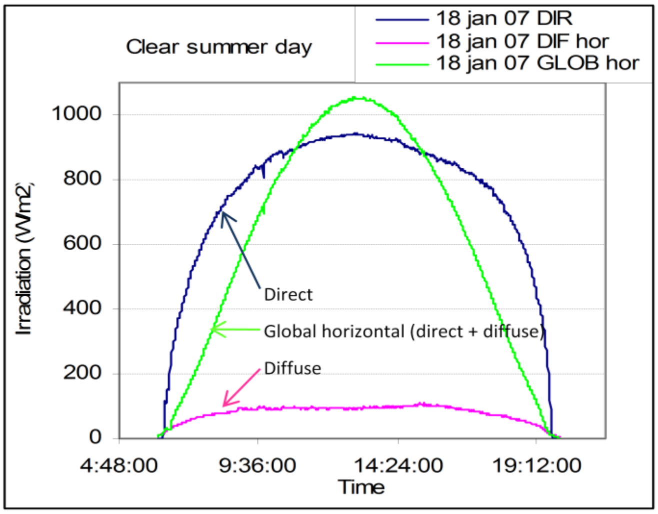


Figure 12: Measurements of the direct, global, and diffuse radiation on a clear summer day (example is taken from Newcastle, Australia).

Figure 13: Measurements of irradiation can be done by pyranometers (right) or reference cells (middle). Using a shadow ring, the diffuse radiation can be measured with a pyranometer as shown in the right picture.

Reference solar cells (also shown in Figure 13) are cheaper than pyranometers, but less accurate. Errors between 2 % and 5 % are typical for general measurements of the insolation. However, if reference cell measurements are used to estimate the yield of PV panels, the error is smaller because reference cells have higher accuracy for the parts of the spectrum that is absorbed by solar cells. Reference cells are therefore often used to monitor PV systems. It is important that a reference cell is made of the same material as the monitored cells. Reference cells also have to be calibrated by a qualified laboratory before use. This means measuring the short circuit current delivered by the cell as a function of the insolation.

2.3 Solar cell technology

In photovoltaic cells a fraction of the energy in the solar radiation is converted directly to electrical energy by the photovoltaic effect. When light is absorbed by a solar cell, photons[2] transfer their energy to electrons. This excites, that is lifts, the electrons from low energy states to states with higher energy. Left to themselves, the electrons will stay in the high-energy states for a short time before they return to the low energy states. In a solar cell, as many electrons as possible should be extracted from the high-energy states into an electric circuit. The electrons give away energy in this circuit before they are reinserted into the low-energy states in the solar cell.

[2] Photons are light particles or energy packages. Light consists entirely of photons. In a way photons are “the atoms of light”. The energy of each photon depends on the color of the light, including infrared and ultraviolet. The white light from the sun consists of photons with a large variation in energy.

The energy difference between the high- and low-energy states is called the band gap. Materials with an appropriate band gap are called semiconductors. The band gap is the most important parameter of a solar cell material. A semiconductor can only absorb photons with energy larger than the band gap.

In a conventional solar cell one photon excites one electron. A larger number of absorbed photons, which can be achieved with a smaller band gap, means that a larger current can be delivered by the cell. On the other hand, the maximum voltage set up by a solar cell increases with the band gap. The power delivered by the cell equals the current multiplied by the voltage. A compromise must be found between a cell with low band gap, which can deliver a large current but at a low voltage, and a cell with large band gap, which will have a high voltage but will absorb few of the photons in the incident solar spectrum.

Much of the behavior of a solar cell is captured by the current-voltage curve, also called IV-curve, as shown in Figure 14. This is a graph where the current delivered by a solar cell is plotted as a function of the voltage between its terminals. A solar cell that is not connected to an electric circuit or a battery cannot deliver an electric current. However, it will set up a voltage called the open circuit voltage, V_{oc}. This point is indicated in Figure 14.

If the terminals of the solar cell are short circuited, there is no voltage between the terminals, but a current, called the short circuit current, I_{sc}, will flow between them. This point is also indicated in Figure 14. When operated at a point in the first quadrant the cell delivers energy to an electric circuit or a battery system. The curve between I_{sc} and V_{oc} shows all possible combinations of current and voltage that the cell can deliver. The properties of the external circuit/battery system determine the position on the curve and hence the power delivered by the cell.

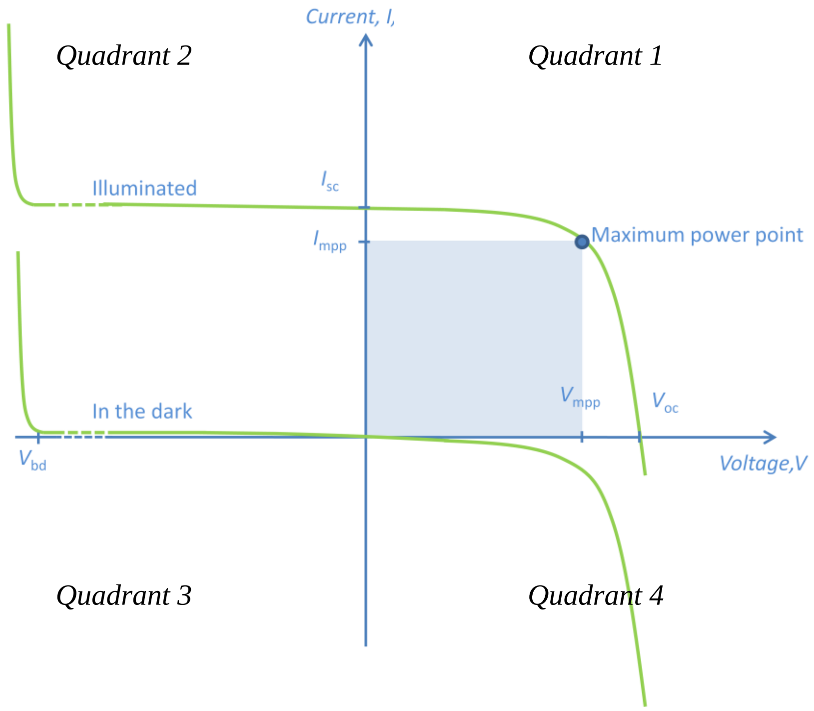


Figure 14: Example of an IV-curve. The power delivered by the solar cell is maximized by operating the cell at the voltage V_{mpp} and current I_{mpp} that gives the largest product, visualized by the shaded rectangle. By choosing a material with smaller band gap, the short circuit current I_{sc} will increase. The open circuit voltage V_{oc} will, to a certain point, increase with increasing band gap.

The power delivered by the cell equals the current multiplied by the voltage. To maximize the energy output, the cell should therefore be operated at the voltage that results in the largest product of voltage and current. This is called the maximum power point (MPP). Electronic equipment that controls the PV system detects this point and assures that the cell is operated optimally.

In the second and fourth quadrant the cell consumes energy, but such modes can only be reached if a voltage is applied to the solar cell by an external circuit. If a large negative voltage is applied to the cell it can reach its *reverse breakdown voltage*, indicated by V_{bd} in Figure 14. The breakdown voltage is typically -10 to -15 Volts for silicon cells. If this point is reached, the cell can dissipate large amounts of energy and become overheated. This can happen when a cell in a PV module is shaded, as will be explained later.

To be able to extract electrons from their high energy states, the solar cell consists of two layers of the same material, but with different doping atoms. Doping is adding in layers small concentrations of other elements. In silicon cells it is common to have one boron doped layer (p-type doping) and one phosphorous doped layer (n-type doping).

The doping changes the energetic position of the electron states and makes it possible to extract electrons from the high energy states on one side, and re-insert electrons to the low energy states on the other side, using metal contacts. A sketch of the layered structure of a solar cell is shown in Figure 15. The difference in energy between the electrons that are extracted and those re-inserted into the cell is the energy that can be delivered to an external electrical circuit.

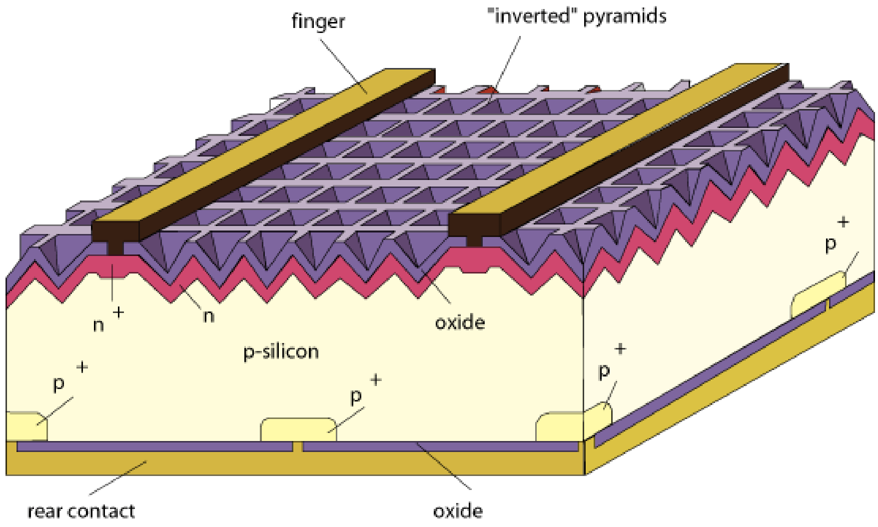


Figure 15: The structure of the World record silicon solar cell made by the University of New South Wales, Australia. The metal contacts (fingers) on the front side are connected to a layer of n-doped silicon and extracts electrons from high energy states. The metal contact on the backside is connected to p-doped silicon and re-inserts the electrons to low energy states. A surface texture shaped like inverted pyramids acts as a light trapping surface and increases the absorption of light.

To enhance the absorption of light, some cells (especially silicon cells) have a surface texture that reduces reflection loss and traps the light inside the cell. Solar cells are also covered with an antireflective coating to reduce the reflectivity of the cell itself.

The theoretical efficiency limit of conventional[3] solar cells with an optimal band gap is 31 % [Shockley, 1961]. No known material has the exact optimal band gap, but silicon and some other materials are quite close. The most common solar cell materials are described below.

2.4 Solar Cell Types

2.4.1 Silicon

Silicon is the dominant solar cell material, with a market share of over 80 % in 2010 [EPIA, 2011]. It is a highly abundant material, 27.7 % by mass of the earth's crust is silicon [Lutgens, 2000]. Silicon is the most important material in electronics, and the properties of pure silicon have been thoroughly studied and are well documented.

For the electronics industry, it is crucial to have materials of the highest quality to produce reliable components. So-called electronic grade silicon has very high purity and consists of single crystals where the silicon atoms are positioned regularly and systematic throughout the entire piece. Experience has shown that solar cells of reasonably high quality can be made with silicon of lower quality than electronic grade. When the cost saved by using less pure materials exceeds the price of the energy that is lost due to lower cell efficiencies, it is economically viable to use less pure material.

A huge effort is and has been made by the photovoltaic community to understand how various impurities and material defects affect the cell efficiency. Such knowledge is important when trying to make silicon of sufficiently high quality for the lowest possible cost.

Silicon solar cells typically have a dark bluish appearance, sometimes almost black, as shown in Figure 16. One can, however, also find sili-

[3] By 'conventional solar cell' we mean a cell where the active layer consists of only one type of solar cell material and where no light concentrating components are used.

con cells with other colors, as shown in Figure 17. Such cells have a non-optimal anti-reflection coating and will not deliver as much electricity as blue cells, but they leave an opportunity for architectonic variety.

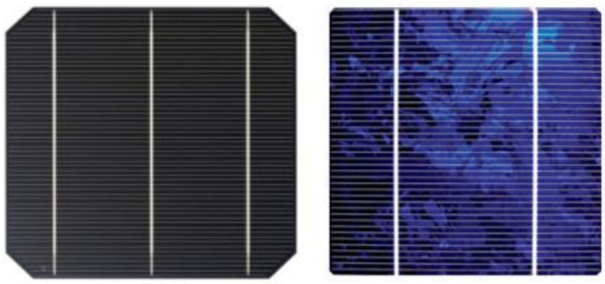


Figure 16: (Left) Mono-crystalline and (right) multi-crystalline silicon solar cells. It is possible to see the grains in the multi-crystalline cell.

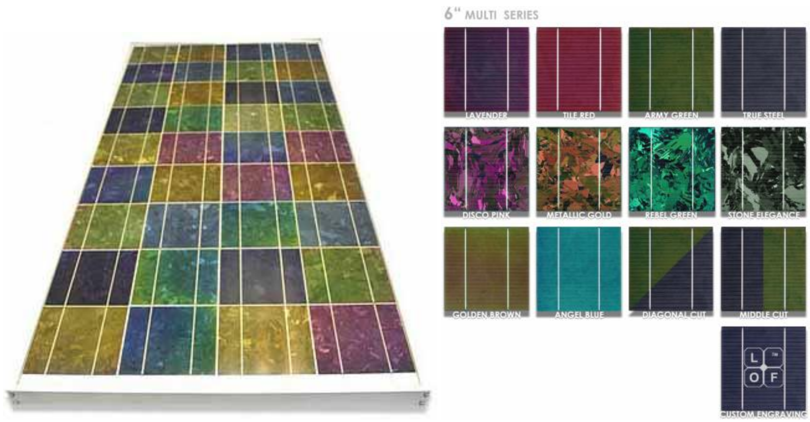


Figure 17: Silicon solar cells can be made in different colors by adjusting the antireflective coating. Sources: (left) www.energymasters.com, (right) www.lofsolar.com

For solar cells three forms of silicon are used: Mono-crystalline (mono-Si), multi-crystalline (multi-Si) and amorphous silicon (a-Si). Mono-Si has the highest quality. Large ingots (cylindrical blocks) where the atoms are regularly positioned as mentioned above, are produced in a very delicate process. These ingots are cut into thin plates, so-called wafers, which are processed into solar cells. A conventional crystalline silicon cell has a theoretical efficiency limit of 30 %, however, the laboratory record efficiency for silicon cells made of mono-crystalline material and illuminated by the AM1.5 spectrum is 25 % [Nelson, 2003], [Green, 2010].

In multi-Si each piece of silicon consists of several crystals or grains, typically a couple of centimeters wide. Within each crystal, the atoms are positioned regularly. At the grain boundaries, however, where the different crystals meet, this is not the case. This disorder reduces the quality of the material.

The advantage of multi-Si is that it can be produced in simpler and cheaper processes than mono-Si. Usually the production processes for multi-Si results in larger concentrations of impurities than in mono-Si, which further reduces the material quality. Despite these challenges, multi-Si with an acceptable quality is produced in large quantities and is, in fact, the most widely used solar cell material today.

The third main type of silicon used in solar cells is amorphous silicon (a-Si). In amorphous silicon, the atomic structure has no long range symmetry and the structure is not crystalline. The atoms are positioned more randomly, although some short range order exists due to the relative rigid bonding angles of silicon atoms. a-Si cells are so-called thin film cells. They are not made of wafers cut from blocks of raw material, but deposited by chemical methods as very thin layers on a substrate of glass, metal or plastic.

Amorphous silicon has a higher absorption coefficient than crystalline silicon, so thin layers of a-Si can absorb light equally well as much thicker slabs of crystalline Si. The amount of silicon used to produce an a-Si cell is typically 1 % of the amount of silicon used in crystalline cells, which brings down the material costs. The major drawback is that the films have many defects, and these result in low cell efficiencies. Over time, a-Si is also subject to light induced degradation. This means that light exposure reduces the material quality – obviously not a very attractive property in a solar cell material.

2.4.2 Gallium Arsenide

Gallium arsenide (GaAs) is the material that holds the current efficiency world record for conventional solar cells [Green, 2010]. Compared to silicon it has a couple of advantages. It has better light absorption so the cells can be thinner, and it performs better at elevated temperatures.

Unfortunately, high purity GaAs is very expensive. Although GaAs cells can be made thinner than silicon cells, the material cost for GaAs cells is 5 to 10 times higher than for silicon. Therefore, GaAs does not have an important role as a material for terrestrial solar cells. Some work is being done, however, to develop GaAs cells for use in light concentrating systems where tolerance of high temperatures is an important quality.

In space, however, weight and reliability is more important than price. GaAs has a high tolerance to radiation damage, which makes it attractive for use in space [Nelson, 2003].

2.4.3 Cadmium Telluride

Cadmium telluride (CdTe) is a semiconductor that absorbs light very well and is the thin film material with the second highest efficiency record (after CIGS, see next section). It can be monocrystalline or polycrystalline (multicrystalline with small grains). Practically all CdTe cells are manufactured by US-based First Solar. In 2009, CdTe PV modules constituted 11 % of the global production, only exceeded by silicon modules [GTM, 2010].

Unlike silicon, cadmium telluride is toxic if ingested. The toxicity of the material has caused concern about waste treatment and potential leakages into surrounding areas. But according to the U.S. Department of Energy, large scale use of CdTe solar panels will not represent a risk to health or environment [Ftenakis, 2004]. The cells are very well encapsulated in the modules and if the cells are recycled, disposal of waste CdTe can be avoided. CdTe cells are likely to be recycled because tellurium is a very rare element.

Problems with the quality of the CdTe crystals are a challenge for using this compound as a solar cell material. The poor quality is evident by the low record efficiency of 16.4 % and the typical efficiencies for commercial modules around 10 %. Despite the rather low efficiency, the price per Watt for commercial CdTe cells is highly competitive with the price per Watt for silicon cells due to lower manufacturing costs [Photon, 2010].

2.4.4 Copper Indium Gallium Diselenide

2 % of the world's production of PV modules is based on copper indium gallium diselenide (CIGS), making this the third most used solar cell material and the second most used thin film material [GTM, 2010]. CIGS is the thin film material with the highest cell efficiency record, 19.4 %.

As the name indicates, CIGS crystals are built up by four types of atoms. These atoms not only need to be regularly placed, as in silicon, but the right type of atom should also be placed at the right position in the crystal lattice. The correct atomic structure is not always achieved, especially not in mass production facilities. Therefore CIGS crystals usually have high defect densities.

These defects, together with some doping related issues, are the main reasons why commercial CIGS panels have efficiencies of only around 10 %. This is typically 5 % (absolute) less than silicon panels. Despite this lower efficiency, the relatively cheap production of CdTe makes CIGS economically competitive.

2.4.5 Multi Junction Cells

Solar cells with different band gaps respond differently to different parts of the solar spectrum. Optimum utilization of solar radiation is achieved by using multi-junction cells, where two or more cells are stacked on top of each other. The cell with highest band gap is on top and absorbs high energy photons. Photons with lower energy will be transmitted to the second cell, which has a lower band gap and can absorb photons with too low band energy to be absorbed by the upper cell. Multi-junction cells thus get a better utilization of the solar spectrum than conventional cells and harvest the solar energy more efficiently. Figure 18 shows how the three cells in a triple junction cell utilize different parts of the spectrum.

Triple junction cells made of gallium indium phosphate (GaInP), gallium arsenide (GaAs) and germanium (Ge) represent the most efficient type of solar cells today [Green, 2010]. Figure 19 shows the layered structure of such a triple junction solar cell. The complexity involved in deposition of several layers with high quality makes triple junction cells an expensive alternative. They are, like gallium arsenide cells, mainly candidates for use in space or in concentrator systems.

Dual junction cells with amorphous silicon and a layer of mono-, micro- or nano[4]-crystalline silicon is another multi-junction concept that can potentially be manufactured at lower cost. Today, such cells have low efficiency and are not produced in very large scale.

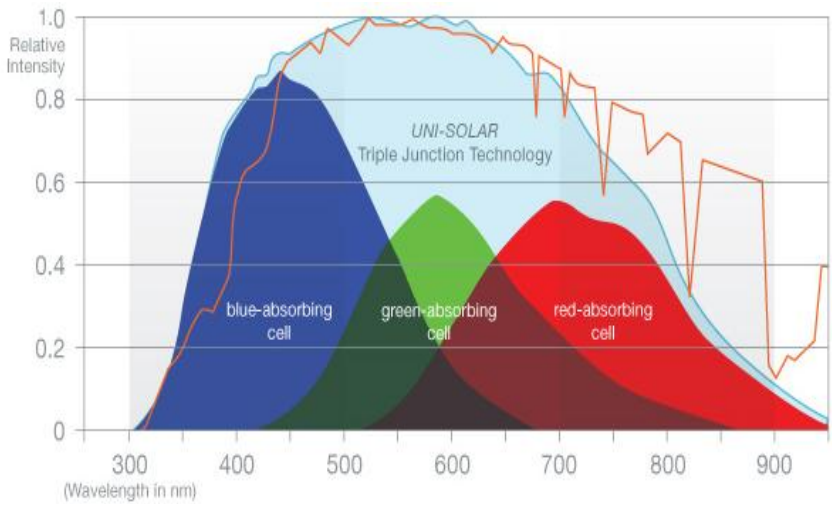


Figure 18: The three cells (blue, green and red) in a UNI-SOLAR triple junction solar cell absorb different parts of the solar spectrum (orange line)). Source: www.uni-solar.com

[4] Nano- or micro-crystalline silicon is a type of multi-crystalline silicon where the grain sizes are in the nanometer or micrometer range, respectively.

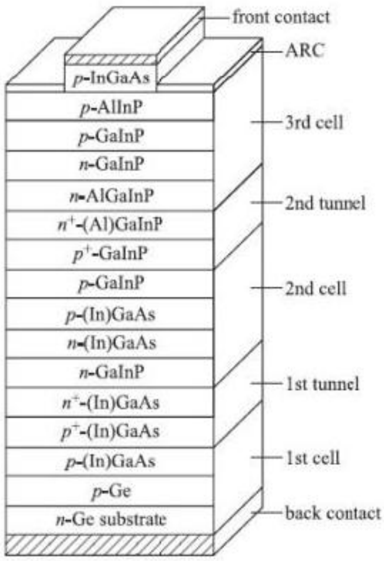


Figure 19: The structure of a highly efficient triple-junction solar cell. This cell has sub-cells of GaInP, GaAs and Ge. Layers of AlInP and InGaAs are also included, but only to improve the electron transport properties of the cell. Between the sub-cells there are so-called tunneling junctions that allow electrons to be transported from one cell to the next with little loss.

2.4.6 Dye-sensitized Solar Cells

Dye-sensitized solar cells are also known as Grätzel cells, after their inventor Michael Grätzel [Grätzel, 2011]. This cell type is a photoelectrochemical system based on a different operating principle than the cell types presented above. It consists of a semiconductor located between a photo-sensitized anode and an electrolyte. Grätzel cells can be made of inexpensive materials in simple processes and can have various colors or be flexible, as shown in Figure 20.

Like electrochemical batteries, Grätzel cells have an anode, a cathode and an electrolyte. In addition there is this light sensitive dye that release electrons upon absorption of light. The dye can be applied as a layer on nano-structured titanium oxide.

The liquid electrolyte is a drawback of dye-sensitized cells. It will freeze at low temperatures, causing the cell not to produce electricity, and expand at higher temperatures, which causes stresses on the encapsulation. Electrolyte problems are the major obstacle for large scale production of dye-sensitized solar cells. Research is going on to replace the liquid electrolyte with a solid.

Figure 20: Examples of dye-sensitized solar cells. Source: Fraunhofer ISE, Germany.

2.4.7 Organic Solar Cells

Like dye-sensitized cells, organic solar cells (OPV) are thin film technology resulting in flexible cells. In OPV, organic polymers or molecules, some are shown in Figure 21, absorb light and transport electrons. The carbon chains in these materials have alternating single and double bonds which allows them to conduct electricity. Just as in semiconductor solar cells, electrons are excited from low energy states to high energy states, but the electron transport and extraction mechanisms are different.

The active, organic layer is sandwiched between two plastic sheets. Low production cost and flexible modules make OPV an attractive technology. The efficiency of organic cells is low and the active layer suffers from rapid light induced degradation. Research on OPV focuses on improving absorption and transport properties as well as on reducing the light induced degradation to increase the lifetime of the panels.

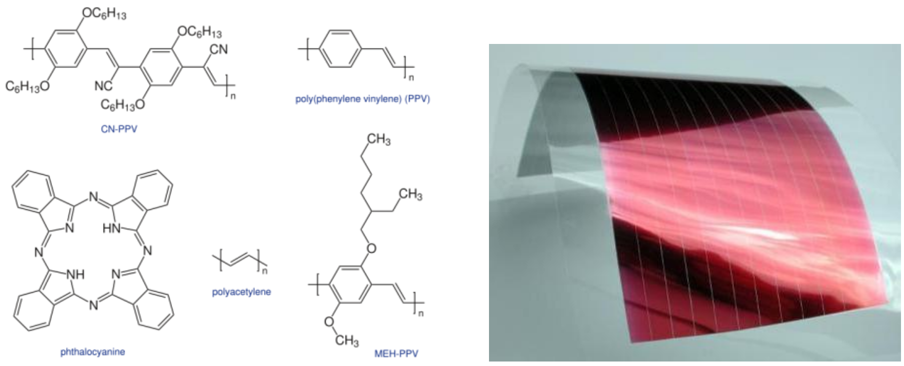


Figure 21: (Left) Examples of various molecules that can be used in organic PV. Source: http://en.wikipedia.org/wiki/Organic_solar_cell. (Right) A finished, flexible organic cell. Source: http://www.impactlab.com

2.5 Solar cell efficiencies

The highest efficiencies achieved for cells made from various materials are shown in Table 4. If several materials with different band gaps are stacked on top of each other, as in multi-junction cells, the theoretical efficiency limit increases. This is also the case if lenses or mirrors are used to concentrate the light onto a solar cell (Table 5). Some of the cell types in Table 5 therefore have efficiencies higher than 31 %, which was mentioned earlier as the theoretical efficiency limit for conventional cells. The overall world record is held by Spectrolab and their multi-junction cell, which is 41.6 % efficient when illuminated with light concentrated to 364 times the intensity of the sun.

NREL (National Renewable Energy Laboratories), the main institution for renewable energy and efficient energy use in the USA, has made a survey of the best available commercial PV panels [Roedern, 2010]. Mono-crystalline silicon panels from SunPower top the list with an efficiency of 19.3 %. Efficiencies of some other types of panels are shown in Table 6.

The record efficiencies of modules are always lower than those of single cells due to losses related to the encapsulation, wiring, etc. In addition, commercial cells and modules always have lower efficiencies than record cells and record modules. The energy that is delivered to the end user is reduced further by losses in systems components like the inverter, which will be described later.

Table 4: Record efficiencies for a various solar cell materials and combinations of materials when illuminated by the AM 1.5 spectrum (corresponding to 1000 W/m^2). Source: [Green, 2010].

Cell material	Efficiency, AM 1.5	Band gap (electron volt)	Manufactured by
Multi-junction GaInP/GaAs/Ge	32.0 ± 1.5 %	1.88/1.41/0.67	Spectrolab, USA
Multi-junction GaInP/GaAs	30.3 ± ---- %	1.88/1.41	Japan Energy, Japan
GaAs (crystalline)	26.4 ± 0.8 %	1.41	Fraunhofer ISE, Germany
Multi-junction GaAs/CIS (thin film)	25.8 ± 1.3 %	1.41/1	Kopin/Boeing, USA
Si (mono-crystalline)	25.0 ± 0.5 %	1.12	UNSW, Australia
Si (multi-crystalline)	20.4 ± 0.5 %	1.12	Fraunhofer ISE, Germany
CIGS (thin film)	19.4 ± 0.6 %	1.15	NREL, USA
CdTe (thin film)	16.7 ± 0.5 %	1.44	NREL, USA
Dye sensitized	10.4 ± 0.3 %		Sharp, Japan
Si (amorphous)	10.1 ± 0.3 %	≈ 1.7	Oerlikon Solar, Switzerland
Organic polymer	5.15 ± 0.3 %		Konarka, USA

Table 5: Record efficiencies for various types of solar cells when the light is concentrated by lenses or mirrors. The concentration factor X tells how many times the light is concentrated (for instance, X = 364 means that the insolation is 364 * 1000 W/m2 = 364 000 W/m^2).

Cell material	Efficiency, concentrated light	Band gap (electron volt)	Manufactured by
Multi-junction GaInP/GaAs/Ge	41.6 ± 2.5 % X = 364	1.88/1.41/0.67	Spectrolab, USA
Multi-junction InGaP/GaAs/InGaAs	41.3 ± 2.4 % X = 343	1.88/1.41/1	NREL, USA
GaAs (crystalline)	29.1 ± 1.3 % X = 117	1.41	Fraunhofer ISE, Germany
Si (crystalline)	27.6 ± 1.0 % X = 92 X	1.12	Amonix, USA
CIGS (thin film)	21.8 ± 1.5 % X = 14	1.15	NREL, USA

Table 6: Efficiencies of the best production line for PV modules.

Technology	Manufacturer	Efficiency
Mono-Si	SunPower, USA	19.3 %
Multi-Si	Kyocera, Japan	14.5 %
CIGS	Solibro (Q-Cells), Germany	12.0 %
CdTe	First Solar, USA	10.8 %
a-Si	Sharp, Japan	10.0 %

2.6 PV systems

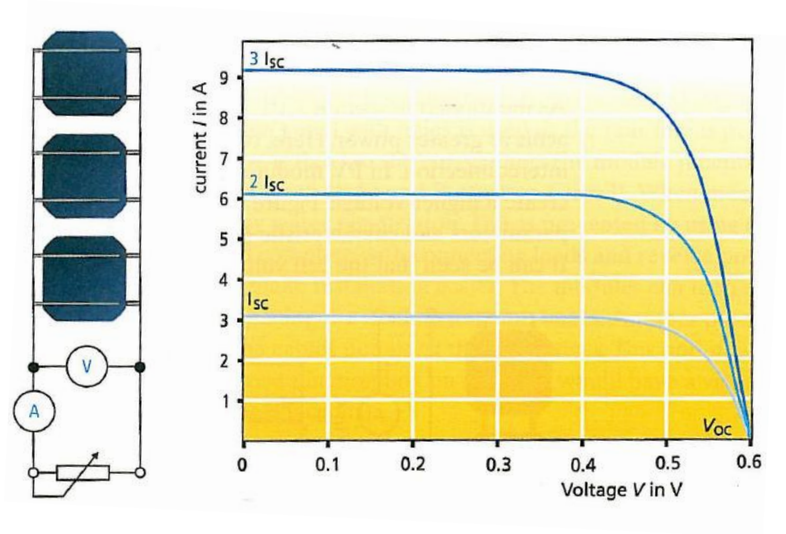
PV systems can be either grid-connected or stand-alone. In grid-connected systems the electricity grid is used for energy storage. When the solar panels produce more electricity than the local demand, surplus electricity is delivered to the grid. Whenever the local electricity demand exceeds the local production by the PV system, the needed electricity is bought from the grid.

Stand-alone systems are not connected to the main grid, and use batteries for energy storage. The solar panels are the same regardless of system type, but the electrical components used to receive, distribute and store energy obviously have differences. In the following sections, the various parts of PV systems are described.

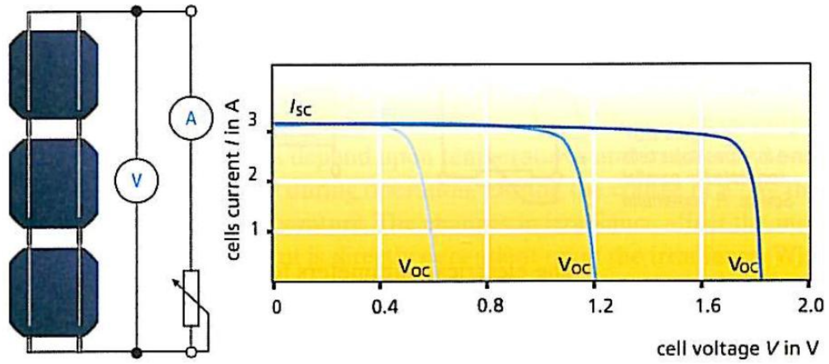
2.6.1 Modules and arrays

The voltage of a single solar cell is too low for use in common electric devices. Silicon cells typically have an open circuit voltage of around 0.6 Volts. To increase the voltage, several cells are series connected and assembled in modules. The modules in REC’s AE-series, for instance, consists of 60 series-connected cells and have an open circuit voltage of around 36 Volts. Single modules can have effects ranging from a few Watts (small modules) to above 300 Watts (large silicon modules). By connecting modules in series and parallel one can further increase the voltage and current.

Figure 22 shows how the IV-curves change when identical cells are connected in a) parallel or b) series. In parallel, the current of the system equals the sum of the currents from the individual cells. The open circuit voltage of the system will equal the open circuit voltage of one single cell. When connected in series, the voltages of the individual cells are summed while the short circuit current equals the short circuit current of a single cell.



a)



b)

Figure 22: Three solar cells in parallel gives three times the current of one cell. b) Three cells in series give three times the voltage of a single cell. Source: [DGS, 2008].

PV modules are laminated structures. The materials that are used can vary, but most lamination techniques follow the same main principles. The cells are placed between two sheets of a polymer material like ethylene vinyl acetate (EVA). On top of this there is a highly transparent glass plate, typically 4 mm thick. At the bottom there is a plate of an opaque film, a metal plate or a second glass plate. It is very common to use an opaque film of polyvinyl fluoride, a strong and durable material that has the commercial name Tedlar.

In the lamination process the structure is heated until the polymer sheets melts. The layers are then pushed together. The temperature and other process parameters must be carefully adjusted to achieve high quality laminations without air bubbles. Upon cooling the polymer material congeals and glues the structure.

2.6.2 Shading

The current flowing through a chain of series-connected elements in an electrical circuit in steady state has to be the same throughout the whole chain. This is a fundamental physical principle that is important when series-connecting solar cells. If one solar cell in a string of series-connected cells gets shaded, this cell will produce less current than the other cells. Due to the above-mentioned principle, the current is reduced not only in the shaded cell, but in the whole string.

If one cell is completely shaded, the other cells in the string will impress a negative voltage on the shaded cell. In long strings this voltage can be quite large, and the shaded cell might reach its reverse breakdown voltage (see Figure 14). Instead of delivering energy, the cell will be consuming energy from the unshaded cells and get heated. This might eventually damage the cell through the occurrence of hot spots, small areas that are permanently scarred by overheating.

To reduce negative impacts of shading it is common to include bypass diodes. Taking REC's AE-series again as an example, each module has 3 bypass diodes. These diodes are connected in parallel with 20 cells each in a configuration similar to that shown in Figure 23.

In panels with bypass diodes, the term string is used for sections bypassed by the same bypass diode, rather than for a complete chain of series-connected cells. If a cell in one string is shaded, the current from the other strings can go via the bypass diode in parallel to the string with the shaded cell. The cells in the string containing the shaded cell will not deliver any energy, but the other strings can work optimally.

Figure 24 shows examples of IV-curves with and without bypass diodes. Remember that the power of the module is the current multiplied by the voltage, which can be visualized by the size of a rectangle as shown in the figure. A larger rectangle, which means more energy, can be placed under the curve with bypass diodes than under the curve without bypass diodes.

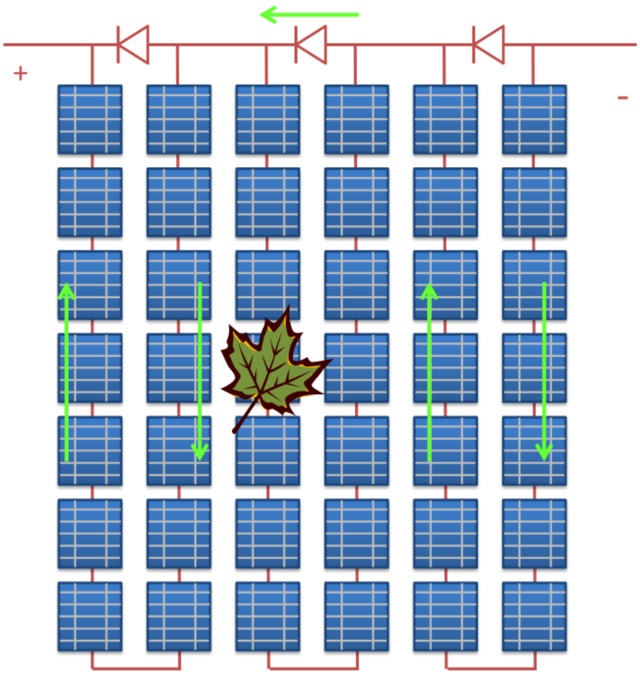


Figure 23: PV module with three bypass diodes dividing the panel into three strings. A large maple leaf is shading one cell, causing the current to bypass one of the strings as indicated by the green arrows.

In addition to increasing the output power, the bypass diodes also prevent the module from overheating the shaded cell. Ideally, each cell should have a bypass diode. All un-shaded cells would then be allowed to operate optimally. The cost and complexity of the wiring prevents this solution from being used in practice. It is more typical to have around 20 series-connected cells in each string.

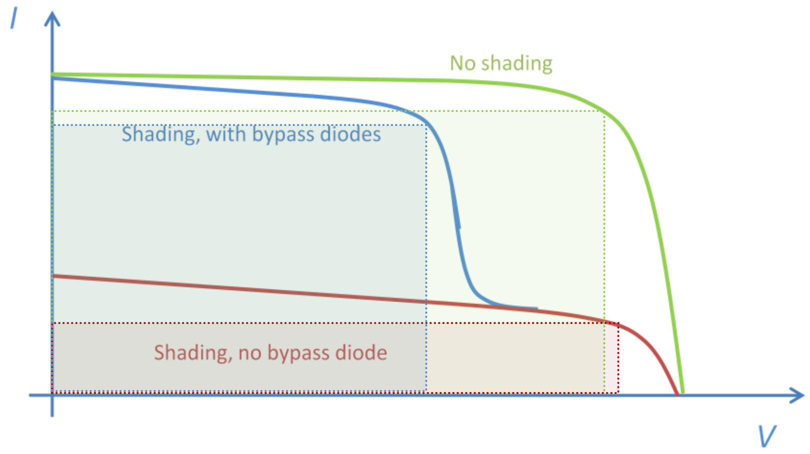


Figure 24: Example of IV-curves for an unshaded module as well as shaded modules with and without bypass diodes. The shaded panel with bypass diodes will deliver more energy than the one without bypass diodes.

For planners and installers of PV systems it can be very important to be aware of the fact that shading of one cell reduces the energy production in other cells. If shading is unavoidable, the module should preferably be oriented so that the shaded cells are in the same string.

Shading a few cells in several strings might lead to an unnecessarily large drop in the electricity generation. In general, thin film modules are less sensitive to partial shading because the individual cells are usually larger than those in wafer based silicon modules. An example is shown in Figure 25. Here the power output of the thin film module is reduced by a factor corresponding to the shaded fraction of the module area. The output of the silicon module, however, is halved because some individual cells are completely shaded, causing one of two strings to be bypassed.

The bypass diodes are usually placed in the connection box where the connection cables enter the module. This allows them to be easily replaced. Some module designs have the bypass diodes embedded in the module itself. This allows more diodes to be easily installed in the module but makes them impossible to replace if they should be damaged by overvoltage caused by lightning strikes in nearby areas or if the module is accidentally connected with the wrong polarity.

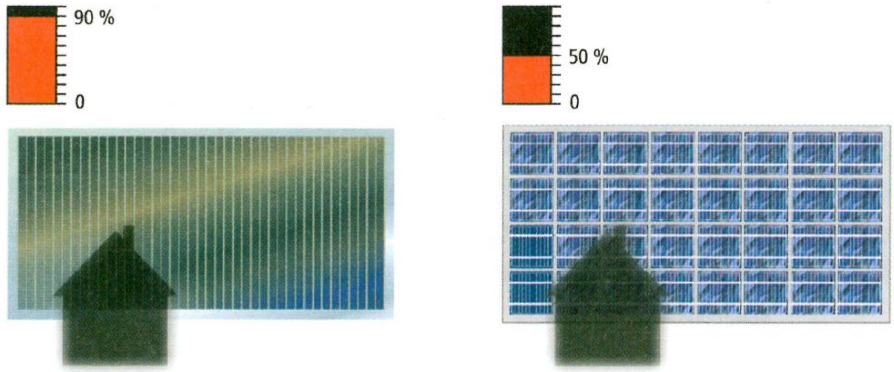


Figure 25: Thin film panels (left) with stripe shaped cells can be more tolerant to partial shading than traditional silicon panels (right). None of the thin film cells are completely shaded, while two of the silicon cells are completely shaded. This causes half of the cells in the Si-panel to be bypassed. Source: [DGS, 2008].

2.6.3 Grid connected systems

The energy production from solar cells only occasionally matches the power consumption in the building where it is installed. In a grid connected system, excess energy can be sold to the electricity company when the PV-panels produce more electricity than needed in the building. At times when the energy demand in the building is larger than the production, the building gets the additional electricity from the grid.

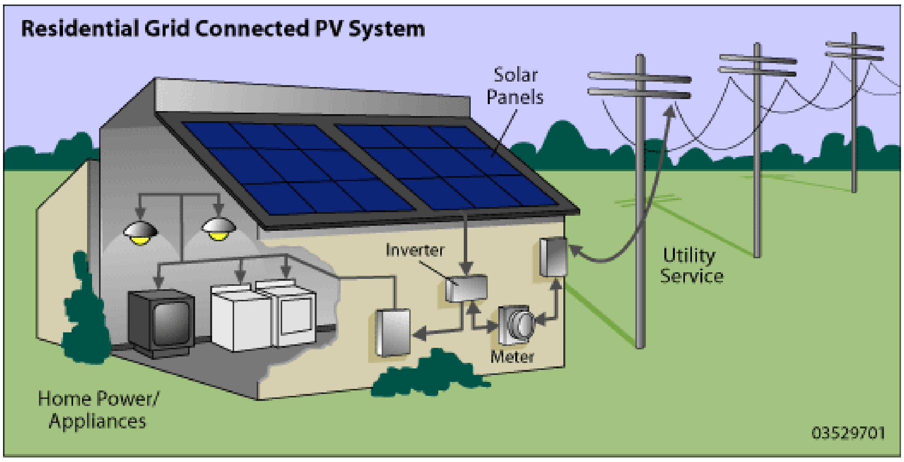


Figure 26: Sketch of a grid connected building integrated PV-system. Source: www.energyeducation.tx.gov

A residential grid connected PV system is illustrated in Figure 26. A grid connected system usually consists of the following main components [DGS, 2008]:

- Solar cell modules (in series and/or parallel)
- Connection box with good electrical insulation and protection
- Main switch for the DC connection (the current from the cells)
- DC/AC inverter
- AC cables
- Electrical cabinet with power managing controller, grid connection and meters for bought and delivered electricity.

The components of a grid connected system without battery back-up are shown in Figure 27. A number of modules are connected through a grounded connection box/circuit combiner in a configuration that gives the desired current and voltage. The DC current from the connection box is connected to the DC/AC inverter which transforms direct current to alternating current with a voltage and frequency matching the grid system. Various switches and fuses are used to control and protect the components.

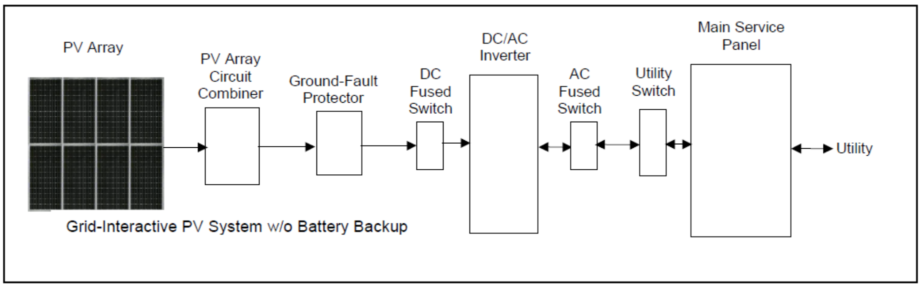


Figure 27: Main components in a grid-connected PV-system without battery reserves. Source: [CEC, 2001].

The utility switch is important if the grid is down due to snowfall, thunderstorm or for other reasons. It prevents the PV-system from delivering electricity to the grid when the grid is down. Isolation of a PV system due to grid problems is called islanding. The electricity exchange is supervised and controlled from a main service panel that connects the PV-system to the grid and to the electricity infrastructure of the building, as well as measures the energy flow to and from the grid.

Adding a backup battery to the system assures that the building has electricity even if there are grid problems and no sunlight. As shown in Figure 28 it also increases the complexity of the system. Battery charge controllers and more complex system controllers have to be included to balance the various components.

In situations where the energy from the backup battery has to be used, a critical load sub-panel can be used to manually switch on and off important and unimportant circuits to prevent wasting energy on less critical equipment or building sections. It should be noted that batteries are relatively expensive, need regular maintenance, and have a limited lifetime.

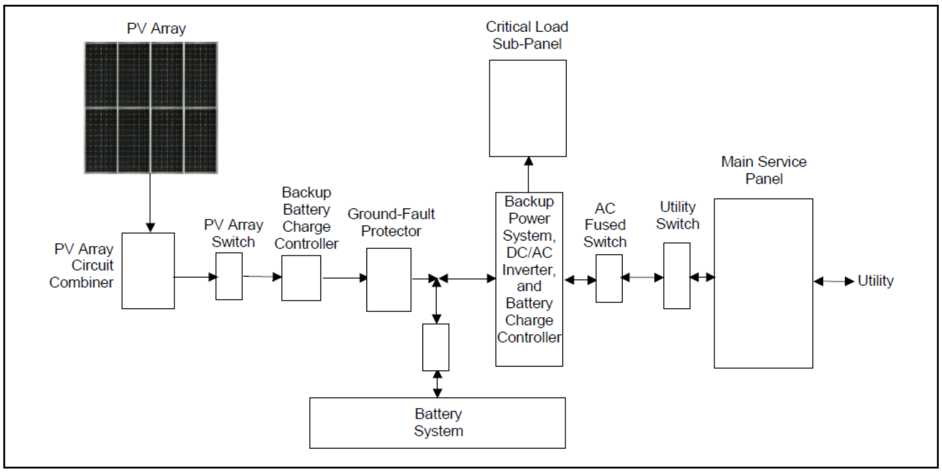


Figure 28: Main components in a grid-connected PV-system with battery backup. Source: [CEC, 2001].

2.6.4 Stand-alone systems or off-grid systems

Stand-alone systems are not connected to the grid, and normally use batteries for energy storage. Energy losses are unavoidable in batteries and batteries are expensive. Conversely, a connection to the grid can also be very expensive, if the distance to the closest connection point is long and the energy demand is small. In remote locations, stand-alone PV systems can therefore be an advantageous solution. The use of PV systems in vacation cottages has already been mentioned. Other important stand-alone PV systems are for meteorological stations, marine- or traffic-related applications, and electrification of rural villages in developing countries.

The configuration of a stand-alone PV system will vary from case to case, but one solution is shown in Figure 29. All systems need a PV array, a controller and a battery. The controller manages the energy flow between the components. It is particularly important that the controller can identify the charge status of the battery to prevent over-charge or over-discharge.

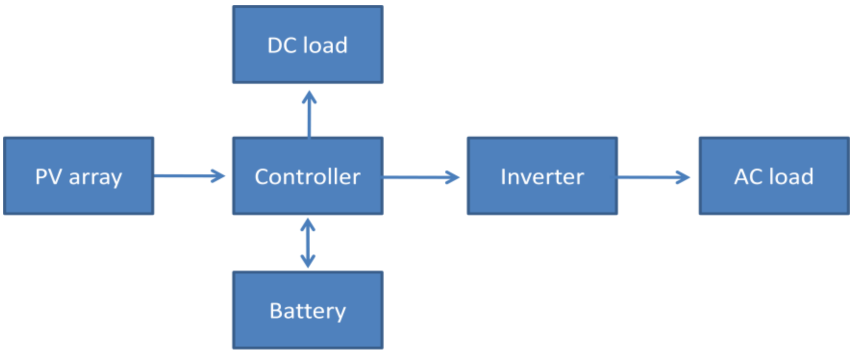


Figure 29: The main components of a stand-alone PV system. Switches and fuses are not shown, but should be included to protect the system.

Many modern electronic devices, like PCs and mobile phones, run on low voltage direct current. Since energy losses are unavoidable when transforming electricity from DC to AC or vice versa, it can be favorable to have a separate DC circuit for such equipment. This circuit gets its energy directly from the battery without conversion. On the other hand, most electric equipment, including all kinds of devices with electro motors, requires alternating current. An inverter that can serve an AC load is therefore included in many stand-alone systems.

2.6.5 Inverters

Correct dimensioning of the DC/AC inverter (or inverters) is important to optimize the system. It is possible to have several smaller inverters or one large inverter [DGS, 2008]. Large central units are suitable for systems with modules of the same type, with the same orientation and where partial shading is not a big issue.

An advantage of smaller units is that the system will get a better response to small variations between different parts of the system. If a panel is shaded it will affect the output from the panels connected to the same inverter. With several inverters the number of influenced panels can be reduced. Many small inverters also allow most of the system to operate as usual if one of the inverters is not working.

Some years ago the DC voltage from solar panels was lower than today, resulting in thick cables and relatively large transmission losses. This situation favored smaller decentralized units. Today the voltage at the DC-side is usually the same or higher than the AC-voltage. This reduces the cable thicknesses and transmission losses, which makes larger centralized inverters more attractive.

To draw a maximum amount of power from the PV-panels the inverter should be a bit oversized in sunny areas. Its capacity should typically be around 110 % of the rated power of the connected array of PV-modules. In less sunny areas, the most economical solution is found with an inverter that is slightly undersized. In such areas PV-panels very often operate at lower illumination values than the reference irradiation of 1000 W/m^2. In Central Europe, for example, the optimal inverter capacity is around 90 % of the rated power of the PV-system [Mondol, 2006].

Good inverters have an efficiency of around 95 %, but this varies with parameters like input voltage and temperature as well as the over- or under-dimensioning of the system. All inverters have an optimal voltage where its efficiency is peaking. If possible, the voltage at the maximum power point (MPP) from the modules should match this optimal voltage at typical operating temperatures.

The energy loss from the inverter is dissipated as heat. The inverter should therefore be placed in a location where it will not cause an increase in the demand for cooling. Some inverters are made for outdoor mounting. Inverter failure is the most common reason for shutdowns of PV-systems. Buying a well-dimensioned, high quality inverter and a good service agreement can consequently be considered a good investment.

2.7 Installation, operation and maintenance of PV-systems

2.7.1 Design and planning

Before the installation of a PV-system the following points should have been checked:

- The installation site (roof/wall) is suitable for mounting the panels with a good orientation without (too many) shading objects.
- The area of the site is adequate.
- The building can bear the extra weight.
- The mounting will not cause perforations that may result in water leakages.
- Grounding of the system is possible without causing installation problems.
- Cable lengths are kept to a minimum to avoid transport losses.
- Adequate protection of all components (batteries, inverter, connection boxes, etc.)
- The system will be inspected and approved according to all relevant rules and regulations.
- If the system is to be used for profiling or marketing, it is advantageous to have capabilities for data acquisition, data processing and presentation of data on the internet or in other media.

Some further advice for a successful installation are [Prasad & Snow, 2005]:

- Position the modules wisely with respect to bearing structures. If the system is roof-mounted, pay careful attention to where the mounting will perforate the outer shell of the building. The position of water and ventilation pipes should be well known before installation. Try to position the panels in a symmetric way that suits the structure of the building. Symmetric grouping of the panels makes the mounting and wiring easier.
- Estimate the impact of shading using the Solar Pathfinder or a similar kit. (http://www.solarpathfinder.com). Do not forget to take chimneys and flues into consideration. Evaluate other loca-

tions for the system if shading issues are significant. If impossible to avoid, modules in the same shading zone should be grouped and connected to the same inverter.

- Measure the distances between the various components and make a sketch for the entire system, both structural and electrical. This should include PV modules, ducts, connection boxes, inverters, critical load panel, main panel, switches and, if included in the plans, monitoring elements.

2.7.2 Installation

During installation on a roof, extra care should be taken to avoid damaging the roof. The producer of the roof cover should be contacted to sign off the installation procedure to reduce the risk of damage and avoid warranty issues. After installation the roof should be inspected together with the producer or builder of the roof. At critical points the stress imposed by the panels on the roof can be large. It must be determined that this stress will not exceed the limits of the roof.

Tilted panels mounted on a flat roof need extra support to withstand strong winds. The roof itself also has to bear the load of the solar panels when they are exposed to heavy wind. The mounts should be stabile, durable and affordable.

Installing systems including batteries is more labor intensive than ordinary systems [Prasad & Snow, 2005]. Batteries add an extra element to the dimensioning of the system, and it can be advantageous to use standard kits where the producer has already balanced the various components. This is likely to reduce the risk of problems during installation, start up and operation.

2.7.3 Operation

During operation, solar panels are not likely to cause any damage to the building although extreme winds can rip off parts and potentially damage buildings or other nearby objects, including people. The installer should therefore have documented that the chosen solution will not be damaged by any winds that can be expected in the particular area.

A survey in Germany [Lukamp, 2002] has concluded that inverter failure is the most important reason for operational stops in PV systems. Certified inverters with good warranties, e.g. 10 years, should therefore be selected to minimise the risk for problems during operation. A maximum time for reparation or replacement of defective inverters should be specified in the service agreement with the supplier. Local suppliers with short response time might be an advantage.

Other reported errors include corrosion of cables and contacts, mechanical defects, de-lamination of panels or jointing materials. [NREL, Defects]. However, PV systems are generally considered to be reliable, low-maintenance systems with long lifetimes.

Most producers of PV panels today have long-term extensive warranties. Several types of warranties are available. *Product warranties* for panels are typically 20-30 years, while batteries and inverters often have 5 to 10 year warranties. For panels it is common to specify the warranty as an *effect warranty*. A typical effect warranty states that the panel should maintain 90 % of its initial power after 10 years and 80 % after 25 years.

System warranties typically guarantee a certain production of alternating current from the system under standard test conditions after five years. It is also possible to get *energy warranties.* This means the system should produce a pre-defined amount of energy in a certain time. Energy warranties give the customer an economic safety net, but are not commonly provided by PV suppliers today.

2.7.4 Maintenance

As mentioned above, PV systems are generally known to be reliable and do not need much service or maintenance. A few suggestions, however, are as follows [Prasad & Snow, 2005]:

- Wash the panels when a visible amount of dust or precipitates is accumulated.
- Inspect the system periodically to be assured that all cables and other parts are intact.
- On a sunny day around the 21st of March or the 21st of September (solar solstice), check the performance of the system to see if it is

close to last year's performance. Log the readings and watch out for large changes, which can indicate errors.

2.8 The energy output from PV systems

A number of factors can influence the output from PV panels causing discrepancy between delivered energy/power and the specifications from the manufacturer. The most important factors are [CEC, 2001]:

- *Standard Test Conditions:* The rated power of PV modules is the power under standard test condition (STC). That is 1000 W/m^2 insolation spectrally matched to the AM1.5 spectrum and a module temperature of 25 °C. The actual conditions experienced by a panel in the field can deviate dramatically from this, and will only occasionally coincide with STC. The efficiency of a PV module increases with the insolation and decreases with the temperature.
- *Statistical variations:* The power output of mass produced panels of the same model varies within a certain interval. A panel rated at 100 W ± 5% can deliver 95 W under STC and still be considered a 100 Watt panel.
- *Accumulation of dirt*: Dirt reduces the power output of PV panels. Rainfall will usually wash away most dust and dirt from PV panels, but accumulation of dust and dirt can typically give reductions in the output of around 5 %.
- *Module mismatch:* The maximum power output from a PV system is always lower than the sum of the maximal output from the individual panels. Small differences between the panels make it impossible to have all of them at their individual maximum power point. The loss due to this can typically be around 2 %.
- *Transport losses*: There will always be some resistive losses in the cables in the PV system. It is hard to keep these losses under 3 %.
- *Inverter losses:* Losses in the inverter typically leads to another loss of 5 – 10 %.

When dimensioning PV systems it is important to base the calculations on actual power output. This can vary significantly between different locations. Experience from nearby systems or field measurements at the actual location are usually very useful.

3 Examples of BIPV applications

Photovoltaic modules on buildings can be mounted on rooftops or walls as external components on a building, or they can be completely integrated in the building structure as a façade element. Building integrated photovoltaics have many advantages compared to externally mounted systems, including [Prasad & Snow, 2005]:

- The building acts as a supporting structure for the PV system.
- The photovoltaic components replace other façade elements.
- The man-hours required to install the BIPV system replaces installation of traditional building elements.
- A well integrated architectural design makes a building more attractive and might increase its value.
- BIPV is an effective way to show the world that you care about environmental issues.

One of the first issues to address when considering the use of BIPV is how to combine electricity generation with solar lighting and passive heating. It is much more energy efficient to use daylight as indoor illumination than a lighting system powered by electricity from a PV-system. It is also much better to let sunrays into a building for room heating than using PV-generated electricity to run electrical heaters. An easy and traditional way to balance this is by supplying the building with an appropriate window area. This can, however, lead to non-uniform lighting and heating, which can be a problem on sunny days.

Semitransparent PV-modules can be a good solution for combining electricity generation with homogeneous natural lighting and passive heating,. Such modules typically consist of interconnected opaque solar cells embedded in a polymer material sandwiched between two transparent glass plates. By varying the distance between the cells, one can adjust the overall transparency of the module. Examples of this are shown in Figures 30, 31 and 32.

A second way to construct semitransparent modules is to make patterns of holes in the cells. This can be done by laser drilling, which is particularly interesting for cells made of amorphous silicon and other thin film materials. Finally, it is also possible to manufacture semitransparent liquid dye solar cells. Such cells can be made in different colors and give nice visual effects.

Figure 30: The inside of Solar Office Doxford International, Sunderland, UK. (Source: Denis Gilbert Photographer).

Figure 31: Fire station in Houten, Netherlands, designed by Philippe Samyn. (Source: Novem, Hans Pattist).

Figure 32: A wall with liquid dye solar cells. Source: CSIRO Energy Centre in Newcastle, Australia.

As already discussed, the orientation of a solar panel is important for its energy output. BIPV on south facing walls makes sense in northern areas, but not close to the equator where roof mounted systems would be better. As a rule of thumb, the tilt of a panel should be approximately the latitude of the location where it is installed [Prasad & Snow, 2005]. This is less accurate in northern areas. The exact optimal tilt can be found with simulation tools like PV-GIS (http://re.jrc.ec.europa.eu/pvgis/). In Kristiansand the optimal tilt is 38 degrees, which is less than 58 degrees suggested by the rule of thumb. As can be seen from Figure 9, however, smaller deviations from the optimal tilt do not have a major impact of the yield of the solar panels.

In the previous chapter it was shown that zenith angles between 20 and 60 degrees can collect over 1000 kWh/m^2 per year in Kristiansand (Figure 9). For BIPV, a tilted position can be achieved by means of inclined walls. An example is shown in Figure 33. Another way to get the desired tilt is to have solar panels on window shades like those in Figure 34 b).

Facade systems can be both passive and active [Glassportal, 2010]. *Passive window systems* can reduce heat loss as well as providing shade to prevent overheating to various degrees. *Active systems* can integrate the façade with both ventilation and heating properties. The latter is also sometimes called hybrid façades.

Active façades can have integrated PV cells supplying the ventilation system with electricity, and have solar water heaters for tap water. Figure 34 shows some façade elements where the producer has integrated PV-cells in various aesthetic and functional structures.

Figure 33: The exterior of the Solar Office Doxford International. (Source: Denis Gilbert Photographer.)

(a) (b) (c)

Figure 34: (a) Façade element with integrated amorphous thin-film PV modules (Schüco FW 50+.SI). (b) Window shades with solar cells. (c) Façade with crystalline silicon cells and poor thermal properties (Schüco USC 65). Source: [Schüco, 2009].

Some larger BIPV demonstration systems have been installed also in Norway. One example is the opera house in Oslo (Figure 35), which has 300 m^2 of PV modules installed in a 450 m^2 south facing glass façade. These numbers actually make the system one of the world's largest glass facades with integrated solar cells according to Fornybar.no [Fornybar, 2010]. Only 50 % of the module surface is active, light-collecting area. The modules are made of high-quality monocrystalline silicon cells with a cell efficiency of 16 %.

The generating power of the opera house system is 35 kW at standard conditions (STC). The system is expected to deliver approximately

20,000 kWh per year, which is the annual demand for an average Norwegian household. The system is grid-connected, which means excess energy will be delivered to the electricity grid. The solar cells also function as sunshade screens, preventing overheating on sunny summer days.

Another example of a large BIPV system, the Oseana culture centre currently being commissioned in Os outside Bergen, is included in section 4.3.6

Figure 35: The new opera house in Oslo. Solar cells are integrated in the triangular, south facing glass façade. Kilde: [Fornybar, 2010].

The largest grid-connected PV system in the Nordic countries is installed by ABB on the roof of their factory in Finland. The rated capacity of this system is 181 kW, which will give an annual production of around 160,000 kWh [ABB, 2010].

Another BIPV example is the new headquarter for the Syracuse Center of Excellence (http://www.syracusecoe.org), which was opened in New York in March 2010. The building is supposed to be a living laboratory and a platform showing technological innovations. The southward facing façade includes an area dedicated to the testing of building envelope and window systems.

The Syracuse center has installed an integrated concentrating combined PV and heating system, shown in Figure 36, which is currently being tested. This active façade consists of several sun tracking lenses that concentrate the sunlight on small solar cells. The light also heats the cells, and some of this heat is extracted by thermal collectors. Improved daylight quality and less overheating are benefits provided by this structure.

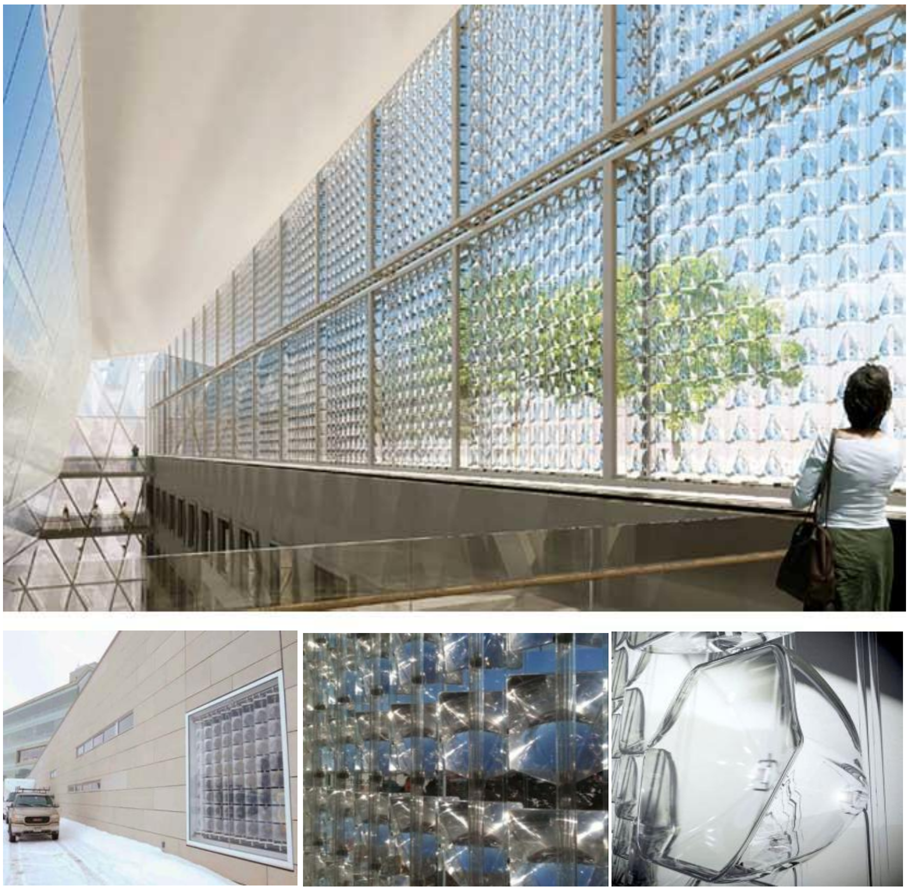


Figure 36: Façade with an integrated concentrating solar cell system. The system delivers both electricity and heat. Source: [Jetson Green, 2010].

The advances within the BIPV field have been extensive lately, so below follows some further examples of building integrated systems, ranging from the most practical to the more exotic.

Figure 37: PV-thermal hybrid system, from Atlantis Energy Systems (http://atlantisenergy.com). The cells constitute a water proof roof cover. Heat is collected from the back side of the PV panels and is used for water heating.

Figure 38: 'Sunslates' are roof tiles with solar cells. From World Technology Corporation (http://www.sunslates.net).

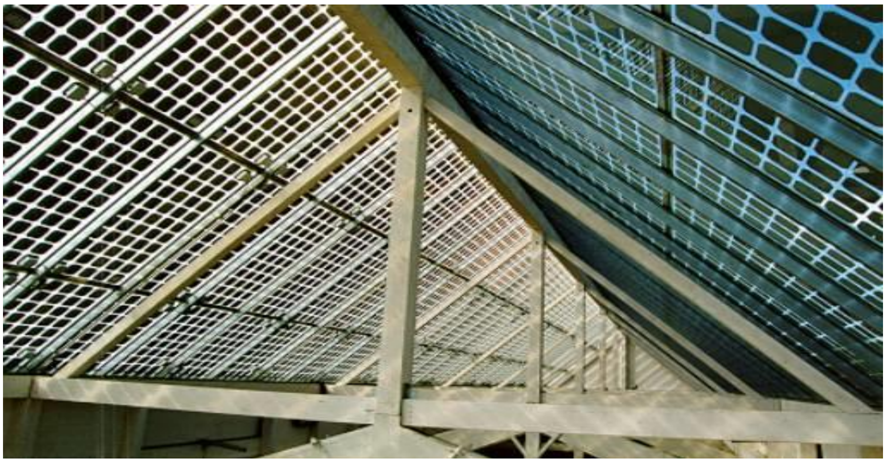


Figure 39: PV solution combining electricity generation and day lighting. From Atlantis Energy Systems (http://atlantisenergy.com).

Figure 40: Melbourne university, Australia. (Source: Sustainable Technologies International, Australia.)

Figure 41: Solution for PV combined with daylighting, atrium in Kankakee from Atlantis Energy Systems (http://atlantisenergy.com).

Figure 42: Solar cells embedded in colored glass, from Atlantis Energy Systems (http://atlantisenergy.com).

Figure 43: Shading of parking lot with semi-transparent PV modules, from Atlantis Energy Systems (http://atlantisenergy.com).


Figure 44: Sun screening of window by solar cells from Atlantis Energy Systems (http://atlantisenergy.com).


Figure 45: 'Megaslates' PV-panels on the roof of a house. From World Technology Corporation (http://www.sunslates.net).

Figure 46: The Coca-Cola building in Los Angeles is equipped with 375 kW flexible thin film PV panels from UNI-SOLAR. The photo shows the panels being rolled out on the roof. Source: www.uni-solar.com.

Figure 47: Rome Trade Fair in Italy has 1400 kW PV installed. The modules are flexible thin film panels from UNI-SOLAR. Source: www.uni-solar.com.

4 Policy framework and development incentives

4.1 The general scenario

The framework for renewable energy development is often understood as the national authorities' measures to improve the competitiveness of such energy production.

Generally, renewable energy has relatively high entry costs and low operating costs compared to other energy alternatives. Globally, solar energy competes primarily with energy production based on coal, oil, gas and nuclear power. In a global perspective, the energy produced by hydroelectric plants is small, although it constitutes a high fraction in some countries such as Norway. Of these sources, coal, oil and gas have low entry costs due to a well-developed market and infrastructure, and have also had an advantage in input availability in a short-term market.

Despite the fact that renewable energy solutions until now often have been more expensive than traditional sources, an increasing number of nations are choosing market-based management to encourage the renewable energy sector. This means that different energy sources then have to compete on price and quality in the same market. This is aimed at ensuring sustainable development based upon profitable and renewable projects that survive when the subsidies are phased out.

In order to achieve this objective, it is important that politicians ensure that environmentally friendly solutions can compete by having a competitive framework for renewable energy promotion. Political will is therefore necessary in Europe to facilitate development of renewable energy. There are, however, many different approaches that are used to achieve this objective.

In order to have specific regional relevance, this report will focus on political actions that will facilitate renewable energy development in Norway, Sweden, Denmark and Germany. Furthermore, this work attempts to understand how these countries are influenced by each other through the European Union (supra-national level), and how the supra-national goals can be achieved thought bilateral agreements, e.g.

agreement on green certificates between Sweden and Norway. In this chapter we will describe the role of the European Union (EU) in terms of its significant influence on policies in Europe, and in terms of the effect it has for the political framework for BIPV.

4.2 EU: Supra-national regulations and incentives

Since the energy crisis in the 1970s, most industrial nations have launched programs to develop renewable energy solutions. However, with the return of low oil prices the interest and incentives to develop renewable energy technologies to realistic alternatives was diminished and virtually halted in many countries. It was the drive for effective reduction of CO_2 emissions that renewed political focus on developing cleaner renewable energy resources, with the aim to develop large-scale commercial applications based on technological improvements and benefits from economies of scale.

In 2009, renewable energy delivered 19 % of the global *final* or *end user* energy consumption, where traditional biomass contributed 13 %, hydropower 3.2 % and the sum of other sources only 2.7 %. Of the global electricity production, 15 % was from hydropower while 3 % was generated by other renewable non-hydro installations [REN21, 2010]. The IEA's World Energy Outlook 2010 foresees in its Alternative Policy Scenario that the energy harvested from renewable sources will triple by 2035, increasing the share of renewables of the global supply of *primary* energy from 7 % in 2008 to 14 % in 2035 [IEA, 2010a].

The European Commission published a White Paper in 1997 setting out a common strategy for achieving a 12 % share of renewable energy in the EU's energy mix in 2010. The decision was motivated by concerns about security of supply and environmental protection [EU, 1997].

The 12% target was adopted in a 2001 directive on the promotion of electricity from renewable energy sources, which also included a 22.1% target for electricity for the member countries. The legislation was an important part of the EU's measures to deliver in relation to commitments made under the Kyoto Protocol. Nevertheless, the targets were not binding and it soon became evident that they would not be met.

In January 2007, the European Commission published a Renewable Energy Roadmap, outlining a long-term strategy. It called for a mandatory target of a 20 % share of renewable energy in the EU's energy mix by 2020. The target was endorsed by EU leaders in March 2007, and has been the main driver for developing renewable energy sources [EU, 2007].

To achieve this objective, the EU adopted a new Renewable Directive in April 2009, which sets individual targets for each member state. The directive is also relevant for associated countries like Norway. Norway had in 2005 a domestic energy consumption of 227 TWh including oil and gas. The renewable energy share was 59.8 % (mainly from hydro power). The share of renewable energy is already fulfilling the EU demand, but this does not mean that Norway is exempt from taking further action. A comment on this subject from the EU ambassador to Norway is included below.

> The EU Ambassador to Norway János Herman explains how the calculation was done;
>
> "We start with the share of renewable energy in 2005. The objectives which are set for each country are not based on at what level they are already located, but the extent to which their level of prosperity provide opportunities to increase the percentage. Sweden, for example, is a country that has come a long way already, but that does not mean they do not continue to have ambitious goals"
> *Aftenposten, July 8, 2010*

Figure 48 shows the national production of renewable energy in 2005 and the target in 2020 for all EU countries.

The main points of the new EU renewable directive are:

- Mandatory national overall targets and measures for the use of energy from renewable sources, as well as an indicative trajectory how to reach the targets;
- National Action Plans containing targets for transport, electricity, heating and cooling in 2020;

- Member States shall provide for either priority access or guaranteed access to the grid-system for electricity produced from renewable energy sources;
- Each Member State has to submit a report to the Commission on progress in the promotion and use of energy from renewable energy sources by 31st December 2011, and every two years thereafter. The sixth report to be delivered on 31 December 2021;
- Criteria and provisions to ensure sustainable production and use of bio-energy and to avoid conflict between different uses of biomass.

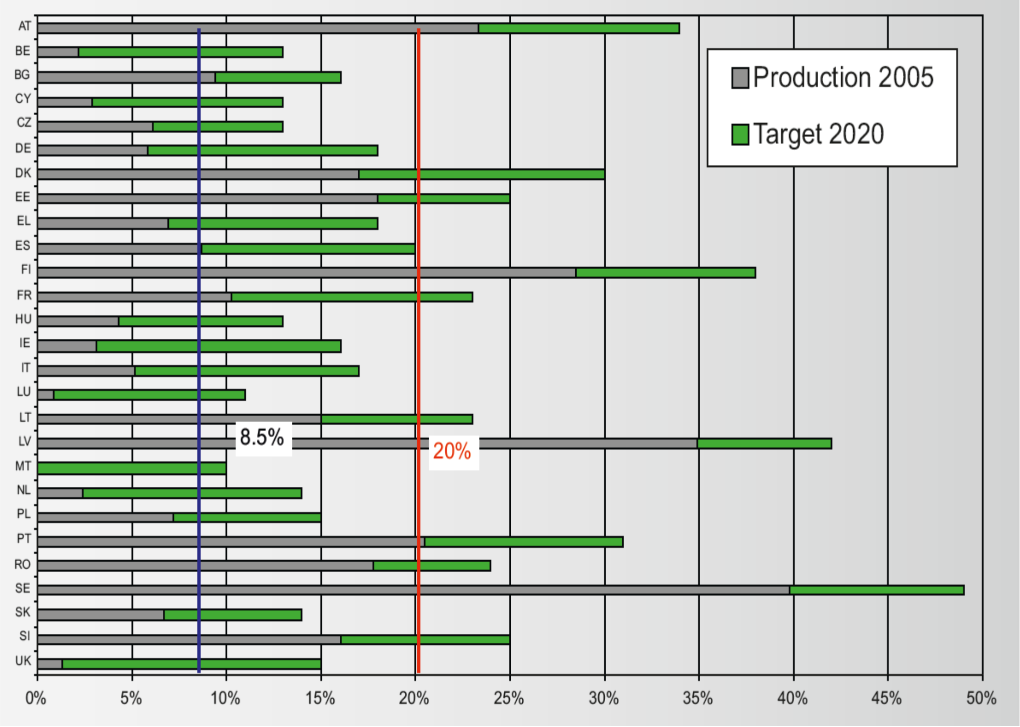


Figure 48: Actual in 2005 and planned clean renewable energy production by 2020.

The richest countries must contribute the most; there will be a GDP weighting and therefore the 2020-requirement for each country will vary:

- UK needs to increase its renewable energy share from 1.3 to 15 %
- Sweden from 39.8 to 49 %
- Romania from 17.8 to 24 %

The formal process between the Norwegian government and the EU is now in progress, but the outcome of the negotiation remains to be seen.

A key part of related legislation is the Energy Performance of Buildings Directive (EPBD), which requires all EU countries incorporate it into their national building regulations and to introduce energy certification schemes for buildings. The purpose of the directive is that it will contribute to greater energy efficiency and reduce energy use in European buildings.

The Norwegian Parliament (Stortinget) decided in 2003 that EPBD should be implemented in Norway. The Norwegian Petroleum and Energy Ministry, and the Ministry of Local Government and Regional Development have been given the responsibility for implementing the directive in Norway. Norwegian Water Resources and Energy Directorate (NVE) and the National Office of Building Technology and Administration have delegated responsibility for the design of the practical initiatives.

The main elements of the directive are:

- A method to calculate the building's energy state (energy performance).
- Minimum requirements for the energy state of new and renovated buildings.
- Energy labeling of buildings.
- Energy assessment of boilers and air conditioning equipment.

The EPBD identifies solar thermal as one option for increasing the energy performance of a building (cf. Annex of the directive). Where the performance requirement is relatively strict, solar thermal is usually among the lowest-cost options [EPBD Annex].

4.2.1 Funding incentives for BIPV in EU

Many funding sources are available to support energy-related research activities. Each instrument has a dedicated focus and targets certain actors and activities. For Norway, as a member of European Economic Area, the Framework Program (FP7) is the most important. EUs FP7 for research and technological development is the main EU tool for financing the priority areas during the period 2007 to 2013.

The EU framework programs coordinate all research-related initiatives under one common structure. CORDIS is EU's official web portal for participation in these programs. The total budget is € 51 billion over a period of seven years, or on average € 7 billion per year. The EEA agreement (EØS-Avtalen) gives Norway the same rights and duties as the regular member countries.

Norway will have contributed nearly NOK 9 billion over the seven year period, representing around 2 % of the total FP7 budget. But this makes Norwegian institutions and corporations equally eligible to apply for research support from the program as EU members [EU, 2011].

4.3 Norwegian national policy and incentives

Norway has no public schemes for supporting the installation of PV systems. Consequently, there are few large grid-connected PV systems in use. The main market for PV in Norway continues to be off-grid recreational applications and special areas such as lighthouses and telecom.

However, politicians have ambitious goals for the future of renewable energy as an element of the climate policy. Solar power will therefore play a bigger role in achieving these goals as the technology advances, through developing more efficient modules and systems, and as the components become cheaper. One important step in renewable energy implementation in Norway is the climate accord; “Klimaforliket”. This agreement is built upon a political consensus on climate policy in the Norwegian parliament, and will ensure a long-term, stable climate policy regardless of changing governments.

4.3.1 The Climate Accord

It was a near united Norwegian Parliament that called for a new climate policy. The Norwegian electrical system is mainly supplied by electricity generated by hydropower. Subsea cables connecting the national grid to the European grid has opened the Norwegian market up for export and import of energy.

Increased consumption, limited increase in production capacity (new power plants), and integration into the European grid has lead to rising costs for the consumer and also growing imports from less “clean” or renewable sources. Focus in environmental issues, security of supply, etc. has lead to an increased interest in domestic renewable energy production, such as wind and small hydro, but also in bioenergy, geothermal, solar and heat pumps as a substitute to electric space heating.

This development is in line with an environmental agreement between the political parties AP, SP, SV (current coalition government) and H, KRF and V [SM 34]. The Parliament of Norway adopted in 2008, with broad political support, a new climate policy [Parliament, 2008]. The agreement sets a target that CO_2 emissions in Norway will be cut by 15-17 million tons of CO_2 equivalents in relation to the reference scenario presented in the national budget for 2007, which includes the impact of forests.

There are many aspects to this agreement. One of them is related to buildings. It states that there will be an increased effort to develop more energy-efficient buildings and continue the work that Enova and Husbanken already have undertaken in this area. It also proposes that the energy requirements used for establishing technical regulations be revised much more frequently than what has been common in the past, with a target of at least every five years or less.

Phasing out non-renewable energy for the heating of homes is a priority for the new climate policy. This will be achieved through government grants channeled though Enova. Solar power is not specifically mentioned as a priority in the climate policy but, along with the other alternatives, is clearly seen as an important source of energy in the years to come.

Another of the issues that the Parliament agreed on was establishment of a common green certificate market on renewable energy with Sweden. The certificates will help renewable electricity producers to achieve higher profitability in competition with non-renewable electricity producers.

4.3.2 Green certificates

The green certificate is a financing scheme to promote more renewable energy generation. In Sweden, electricity certificates were introduced in 2005 and have in recent years been planned in Norway. In 2006, negotiations took place between Norway and Sweden with the view to introducing a common certificate system, but negotiations stalled.

Now that the renewable directive is in place, the government has once again made an attempt to establish a joint Norwegian-Swedish certificate system. In September 2009, Petroleum and Energy minister Terje Riis-Johansen signed an agreement with Sweden on principles for further work to achieve a common electricity certificates market. According to the agreement, the goal is to establish a common green electricity certificate market from 1. January 2012. There is now a broad political consensus in both countries for achieving a common green certificate system with Sweden [Parliament, 2010].

A green certificate market is based on a requirement that a certain percentage of the power sold by producers will have a green el-certificate. This means that those who do not produce renewable energy must purchase a certificate from other manufacturers. Those who generate electricity with an el-certificate will therefore obtain a higher price for what they produce, because they can sell both power and the certificate on the open market. The green certificate will also be relevant for those delivering solar electricity to the grid .

In Norway, the hydroelectric power generators will dominate in the use of green certificates, but there is room for other renewable energy platforms to be included. The certificate scheme is intended to encompass all forms of renewable energy, making the system basically technology neutral. Instead of supporting specific technologies, the certificates will ensure that the most profitable technologies are developed first.

Another incentive system that has proved to be of significant importance for development of the PV (or BIPV) market in Europe is a subsidy arrangement for renewable energy sources in the form of high "feed-in" tariffs[5]. As of now, Norway has not adopted any such facility.

4.3.3 Technical regulations

The Norwegian Government White Paper 11 (2006-2007) "Support facilities for el-generation from renewable energy resources" proposed production incentives on different levels [WP, 2006]. The proposal was primarily aimed at triggering increased energy production based on mature technologies, and to some extent also new technologies. Interestingly, although PV is regarded as a mature technology, there is still no specific proposed support for solar energy.

The current building code requirements also have significance for the development of renewable energy production. The Technical Regulations TEK10 state, among other regulations, that in buildings with over 500 m^2 heated area, at least 60 % of the net heating demand should originate from other sources than direct electricity or fossil fuels at the end user. The equivalent number for buildings with less than 500 m^2 heated area is at least 40 % of the net heating demand originating from other energy sources [TEK, 2010].

This requirement has some exceptions, but an issue is that there is an opening for the choice of a variety for renewable energy technologies. According to the White Paper 11 [WP, 2006], the typical solutions to satisfy the requirement could be solar, district hot water heating, heat pump, pellet stove, wood stove, bio-boiler, biogas, etc.

4.3.4 Governmental support

BIPV is still not a political priority in Norway, but there are ways to get support for the implementation of projects.

a) For the private market and municipalities

[5] A feed.in tariff (FiT) is a policy mechanism designed to encourage the adoption of renewable energy sources and to help accelerate the move toward grid parity. http://en.wikipedia.org/wiki/Feed-in_tariff

Enova
Enova is owned by the Norwegian Oil and Energy Ministry, and was established to promote environmentally friendly restructuring of energy use and energy production in Norway. The core of Enova's work is to develop viable markets for efficiency, welfare and environmentally friendly energy solutions, including new production and consumption. To achieve this in a cost-effective manner requires a conscious and critical use of instruments and close collaboration with other funding agencies. First and foremost, however, it requires broad co-operation with the market.

The instruments that Enova uses to achieve these objectives are comprehensive and varied. Arrangements with financial support are organized in program areas that reflect the priorities of Enova that set clear goals for Enova's activities. Enova has to document the results of its work. Enova's subsidy for households provides funding for the purchase of products for alternative heating and reduction of power consumption.

The purpose of the scheme is to develop the market for new technologies. The characteristics of the products in the scheme are that they are technologically mature, but for an immature market. It is estimated that Norwegian households collectively have invested nearly one billion in new heating solutions as a result of the program. The background for these types of supports are providing a market for green technology.

This subsidy scheme was introduced by the Norwegian government in autumn 2006 and included the pellet, pellet boilers, central heating control systems, air-water heat pumps and water-water heat pumps. In 2008, it grew to include solar collectors. Of the total 3.34 billion NOK that Enova assigned in 2009, only a miniscule part of the support went to solar technology. Enova may also support projects promoted by the local municipalities.

The Enova support-program for households only provides subsidies for up to 20 percent of documented expenses, with a maximum of NOK 10 000. This program supports the pellet boiler, water/water heat pump, air/water heat and solar hot water systems. The applicant is not permitted to receive additional public support if Enova is supporting the project [Enova, 2011].

Applicants are requested to consult their municipality to clarify local requirements for external alterations. Enova and Husbanken have also entered into a formal cooperation in order to strengthen the use of renewable energy. Key areas of cooperation are research, competence building, and incentives.

Husbanken – the Housing Bank
An important tool for the Housing Bank is to provide additional affordable loans for installations and measures to reduce energy consumption, or for use of flexible heating systems [Husbanken, 2011].

b) For the industry

Innovation Norway
The main objective of this institution is to promote industrial development. An important focus in that regard is to unleash the potentials in various districts and regions by providing support for innovation, internationalization and development. Innovation Norway has offices in all Norwegian counties and in more than 30 countries worldwide. Energy projects based on biomass has priority. Solar heating is not a focus area at this time [Invanor, 2011].

c) For research institutions

The Norwegian Research Council
The Norwegian Research Council (NRC) is an institution within the government that supports strategic research at universities and research institutions. As a follow-up to the White Paper 7 (2008-2009) – “Et nyskapende og bærekraftig Norge” (Innovasjonmeldingen) [WP, 2008a], the Ministry of Petroleum and Energy in July 2008 created a unit within NRC called Energi21. This unit should establish a comprehensive strategy for research and technological development in the energy sector, and thus complement the government's overall strategy.

Among the measures described was the establishment of subgroups in thematic priority areas in the Research Council RENERGI Program and within relevant instruments in Enova. Hydropower, solar, wind and biomass are in the White Paper and are expected to increase in importance as sources for the future energy supply [NRC, 2011].

The RENERGI program aims at developing basic knowledge and solutions that are environmentally friendly, are economical and ensures efficient management of the country's energy resources, are high in supply-security, and show internationally competitive economic development related to the energy sector.

The earlier mentioned Energi21 strategy is politically well anchored and covers topics that are relevant for stationary energy production, transport of energy, and energy use. Energi21 recommends R&D investment in the following areas:

- Efficient energy use in buildings, household and industry.
- Climate-friendly electricity from hydro, wind and sun.
- CO_2-neutral heating from bio-resources and heat pumps.
- Energy systems (infrastructure and transmission grids).
- Framework conditions for research and innovation.

The research council follows up this strategy primarily through the RENERGI program and the eight (recently increased to eleven) research centers for sustainable energy, FME. The purpose of the FME initiatives is to establish research centers concentrating on long-term research at an international level. An FME objective is to raise the quality of Norwegian research and provide useful knowledge and solutions in specific subject areas. The new research centers for sustainable energy were announced during Energy Week in Oslo on 4 February 2009.

Another NRC program within new materials and nano-technology, NANOMAT, supports fundamental research tied to development of new materials also having relevance for future PV solutions. The total funds for PV-related R&D projects were approximately 17-18 MNOK in 2009. Most of the R&D projects are focused on the silicon chain from feedstock to solar cells.

In the recent Norwegian government White Paper 30 (2008-2009) – Klima for forskning (Forskningsmeldingen) [WP, 2008b] the objectives for production of renewable energy and energy efficiency are established. The goal is to increase value creation by focusing on R&D and new technology and thereby lay the foundation for Norway to continue as a net exporter of renewable clean energy to Europe.

One of the dominant research centers in the study of PV is *The Norwegian Research Centre for Solar Cell Technology - IFE*. The main goal for the center is to provide both current and future actors in the Norwegian solar cell industry access to world-leading technological and scientific expertise. In this way, the center is meant to help ensure that the Norwegian solar cell industry remains an international leader and one of the most important land based industries in Norway.

IFE's research activities are grouped into six work packages, five of which involve competence-building: mono- and multi-crystalline silicon, next-generation modeling tools for crystallizing silicon, solar cell and solar panel technology, new materials for next-generation solar cells, and new characterization methods. The sixth is a value-chain project that will apply the findings of the other five work packages to produce working solar cell prototypes. The centre will have annual budgets in the range of 7-20 MNOK for the next eight years [IFE, 2010].

4.3.5 Regional policy

The current regional development plans, Regionplan for Agder 2020 [Agder, 2020] states that:

"*climate considerations should be a primary consideration in connection with all the political decisions made in the region" and efforts should be made ..*

"-to develop information with the intent to change attitudes for cleaner energy use at the local level, establishing collaborative efforts with partnership with businesses that work specifically with renewable energy, prioritize low-and zero-emission vehicles by public procure-

ment, facilitating the use of climate-friendly fuel and emphasis on reduced transportation needs in all land use planning."

Nothing is mentioned about the commitment to promote BIPV, but it can be argued that this segment is already included in the energy mix. The Regional plan also states that: "Renewable power from wind and sun is "valuable" seen in a context of achieving the EU renewable directive and the targets set for 2020 that Norway has adopted".

The University of Agder has established a Masters Degree program for renewable energy studies. This will be an important contribution to increasing the local knowledge base. Students will focus on design, management and regulation of the electrical energy systems, particularly of wind, solar technology and hydrogen technology. This is clearly an important contribution to increasing local competence.

Collaboration between the research institute Teknova and the University of Agder has also been established to further studies within renewable energy. This is a significant strengthening of the competence and R&D of clean and renewable energy in Agder. Some information about related PV projects and activities is given below.

The University of Agder has for the last ten years operated a 20 kW peak PV array at Dømmesmoen, Grimstad. This was a demonstration of an integrated energy system and long-term measurements of different kinds of PV modules. With the move to a new campus, the demonstration system was closed down in 2010 and new R&D facilities have been installed on campus, including both an indoor PV laboratory and an outdoor PV testing area.

A four-year project on End Use of Photovoltaic Technology in Norway is currently underway, in partnership with Elkem Solar and co-financed by The Research Council of Norway and the City of Kristiansand. Ten different PV module technologies have been installed on the roof of the new campus, providing data for research and Ph.D. students. Other activities include a study of degradation of crystalline PV modules, and research in power electronics for PV applications. Computer modeling and simulation has also been initiated in order to do theoretical studies of such concepts as tandem cells, intermediate band gap cells and spectrum splitting schemes, and to better understand PV system behavior.

The research group on PV technology consists of about 10 persons, including 3 professors, 1 Postdoc. and 4 Ph.D. students. In addition there is close collaboration with

3 senior researchers at Teknova having expertise in solar cell physics. The university has a study program in renewable energy at bachelor, master and Ph.D. levels. This route can lead to a specialization in PV technology at the Ph.D. level.

The County Council of Vest-Agder participated in 2003 in an EU project where 48 PV panels with a 5 kWp capacity combined with sun shading properties were installed in a demonstration project at Kongsgaard Rehabilitation Center in Kristiansand. Due to lack of technical maintenance, the system has had limited operational time.

Figure 49: Kongsgaard Rehabilitation Centre, Kristiansand – PV sunshades.

Another example of a PV system in Kristiansand can be found at the vocational training centre *Kvadraturen skolesenter*, where they offer a study on the use of solar modules. This involves a series of test panels placed on the roof, which is run in cooperation with a college in Kenya, *Kisumu Polytechnic College*. In both cases, the produced PV electricity is used for lighting and other local demands [Imenes, 2010].

4.3.6 Examples of public grants to PV projects

The development and use of solar energy as a source of energy has not been a national priority in Norway and it is not therefore expected that solar power would be a priority regionally, in spite of the existence of large producers for the solar cell value chain. Until now, none of the municipalities in Agder have had a prioritized focus on solar energy and the use of BIPV. Rather, they have expressed interest in a general approach towards more use of renewable energy.

Reviewing policies for renewable energy in a national context, it is primarily power from hydro generation, wind and biomass that are mentioned. But there exist some examples where public grants have supported demonstration of PV systems. Enova sponsored the installation of a 63.5 kWp PV system for an Art and Cultural Centre named Oseana, recently commissioned in Os outside Bergen [Getek, 2011].

The modules are placed on top of the roof/facade, and the system is as such not a real BIPV case. The inclination of the major part of the roof and module surface is 75 degrees, facing due south. Based on installation costs, an approximate cost of the energy produced may be estimated as well as the investment repayment time. Assuming 25 years service life, the theoretical energy cost per kWh may be estimated at NOK 3 without the subsidy (see also www.getek.no/nettilknytted.html).

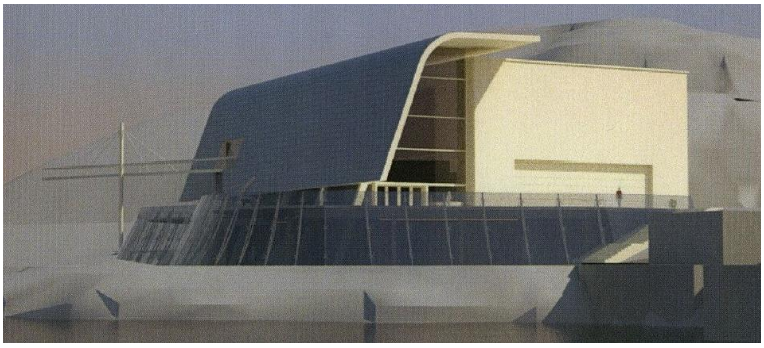


Figure 50: Oseana Art and Cultural Centre with grid-connected PV fasade.

Viability example: Installing 63.5 kWp capacity at OSEANA [Getek,2011]

- Cost of PV system = NOK 2.240 mill
- Installation and training/commissioning = NOK 2.160 mill

Total cost NOK 4.700 mill

Enova grant NOK 1.500 mill

Service life 25 years (PV modules can be operational much longer)

- Estimated annual average production = 42 000 kWh
- *Payback time with NOK 1/kWh ca 76 years*
- *Payback time with NOK 2/kWh ca 38 years*

The cost of this PV system is higher than what is commercially viable, as it is built on top of existing roof and has a very high costs associated with installation, commissioning and training of local personnel for optimal operation. Simple installation should bring the cost closer to 50%. (Consultant: Peter Bernhard, KanEnergi.)

EU grants have supported the earlier mentioned projects at Kongsgaard rehabilitation centre and Oslo opera house. Some municipalities, for instance Oslo, provide grants for solar and bioenergy systems. Applications are handled individually, with a maximum grant of 30 % of investment costs for solar systems. One can also apply for partial funding of heat storage and water heating systems at the webpage www.enoketaten.oslo.kommune.no. There exists no such energy conservation fund in Agder.

4.3.7 Challenges

One of the challenges an electric power producer confronts in Norway is the legal obligation to pay rent for energy delivered to the grid. The tariff is determined by the government and is independent of who is buying the power. This is an arrangement to compensate for development and maintenance of the grid, and allows competing suppliers to offer supply of power. PV systems are still expensive and it takes a long time to recover the investments made - if possible at all.

The Norwegian energy network tariff is a result of two components: One is the *variable energy component*, which varies with the production and network losses. It is calculated from the marginal loss resulting from the feed-in to the grid. The other is the *fixed tariff component*, which is fixed and calculated from the mean production.

The feed-in of PV electricity can cause both an increase or a decrease of the relative losses in the network. Based on the networks systems-related state, the network owner calculates a percentage between -15 % and +15 %, which reflects the marginal loss (or gain) in the network. In other words, the manufacturer may also benefit from the variable tariffs:
*Variable grid rental tariff = Energy produced * Spot price * (± 15%)*

The fixed tariff component is calculated from the average annual production and the feed-in rate. The guidelines from the government (OED) state that the rate in the central grid shall be normative. For 2011, this rate is set at NOK 0.008/kWh [Statnett, 2011].

*Fixed grid tariff component = Estimated average output * NOK 0.008/kWh*

While many European countries are offering significantly subsidized “feed–in” tariffs in order to promote smaller renewable energy producers, Norway has no such arrangement and this makes most investments in PV systems unprofitable. The grid rental tariff functions as a tax and disincentive for BIPV investments. Some energy utilities even argue that they should be allowed to charge administration fees on feed-in renewable energy, making the disincentive even bigger. Additionally, the price of the grid supplied energy in Norway is still cheaper than in many European countries, making PV even less viable.Development of demand and markets

Today only 0.1-0.2 % of global electricity comes from photovoltaics, but the International Energy Agency (IEA) projects an increase to around 5 % by 2030 and 11 % by 2050 [IEA, 2010b]. The projections presented in Table 7 assume favorable and balanced policy frameworks for market deployment, and that technology developments are encouraged in the future in many countries in similar ways to the handful of countries that provide significant support today.

Table 7: Global PV contribution to Total Electricity Generation [IEA, 2010c].

Year	World Average (IEA)
2010	0,2 %
2020	1,3 %
2030	4,6 %

If the projections are met, there will be a global installed PV capacity of 3000 GW in 2050. This corresponds to an electricity production of over 4000 TWh per year. In the near future, the IEA projects a cumulative installed capacity of 200 GW by 2020. This corresponds to an annual growth rate of 17 %, which is less than half the growth seen in the last decade when annual average growth was around 40 %. The IEA assumes that growth will slow down to about 11 % per year between 2020 and 2030, leading to a cumulative installed capacity of around 900 GW in 2030.

Other technology roadmaps predict both higher and lower numbers for the growth of the PV electricity production [IEA, 2010b]. In three different scenarios, the European Photovoltaic Industry Association (EPIA) projects cumulative installed capacities between 77 GW and 688 GW in 2020, with 345 GW as the value in the medium growth scenario. The strategic objective of the European Industrial Initiative on Solar Energy is to provide up to 12 % of the electricity production in the EU by 2020 [EU, 2009].

China is prioritizing PV development and installed a total of 160 MW during 2009, giving the country an overall capacity of 300 MW. While large-scale power plants represented 55 % of newly installed generating capacity, BIPV represented 29 % or 47 MW [SEMI, 2010]. From basically no installed PV capacity, China has established an Energy Stimulus Plan that targets 20 GW installed PV capacity in 2020, with an annual production of 30 TWh or 0.5 % of the total energy requirements in China. A draft proposal from the policy board recommends the target for 2020 to be raised to 30 GW installation representing 1.3 % of the electric energy requirement.

One should be aware that predictions like those above are hard to make. Starting in 2001, the EPIA has made several prognoses for the annually installed capacity of PV. As shown in Table 8, they have consistently underestimated the growth in predictions going more than two years ahead. The EPIA is considered one of the most well-informed sources regarding the PV market, and is not likely to make poorer predictions for the future than others.

Table 8: Predictions of the global annual installed capacity of PV made by the EPIA compared to actual numbers. All numbers are in MW. [EPIA, 2010]

Year	2001	2004	2005	2006	2007	2008	2009	2010
Actual number	*334*	*1,052*	*1,320*	*1,467*	*2,392*	*6,092*	*7,203*	
Prediction 2001	331	659	838	1,060	1,340	1,700	2,150	2,810
Prediction 2004			985	1,283	1,675	2,190	2,877	3,634
Prediction 2006				1,883	2,540	3,420	4,630	5,550
Prediction 2007					2,179	3,129	4,339	5,650
Prediction 2008						4,175	5,160	6,950
Prediction 2010								13,625

Another example of understated estimates is IEA's projections in 2001. The IEA predicted that the global PV marked could reach 3,000 MW by 2020 in their *World Energy Outlook 2001* [IEA, 2001]. Comparing this to the more recent IEA-prediction of around 50,000 MW annually installed PV capacity by 2020, gives an idea of both the difficulties in making accurate predictions as well as the phenomenal growth experienced by the PV industry the last decade.

4.4 Properties of future solar cells and systems

The growth in PV generating capacity is achieved both through increase in volume and increase in the efficiency of solar cells and system components. Development of existing technologies as well as the introduction of new concepts and materials will drive the efficiency improvements. IEA operates with four groups of technologies in their technology roadmap; I) crystalline silicon, II) thin film, III) emerging technologies and novel concepts and IV) concentrating photovoltaics.

Group III includes advanced concepts with high theoretical efficiency and cheaper, flexible concepts such as organic PV. Concentrating PV includes multi-junction cells and other expensive and highly efficient cells intended for use in solar concentrating systems (i.e., using mirrors or lenses to focus high-intensity sunlight onto the cells). Figure 51 shows how the IEA expects the efficiency of these groups to develop the next 20 years. Efficiency improvements of around 25 % are expected during this period.

Improved production processes are believed to require less raw materials and less energy for production of PV cells. This will reduce the energy payback time[6] for PV cells. In 2005, the energy payback time of REC's silicon modules where approximately two years. By the end of 2010 this is reduced to slightly above one year [REC, 2010]. Since a PV system has more parts than just the panels, the energy payback time of the system is somewhat higher. IEA estimated a typical system energy payback time of 2 years in 2010, and expects this to drop to 0.75 years in 2030 and below 0.5 years in a long-term perspective.

[6] The energy payback time of a PV module is the time the module has to operate before it has delivered the amount of energy consumed during production of the module. The energy payback time varies with the location of the panel. IEA use 2000 kWh/m^2 in their calculations.

The operational lifetime is also expected to change. Today, 25 year lifetime is expected, which is reflected in the 25 year effect warranties given by leading producers of PV panels. IEA expects the operational lifetime to increase to 30 years in 2020 and 35 years in 2030. Since the cost of a PV-system is mainly a one-time investment, an increase in the lifetime of a panel by 10 years, or 40 % from an initial lifetime of 25 years, will have a large impact on the price of the energy delivered by the system. Table 9 summarizes the IEA projections of some cell properties.

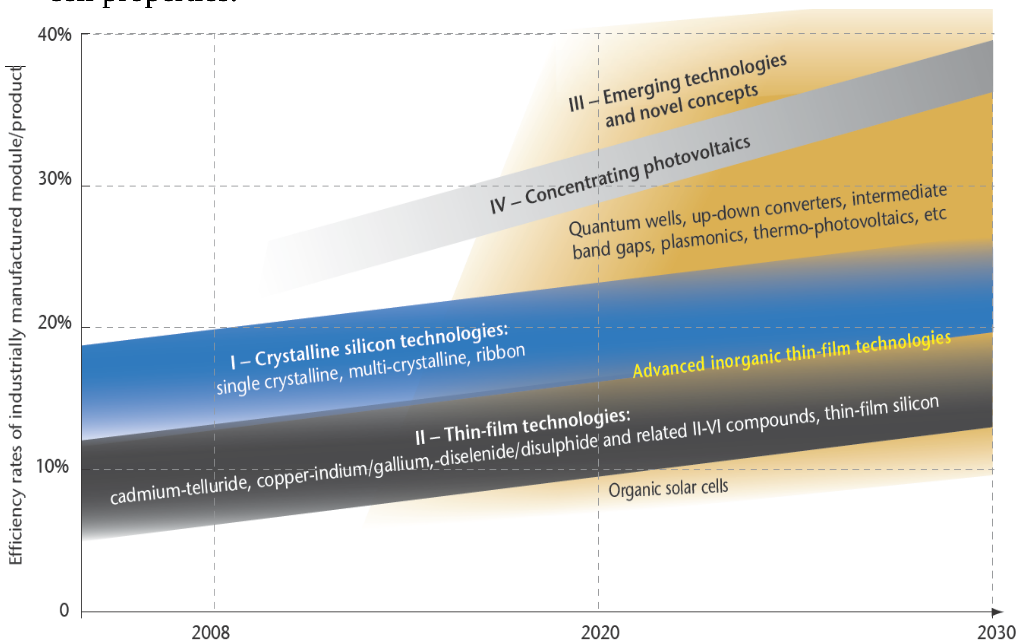


Figure 51: Development in efficiency the next 20 years for various PV-technologies as projected by the IEA. Source: [IEA, 2010b]

Table 9: Properties of future PV modules and systems, as projected by IEA [IEA, 2010b].

	2008	2020	2030	2050
Typical flat-plate module efficiency	Up to 16 %	Up to 23 %	Up to 25 %	Up to 40 %*
Typical system energy pay-back time	2 years	1 year	0.75 year	0.5 year
Operational lifetime	25 years	30 years	35 years	40 years

* 40 % efficiency means that novel concepts have to be implemented, since conventional solar cells has a theoretical efficiency limit of 31 %. 25 % is probably close to the practical limit of conventional cells.

4.4.1 Technology developments

Crystalline silicon solar cells are expected to keep their dominant position until at least 2020, when a market share of 50 % is predicted by the IEA [IEA, 2010b]. The proven technology, long lifetimes and abundant raw materials make silicon cells the most robust technology in the coming years. The major drawback of the silicon technology is the large amount of silicon that is used for each cell. The wafers themselves are thick and the wires that are used to saw wafers from blocks are approximately as thick as the wafers. Therefore around half the silicon is lost in the wafer sawing.

The material usage has a large impact on the module price and energy payback time. Reduction of sawing losses and improvements in other process steps can reduce the material use for silicon cells. IEA expects the use of silicon to drop from over 5 grams per Watt today, to less than 3 grams per Watt in 2020 and less than 2 grams per Watt in a longer perspective [IEA, 2010b].

The thin film technologies are less mature than the crystalline silicon technology. While having low consumption of raw materials, high automation and production efficiency and low sensitivity to overheating, the thin film technologies suffer from lower generating efficiency and limited experience from lifetime performances. IEA points out the need for experience in manufacturing and long-term reliability as the main issues to be addressed by the thin film developers.

There is a large potential in process optimization and improved deposition techniques for thin film cells. The thin film segment has seen a rapid increase in production, from small pilot plants to large manufacturing units in the Gigawatt range in recent years. It is believed that the rapid growth will continue, and that thin film cells will have a significant market share in 2020.

Emerging concepts include dye sensitized cells and organic PV. Such cells are likely to find a market for niche applications. The relevance of these concepts for large scale electricity production has yet to be proven. Improvements in both efficiency and stability are needed before these technologies can be of significance.

Novel concepts that seek to improve the harvest of the energy contained in sunlight are very interesting in a long-term perspective. Concepts that use nanotechnology to change the properties of the cell materials have been suggested as a way to implement concepts with theoretical efficiency limits of 45-50 % without concentration of light.

Concepts that modify the solar spectrum have also been suggested. Spectrum modification can make it possible to harvest more of the energy in the sunlight. All these promising concepts are in the earliest stages where considerable basic research is required to develop well functioning devices.

Another area for research is concentrating lenses that can be made at low cost. Concentrating the sunlight allows small cells to harvest the light collected from a much larger area. Recently, concentrating PV (CPV) systems have gone from pilot facilities to commercial-scale applications.

CPV has the potential to reach higher efficiencies than conventional panels. However, only the direct sunlight can be concentrated, so CPV is only suited for sunny areas with little cloud cover. To focus the solar beam onto the PV cells, a tracking system that keeps the panel oriented towards the sun is required. Highly efficient cells like multi-junction cells or novel cells based on nanotechnology will probably have to be used in concentrating systems to make them economically viable. IEA predicts that CPV-systems might reach 45 % efficiency.

4.4.2 System types in the future

Today, grid-connected systems for the residential sector is the system type with the largest annual installation of PV-panels [IEA, 2010b]. As the technology and market develops, it is expected that commercial systems and utility systems, where electricity is generated in larger solar parks and sold to consumers, will expand. It is also expected that stand-alone systems will increase their share, since such systems are attractive in rural areas in developing countries. With economic growth, more and more villages should be able to afford their own

PV-system. Figure 52 shows IEA's predictions of the future division of the four segments.

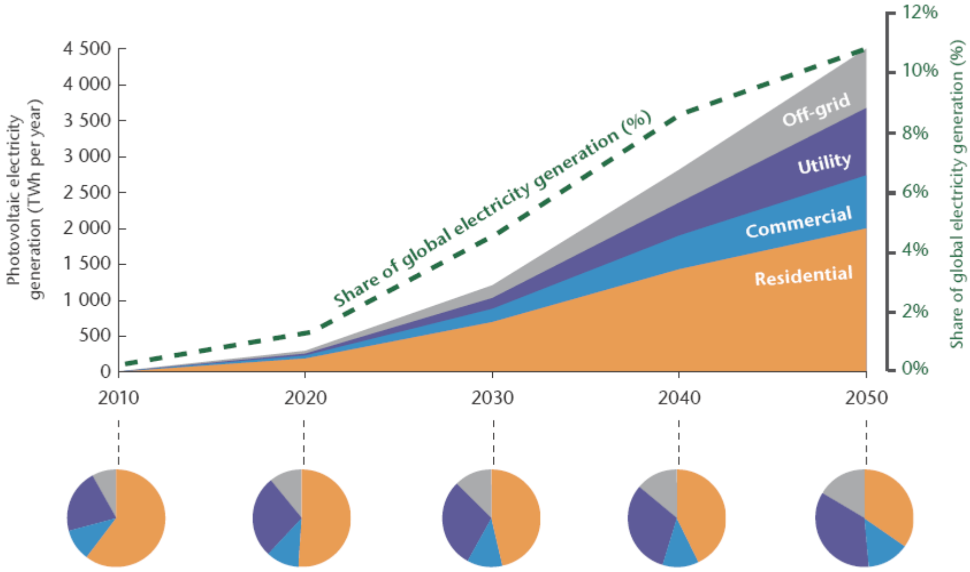


Figure 52: IEA's predictions of the future division of the four PV system types. Source: [IEA, 2010b]

4.5 Developments in the European markets

The European Union has, in order to reduce the CO_2 emissions, approved a target for reaching 20 % of its energy need from renewable resources by 2020. Most European countries face a huge challenge and must now set in place ambitious policies in order to achieve 20 % of their energy from clean renewable resources. National guidelines and incentives have been developed and implemented in most European countries, including a policy for PV energy generation.

The most rapidly advancing European PV markets are commonly called PV hot-spots (see Figure 53) and include Germany, France, Italy, Spain, Portugal and Greece. The development of BIPV in these countries will be studied in more detail below. The material found in the annual reports and country reports from the International Energy Agency Photovoltaic Power Systems Programme have been extensively used in these next review sections (original reports are found on http://www.iea-pvps.org).

Figure 53: Countries representing the "PV hot-spots" in Europe [RE, 2009].

4.5.1 Germany

Currently, and for some years now, Germany is the largest market for BIPV in Europe. In 1999, a soft loan program was introduced in Germany through its *100,000 Solar Roofs Program (HTDP)* to promote BIPV technology. By guaranteeing feed-in tariffs and interest-free loans, the German market developed more quickly than other markets, securing in 2004 the position of the largest PV market in the world[7].

Because of its early focus on BIPV, the country currently has a high level of expertise among BIPV installers, designers, architects and manufacturers, accompanied by a high level of awareness among the end consumers. Recent amendments in Germany's renewable energy act, the EEG (Erneuerbare Energien Gesetz) ensures that Germany will remain one of the largest markets for BIPV in the world[i]. It is the Federal Ministry for the Environment, Nature, Conservation and Nuclear Safety (BMU) that takes the responsibility for renewable energy

[7] http://www.pes.eu.com/assets/misc/issue-9-think-tank-bipvpdf-45.pdf

within the Federal Government. BMU describe EECs[8] feed-in tariff system as the most effective instrument for the promotion of renewable electricity. The EEG registers the input and determines favorable rates for electricity from renewable energy[9].

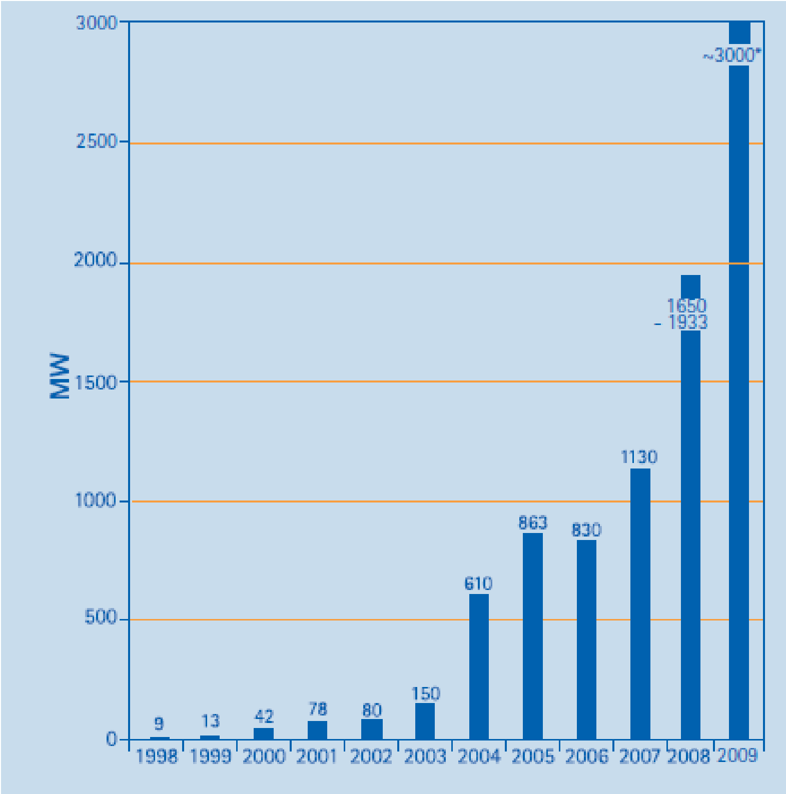


Figure 54: Annually added PV capacity in Germany in MW. [IEA, 2009c]

The IEA PVPS annual report for 2009 reported a total PV capacity of roughly 9 GW installed in Germany, an increase of about 3 GW in 2009 alone [IEA, 2009c]. The annual report for 2010 reports even higher growth, with a total of 17 GW installed [IEA, 2010b]. By the

[8] http://www.gtai.com/uploads/media/EEG_Brochure_01.pdf

[9] *For 2010 the tariffs are currently (January 2010) defined as 28,43 eurocent/kWh for ground mounted systems. For systems attached to buildings the tariffs are: 39,14 cent/kWh for systems smaller than 30 kW, 37,23 cent/kWh for systems smaller than 100 kW, 35,23 cent/kWh for systems smaller than 1 MW, and 29,37 cent/kWh for systems bigger than 1 MW. For self-consumption 22,76 cent/kWh are foreseen, see* http://www.bundesnetzagentur.de

end of 2008, a total of 500,000 solar power systems had been installed on German roofs . Both private and institutional investors in photovoltaic systems receive a guaranteed remuneration (feed-in tariff) for solar electricity fed into the grid. The tariff has been calculated so as to make investment in PV systems economically attractive. The EEG also provides sustained planning security for investors in PV systems and for investors in PV companies who work on the assumption of continuous growth in the PV market.

The German feed-in tariff law requires grid operators to pay producers of solar electricity a fixed remuneration for solar generated electricity that is fed into the utility grid depending on the size of the system and the kind of the installation. These tariffs vary in order to account for the different costs of rooftop or ground-mounted systems and in accordance with the capacity of the system.

Grid-connection is of major importance for a successful PV support scheme. Since the establishment of the first feed-in tariff law in 1991, electricity generated from renewable energy sources enjoys priority status. Any clean energy plant connecting to grid systems must be given priority. The electricity generated in this way must be purchased, transmitted and paid for by the grid system operators at a fixed price, which is set by law for a period of 20 years. Grid system operators are required to extend their grid to accommodate the connection of additional renewable energies to the grid.

With grid parity in sight, market conditions will change and are likely to become even brighter. These processes will probably require policy adaptations. Since 1st of January 2009, the EEG has already been providing a framework to enhance the direct consumption of electricity produced by PV systems. The German government is thereby reinforcing the process of the energy supply decentralization in order to advance innovation, energy independence, and improved base load management for the national grid.

Also during 2009, when the economy was hampered after the financial crisis, the German PV market showed good growth. The driving force for this development is the EEG. Since the beginning of 2009, the owner of new PV systems are legally obliged to register their systems at the German Federal Network Agency. Statistics show that around 159 850 new systems with a total capacity of 3 806 MW were registered in 2009, and 7000 MW additional PV capacity is estimated for 2010.

In addition to the market of grid-connected systems, there is a steady request for stand-alone systems. Rough estimates indicate that an annual capacity of around 5 MW were added both in 2009 and 2010, mainly for industrial applications such as the automotive sector, traffic signals, etc. There is very limited information on off-grid non-domestic systems in Germany because the electricity PV supply is predominantly connected to the public grid.

4.5.2 France

The French BIPV market transformed itself into a hotspot for manufacturers when BIPV-specific FiTs (feed-in tariffs) were introduced in 2006. By the end of 2007, the French market had grown into one of the world's largest markets for BIPV. As France has only recently started focusing on the BIPV sector, the market is still trying to establish a strong manufacturing and consumer base. The French BIPV market is also suffering from a lack of expertise for BIPV, especially in design and installation [RE, 2011].

About 220 MW was installed in France during 2009, and the cumulative installed photovoltaic power was about 1025 MW in 2010 [IEA, 2010b]. Most of this is grid-connected, and nearly 150 000 plants were connected to the network by end 2010. France has set a goal of having 5,4 GW PV installed in 2020. Soaring demand, initiated in 2009, led to a queue of contracts which was reaching 4,1 GW by end of September 2010 [IEA, 2010b].

During 2009 and 2010, development of projects in medium- and high-power capacity were dominant, as well as the development of the BIPV market and the emergence of new industrial actors. The market is influenced by the priorities given to the integration of photovoltaics into buildings. The feed-in tariff policy, introduced in 2006, was a strong incentive, reinforced by the tax credit to stimulate private individual investments.

In the industrial sector, new operators are emerging all along the value chain. At the end of 2009, an estimated 8500 jobs were associated with activities such as component manufacturing and installation of systems. In 2010, the job creation in the industrial sector was reported to 25 000 [IEA, 2010b]. The manufacturing industry in France is integrating with the development of the PV sector along each stage of the value chain of silicon: purification, ingot production, cell- and module manufacturing, distribution of products and systems, and installation and operation of electric power generation systems.

The procedures for grid-connection have been simplified and the processing time of applications has been reduced. However, in late September 2009, 30500 systems were queued up for connection to the continental grid for a total capacity of 1659 MW, to which should be added 957 MW in Corsica and overseas territories [IEA, 2009b].

In 2010 new feed-in tariffs were introduced. The new feed-in rates include an increase in some ground-mounted and BIPV tariffs, as well as some reductions [PVtech 2010; IEA 2010b]. The changes in the BIPV tariff include an increase in fully integrated roofing systems for residential/health/agricultural buildings. These installations will now receive a FiT of € 0.58/kWh in 2010 and 2011, up from the 2009 FiT of € 0.55/kWh but down from the September 2009 proposal of € 0.60/kWh. Commercial/industrial buildings will now receive a FiT of € 0.50/kWh, while simplified BIPV installations will receive a FiT of € 0.42/kWh, down from the 2009 FiT of € 0.55/kWh and below the September proposal of € 0.45/kWh.

For ground-mounted systems, the new tariffs will provide incentives for installations in cloudier areas. For these the FiT varies between € 0.314/kWh and € 0.377/kWh, depending on the solar insolation of the region. This is an increase from the 2009 FiT of € 0.30/kWh, which was in place regardless of the location of the installation. However, it is below the September 2009 proposal of € 0.328/kWh - € 0.394/kWh depending on solar insolation.

4.5.3 Italy

With a location closer to the equator, the Italian market should have been an early haven for BIPV with good climatic conditions and high investment capability. Until recently though, the lack of specific tariffs for BIPV combined with administrative and bureaucratic hurdles have restrained growth. In 2007 the market was finally boosted with the introduction of the "Conto Energia" law, which granted very high FiTs for BIPV, and a clear cut definition for a BIPV installation. It also provided consumers with several payment options and supportive legislation for utilizing the BIPV tariffs.

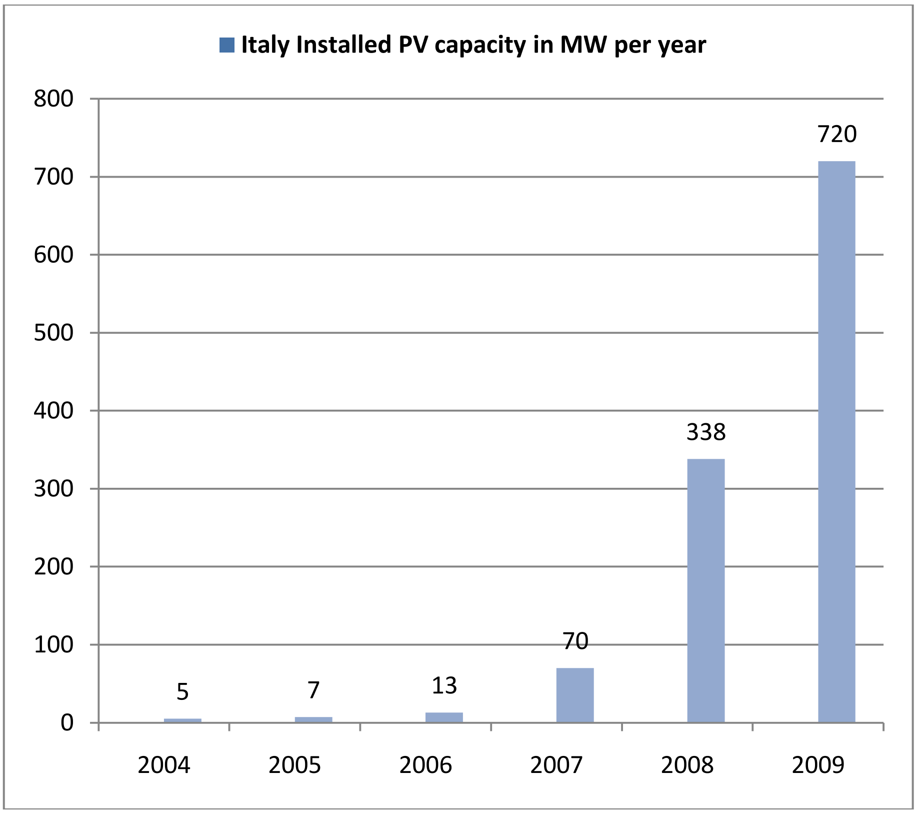


Figure 55: Annual installed PV capacity in Italy.

Due to this program, the market grew rapidly in 2007, and is set to continue its high growth rate in the coming years (see Figure 55). The slow bureaucracy however, has been a restraint to growth, despite government assurances that it will streamline the process. The “Conto energia” promotion program will eventually ensure stability, providing the basis for the expansion of PV market in Italy. Bureaucratic problems related to the incentive mechanism have been overcome while the ones concerning plant construction and grid connection seem to have been smoothed out. During the last year, PV energy has become more common and attained greater importance. The PV consumer market seems to be leading to an adequate growth of the national PV production industry.

The total installed and operating power in Italy at the end of 2009 was around 900-960 MWp, with a growth rate of around 50 % compared with previous years [IEA, 2009c]. This increase has been driven by the support mechanism of grid-connected systems, which now accounts for over 98 % of the installed total photovoltaic capacity. The installation capacities for Italy in the three main sectors of PV power system applications are presented in Table 10. With the attractive incentive scheme, Italy became the world's second largest PV market during 2010. Updated numbers show a continued trend of growth, with an estimated 1700 MWp new installations giving a total of 2900 MW installed PV power by the end of 2010 [IEA, 2010b].

Table 10: PV system types in Italy 2009. Source: [IEA, 2009c]

System type	Capacity
Off-grid Systems:	14 MW (1.5 %)
Grid centralized(>200 kW): Large PV plants.	About 330 MW. Systems corresponding to 28 % of the total capacity installed.
Grid Distributed Systems:	About 800 MW. Dominating Italy's cumulative installed photovoltaic power (70 %)

4.5.4 Spain

With its suitable geographical position, Spain should also benefit from the high availability of solar energy. But the Spanish BIPV market took off only in 2004, hanging on the coat-tails of the market for open-field PV systems. The latter had seen an accelerated growth trajectory following the introduction of liberal FiTs for PV installations in Spain, and supportive schemes like soft loans and PV ordinances for large commercial buildings.

Due to the focus on open-field PV installations, the Spanish BIPV market has experienced less growth than the general PV market. However, this is now set to change following the decision by the Spanish Government to revise its tariffs for PV, giving greater importance to BIPV and scaling down its open-field PV tariffs. This has led to more focus on BIPV from both consumers and manufacturers from mid 2009 onwards, when the tariffs came into effect.

In 2009, the new regulatory framework was established in Royal Decree 1578/2008 for the purpose of rationalizing the deployment of PV in Spain in order to control the impact of the feed-in tariff on the national economic situation. The new regulatory framework dictates a 30 % reduction of the feed-in tariff and further progressive cuts, which could reach 10 % annually. A quota of 500 MW in 2009 and similar for the next three years has been established, together with the creation of a register for allocating new capacity [IEA, 2009c].

This register establishes four calls annually with separate segments; one related to ground-based solar plants, the other to building integrated installations. In the case that a call is covered, a reduction of the tariff is to be expected. The first call in 2009 established a price of 0.29 cents EUR/kWh for ground mounted installations and 0.33 cents EUR/ kWh for building integrated installations [IEA, 2009c].

As a result of the new situation in 2009, 2488 installations were authorized, with a total capacity of 502 MW. This is in contrast to the 2755 MW capacity installed in the previous year, according to the National Energy Commission's data. The new regulatory conditions, combined with the global financial crisis, have dramatically altered the sector's industrial scenario, with 20,000 jobs lost since the reforms according to ASIF, the national PV industry association [IEA, 2009c]. At the end of 2010, a total PV capacity of 3800 MWp was installed, or about 2.5 % of the annual electricity demand in Spain [IEA, 2010b].

The vast bulk of Spain's installed PV capacity is in multi-megawatt ground-based arrays, often rated in tens of megawatts. 37 % of the facilities on the ground have tracking systems, of which 24 % are two-axis tracking and 13 % single axis-tracking systems [IEA 2009c]. The new regulatory framework has established a better price for roof and facades installations, and it is expected that these types of PV installations will take a bigger share of the market in the future. In 2009, almost 50 % of the new, authorized installations will be integrated in the built environment, with further increase in the share in coming years.

4.5.5 Other emerging European hot-spots

Three European countries implemented BIPV-specific feed-in tariffs in 2009, opening up for an era of high growth and consumer interest in PV. Portugal, Greek and Switzerland are now the emerging hotspots but economic hardship, especially in Portugal and Greece, will most likely slow down the growth rate.

4.6 PV development in the Nordic countries

4.6.1 Sweden

Since 2005 there has been increasing activity on the Swedish PV market. This is due to an investment subsidy for PV systems on public buildings that was introduced in 2005 and ended 2008. It is evident that this subsidy has had an important impact on the Swedish PV market. In 2004, only 300 kW was installed and it was mainly off-grid. In 2008, 1.7 MW was installed and composed mainly of grid-connected systems, reaching a cumulative installed PV capacity of almost 8 MW.

The increased market size meant that several new actors were established. For 2009, it was announced that a new subsidy was going to be introduced, but the law was not in place until 1st July 2009. Consequently there was no activity on the market for grid-connected PV systems during the first half of 2009, since all of the stakeholders were waiting for the new subsidy. The situation was further impaired by the financial crisis and subsequently many companies experienced difficulties.

In Sweden it is the Energy Agency (Energimyndigheten) that has the national authority for issues regarding the supply and use of energy.

Their main task is to implement the policy program of the Swedish Parliament. The aim of the program is to develop a sustainable energy system and to secure energy supply. They have updated their private sector subsidy program, similar to the previous one, but it is now open for everyone to apply and the subsidy has been lowered from 70 % to a maximum of 60 % of the investment cost. The budget for this program is 20 mill EUR for the period 2009-2011. By the end of 2009, applications amounting to the total budget amount had already been received [IEA, 2009c].

There exist no national goals or official visions for the use of solar energy in Sweden. However, the strategy of the Swedish Energy Agency is that PV should become an established technology in the overall energy mix [IEA, 2009f]. PV development is a part of a long-term energy research program (LTERP) managed by the agency. The research budget for LTERP for 2009-2011 was increased to about 100 mill EUR.

The Swedish Energy Agency provides funding for PV research, co-financed technological development, demonstration and business development. The budget for these PV projects is in the range of 2-2.5 mill EUR per year, depending on which projects are currently running. Additional funding for PV research in Sweden can be received from e.g. the Swedish Research Council, the Nordic Energy Research program, and private foundations.

The market for PV in Sweden has traditionally been dominated by domestic stand-alone PV systems and there continues to be a stable market for these systems in Sweden. The market for grid-connected PV systems relies completely on public support incentives. This is because all electricity producers in Sweden must pay a fee in order to deliver electricity to the grid. Therefore the majority of PV installations in Sweden are dimensioned so that production never exceeds the consumption in the building.

However, as mentioned earlier the activity in the PV market that delivers electricity to the grid is increasing due to an investment subsidy for PV systems on public buildings during 2005-2008. This subsidy has had an important impact on the Swedish PV market. The Swedish

PV industry has grown significantly over the last couple of years. Today there are five companies in Sweden that produce and mainly export PV modules. They all use crystalline silicon [IEA, 2009f]. The industry still suffers from uncertainty connected to long term support for a Swedish PV market, and would like to see a stable framework to create transparent and secure conditions for all actors.

4.6.2 Denmark

By the end of 2009, Denmark (including Greenland) had about 4.7 MW installed PV generating capacity, an increase of 1.3 MW compared to 2008 [IEA, 2009b]. Similar numbers from end of 2010 show a total of 7 MW installed capacity, i.e., an increase of 2.3 MW from last year. Grid-connected distributed systems constitute about 90 % the PV system capacity. Denmark has no general incentive for reducing the investment cost of PV systems, but has a net-metering scheme for private households and institutions established by law.

The price of PV modules dropped during 2009 by around 40 %. For the individual PV systems installed during 2009, mainly turnkey systems, the prices range from 25 to 50 DKK/W [IEA, 2009b]. The projects completed in 2010 demonstrate turn-key system prices for medium to large scale “roof-tops” of around 20 DKK/W. The price of PV modules dropped also during 2010 but not as dramatic as in 2009. The individual PV systems implemented during 2010 exhibit turn-key system prices in the range of 20 to 40 DKK/W [IEA, 2010d].

Denmark has no national PV program, but a number of projects are supported by the Danish Energy Authority and via the Public Service Obligation of the Danish transmission system operator, Energinet.dk. This is a fully government owned body. In late 2006, a new support mechanism was established; the Energy Development and Demonstration Program (EUPD). This is administered by an independent board with the Energy Authority as secretariat. The first call for proposals ended in September 2007 and has been followed by several new calls. A few PV projects have since received support, but the real extent to which PV can benefit from increased funding by this instrument is not yet known.

A support instrument administered by Energinet.dk and covering the period 2008-2012 is targeting demonstration projects for PV, wave power and other emerging technologies. The first concrete PV project as a result of this instrument was a grant of 22 mill DKK for a project to demonstrate 1 MW of photovoltaics on the building of Skive municipality. This project is expected to have a significant replication potential, and as a result the regional municipality of Bornholm is now considering a major PV installation. By the end of 2009, about 4.6 MW have been installed in the context of various projects and demonstrations plants supported by the different incentives.

A brief history of major initiatives since 2000 is as follows: A 1000 roof-top program was launched late 2001. This program targeted a mix of general cost reductions, increase in end-user payment and promotion of small roof-tops. Only a few weeks after the announcement of this program (SOL 1000), more than 3000 house owners had registered their interest. However, uncertainty about the program due to change of government and increased demand for end-user payment, introduced a delay of almost a year in the program implementation.

By the end of 2002, the program reported a portfolio of some 1300 house owners expressing firm interest in the program. By the end of 2006 about 700 kW had been installed, stimulated by an investment subsidy of 40 % of the turnkey system cost; average turnkey system cost being EUR 4.40/W [IEA, 2009b]. The SOL 1000 program was extended until end of 2006.

Net-metering for privately owned PV systems was established in mid-1998 for a pilot-period of four years. Late 2002, the net-metering scheme was extended another four years up to end of 2006. Net-metering has proved to be a cheap, easy to administer and effective way of stimulating the increased use of PV in Denmark; however, the relative short time-frame of the arrangement has so far prevented it from reaching its full potential. During the political negotiations in the fall of 2005, net-metering for privately owned PV systems was made permanent. Net-metering alone, with a typical level of EUR 0.27/kWh appears on its own not to be able to significantly stimulate growth in PV installations.

Table 11: Total accumulated PV power installed in Denmark in 2009 and 2010.

Installed (kW) PV Power	Off grid domestic	Off grid non-domestic	Grid connected	Total (kW)
Accumulated end 2009	165	375	4025	4565
Accumulated end 2010	220	470	6375	7065

Source: [IEA, 2010d]

Grid-connected PV applications are seen as having the largest potential in Denmark, in particular building integrated applications on single family houses, apartment buildings, commercial and office buildings. The public interest in building integrated PVs is increasing, and most efforts are focused on developing and deploying PVs in the context of existing buildings.

The EU Directive 2002/91/EC (16.12.2002) on energy consumption in buildings was incorporated into a revised national building code in 2005, and enforced from early 2006. This code specifically mentions PV and allocates PV electricity a factor 2.5 in the calculation of the "energy footprint" of a building [IEA, 2010d]. However, due to the inertia in the construction sector, it was not possible to detect any real impact on PV installations before 2009.

Developers, builders and architects openly admitted that the inclusion of BIPV in projects was primarily due to the revised building codes. Ongoing political discussions both on the EU level and on the national level indicate an upcoming further tightening of the building codes, which may further promote BIPV.

4.7 European Market potential

The European BIPV market is still only a limited niche market but with great potential. Although BIPV takes up less than 5 % of the total European solar PV market, there is considerable interest due to its high year-on-year growth and the increasing number of countries with supportive legislation for BIPV [RE, 2009]. In fact, Frost & Sullivan announced in a press release 22 March 2011 a report which projects that the European market for BIPV will grow 108 % to reach 2.70 billion EUR in 2016 [Frost&Sullivan, 2011]. The report credits distinctive tariffs and increasing awareness of the benefits of BIPV as the main drivers of demand for the technology, but also states that more suitable and standardized products are required to fulfill potential growth.

The residential sector has witnessed the highest growth, becoming the largest sector for BIPV. The sudden increase in the growth rates in residential installation can be attributed to the rise of the French and Italian markets. These two markets have, over the past two years, implemented high feed-in tariffs for BIPV systems, especially for small-scale systems, which has increased consumer adoption of the technology. The French market, in particular, has witnessed large growth rates due to a high rate of adoption of BIPV in the residential sector. The Italian market has also witnessed growth but to a lesser degree due to the slow and complicated bureaucratic processes in the country.

The commercial sector has also started utilizing BIPV more, especially in countries where there is a high level of legislative and financial support. In particular, the office and warehouse sectors have witnessed high growth over the last few years. The commercial application of BIPV is likely to become more mainstream after 2011 as it becomes more widespread and as costs decrease, and as the residential sector in new markets like Portugal, Greece, France and Italy begin to stabilize and manufacturers look to other sectors to sustain growth.

The factor common to all the best regions for investment in BIPV has been the legislative support. These regions have not been afraid to support BIPV though financial incentives, usually through feed-in tariffs (FiTs), although easy availability of credit, solar PV ordinances and other supportive legislation is also important to grow and sustain the market. Due to the dominance of on-grid BIPV installations, which make up more than 95 % of current BIPV installations in Europe, there is not much of a market for storage technology in BIPV [RE, 2009].

In terms of module technology, the BIPV market is dominated by crystalline silicon technology, which accounts for about 90% of the market. In this, mono-crystalline silicon technology is used more than poly-crystalline technology, mainly due to aesthetic benefits rather than performance [RE, 2009]. Thin-film and other PV technologies account for less than 10 % of the BIPV market. In the case of thin-film however, the technology has steadily increased in acceptance as manufacturing technology has decreased the cost of the end product, while at the same time bringing efficiencies closer to the levels of crystalline silicon. There is a growing market for thin-film modules for prestige installations or large commercial projects where aesthetics are chosen over performance.

With respect to choice of technology, limited change is expected over the next few years, with crystalline silicon modules being preferred by the majority of consumers. However, as the efficiencies increase and costs decrease, it is expected that there will be greater adoption of thin-film modules post 2012 [RE, 2009].

4.8 The Norwegian Market

The market for PV in Norway continues to be dominated by off-grid applications, primarily for the leisure market (vacation cabins, leisure boats) and to a more limited extent, the professional market (mostly lighthouses/lanterns along the coast and telecommunication systems). The leisure segment accounts for 80-90 % of the market, with 85-120 W as a representative typical system size [IEA, 2010e]. Enova estimates that there are around 150,000 PV installations in Norway with an approximate annual energy production of 6 GWh, which corresponds to the annual energy consumption of 300 households [Enova, 2010].

In the 1990's, the PV powered coastal lighthouses emerged as a significant new market. Even north of 70°, lighthouses may be powered by PV, provided the battery bank has sufficient capacity. In 2010, the Norwegian Coastal Administration operated a total of 3083 PV installations, ranging from a single module 36 W-system to a 88 module system of 4400 Wp. The average is 110 Wp per installation, yielding a total installed PV capacity of 228 kW [IEA, 2010e].

Norway does not have any incentive schemes supporting the installation of PV systems. The absence of such schemes may explain why no large grid-connected PV-systems were built in 2009.

Table 12: Total PV power installed in Norway, 2009 and 2010. Source: [IEA, 2009d; IEA 2010e].

Installed (kW) **PV Power**	Off grid domestic	Off grid non-domestic	Grid connected	Total (kW)
2009	300	20	0	320
Accumulated end 2009	*8080*	*450*	*132*	*8662*
2010	320	20	60	400
Accumulated end 2010	*8400*	*470*	*192*	*9062*

5 Regional BIPV products and producers

A sketch of the value chain of the PV-industry was shown in the introduction (Figure 1). As previously mentioned, the first part of the chain, including all production steps from the raw material to the modules, are handled by larger actors producing for the global market. Downstream activities, such as the installation and maintenance of PV systems, are best performed by local companies.

On the manufacturing side, there are three groups of producers in the Agder region related to the PV industry:

i) The basic raw material producer; metallurgically produced silicon bars (Elkem Solar, Kristiansand).

ii) The suppliers related to processing: Slicing media (from Saint Gobain, Lillesand), and recycling of cutting lubrication media (Metallkraft, Kristiansand).

iii) Different auxiliary products: Low-iron glass for solar panels (Vetro Solar, Kristiansand), and high-efficiency inverters (Eltek Valere, Kristiansand).

The characteristics for all the producers listed are that their customers are predominantly foreigners. They have no significant domestic market. This means being fully exposed to world market trends. Contact information for these companies is listed in Table 13.

Table 13: Local global companies without a significant domestic market.

Company	Business	Address
Elkem Solar www.elkem.no/solar	Producer of solar cell silicon using low-cost metallurgic process.	Elkem Solar P.O. Box 8040 Vågsbygd 4675 Kristiansand
Eltek Valere www.eltekvalere.com	Provider of inverters for PV systems. The R&D department is located in Kristiansand.	Eltek Valere AS Gråterudveien 8 3036 Drammen
Metallkraft AS www.metallkraft.no	Recycles used slurry from the sawing of silicon wafers. The slurry used for this consists of silicon carbide particles in a liquid lubricant.	Metallkraft AS Setesdalsveien 110 4617 Kristiansand

Saint Gobain www.silisiumkarbid.no	Producer of silicon carbide for wafering of silicon. Has plants in Lillesand and Eydehavn.	Saint-Gobain Ceramic Materials AS Postboks 113 4792 Lillesand
Vetro Solar www.vetrosolar.com	Is currently building a factory in Germany for specialized glass for PV-modules. Vetro Solar's head quarter is in Kristiansand.	Vetro Solar AS Gravane 12 P.O.Box 596 4610 Kristiansand

The Agder region does not have much activity in the downstream segments of the value chain. Therefore a list of national companies is shown in Table 14. The list includes a variety of system designers and developers that can perform planning, installation, operation and maintenance of PV-systems.

Table 14: Norwegian companies with downstream PV activities.

Company	**Business**	**Address**
Alternativ Energi AS	Norwegian provider of PV-systems, including modules, batteries and inverters.	Alternativ Energi AS Industriveien 26 4879 Grimstad.
ComPower AS	Produce power electronics including battery controllers and inverters. Deliver tailor-made solutions.	ComPower AS Damsgårdsveien 59 B Postboks 2416 Solheimsviken 5824 Bergen
Energibutikken	Internet store with various types of, modules, batteries inverters etc.	Energibutikken AS Sveberg 7550 Hommelvik
GETEK AS	Supplier of complete PV-systems including planning and installation, delivery of all components, drift and maintenance. Grid connected and stand-alone systems.	GETEK AS Sveberg 7550 Hommelvik
Asplan Viak AS - KanEnergi	Technical consultants with focus on energy, environment, technology and economics.	AsplanViak AS - KanEnergi Kjørboveien 12, 1337 Sandvika

Norsk Solkraft AS	Norwegian solar plant developer. Operates mainly in Southern Europe. Norsk Solkraft makes its own mounting systems.	Norsk Solkraft AS Strandveien 50 1366 Lysaker
RHEINZINK	Norwegian supplier of roof and facade solutions with PV.	RHEINZINK Norge Hamang Terrasse 55 1336 Sandvika
Scatec Solar	International provider of complete grid connected and stand-alone PV-systems including operation and maintenance of larger facilities.	Scatec Sommerrogata 13-15 NO-0255 Oslo
Schüco	Supplier of building integrated solar heating collectors and PV-systems.	Schüco International KG avd. Norge Postboks 56 Bogerud 0621 OSLO
Skjølberg Energiteknikk	Norwegian provider of PV-modules, solar heating collectors and heat pumps.	Skjølberg Energiteknikk Austrevigå 24 4085 Hundvåg
Statkraft SF	The largest Norwegian electricity producer. Statkraft is also involved in PV and has installed a large PV-facility in Italy.	Statkraft Lilleakerveien 6 Postboks 200 Lilleaker 0216 Oslo
Sunlab (Sivilarkitekt Harald N. Røstvik AS)	Architecture, design and consulting for passive and active building integrated solar energy solutions.	Sunlab Kirkegt 3 PB 806 4004 Stavanger
Sweco	International consultants with competence within energy and buildings. Design and evaluation of solar energy projects.	Sweco Norge AS Fornebuveien 11 Postboks 400 1327 Lysaker

6 Prospects and potential regional use of BIPV

There are some indications that the *off-grid PV market* for areas outside the reach of the electricity grid will continue to grow slowly in Norway. The investments in vacation homes are increasing annually. Installation and use of more power-consuming equipment will require more PV panels and increased battery capacity. But it is also a trend that the vacation house owners are showing a keen interest and often succeed in connecting earlier off-grid vacation areas to the grid – and often at significant costs.

For *the grid-connected PV systems*, which in Europe represent most of the installed capacity, the situation in Norway is very different. Only 192 kW of grid-connected PV capacity in Norway was installed at the end of 2010. This is around 2 % of the totally installed PV capacity and was primarily for demonstration purposes. Apart from the drive to establish more PV demonstration installations, there are certain conditions that need to be improved before harvesting the solar energy will have any significant impact in this region with respect to PV and BIPV installations:

- Increased user demand
- Improved system competence
- Simplified and cheaper installation
- Economic justification for the use of BIPV

6.1 Increased user demand

The geographic location of Norway affords access to only about half of the solar energy potential available in areas closer to the equator. Limited insolation when energy is most needed, as for example during the winter, and large variations in insolation both geographically and temporally, limits the public interest in supporting development and use of this type of renewable energy. Without incentives the application has, as described earlier, been limited to off-grid systems.

Even with significantly reduced investment costs for installation of BIPV systems through for example Enova grants, the region as well as the rest of Norway face some major challenges due to high availability of low-cost hydroelectric energy. The normal cost to the consumer varies from around 0.5 to 1.0 NOK/kWh. Agder has generally excess generating capacity and is exporting its hydroelectric power to other regions and abroad though subsea cables and international grids. Since there exists no feed-in tariff incentives in Norway for PV generated power, the solar generated power in grid-covered areas has to economically compete directly with grid energy cost.

Even with the cost for PV modules having fallen sharply during the recent years (Demark went down 40 % during 2009) and lower-efficiency modules now available from about 1 $/Wp, the resulting energy cost is still more expensive than energy from grids. Indicative installed system prices in European countries in 2009 were in the range 4-5 €/Wp (< 10 kW) and 3-4 €/Wp (> 10 kW) [IEA, 2009e]. In Norway, the corresponding costs are approximately twice as high, whereas Denmark and Germany have seen system prices down to around 2.7-2.8 €/Wp. This indicates a significant potential for cost reduction in Norway.

The situation in many European countries is very different from the Norwegian context, where the governments offer "feed-in" tariffs that make the investment profitable. The national interest is to replace polluting coal-fired electricity generation. In Italy or in South Germany the owners of rooftops may now rent out the location to a company that fills the area with panels. As an incentive, they offer the owners cheaper electricity rates than normal instead of rent. In this way, the government stimulates increased production of clean renewable energy and replacement of CO_2 emitting energy production.

It is expected that cheaper PV system prices through large-scale production and more competitive supply, in a context of increasing grid energy costs, will cause price parity in southern Europe within the next five years. However, the massive public subsidized feed-in tariff makes most projects viable even now. The incentives produce a significant driving force to exploit renewable energy in order to quicker achieve the goal of reduced CO_2 emissions.

As long as the feed-in tariffs remain so unfavorable in Norway, this will work as an actual disincentive for the development of the PV and

BIPV market. In spite of the current environmental framework, some concerned consumer groups do still follow closely the evolution of the PV market and will probably, for idealistic reasons, be willing to invest in PV systems in spite of such energy sourcing not being economically profitable. Consequently, this market is not expected to grow significantly before real parity with alternative energy sources is reached.

6.2 Improved PV and BIPV system competence

During design and conceptual studies, architects and technical consultants play an important role with respect to introducing and recommending use of new products and technologies. However, energy use considerations are becoming gradually more important due to stricter public and EU regulations. With limited experience in the field, these groups have generally had a critical attitude towards the use of PV and BIPV products. The typical arguments are that this technology is still not sufficiently developed and still too expensive.

> The use of renewable energy in the building energy balance has for some time been one of the basic issues in all new projects, both in Norway and internationally. With respect to BIPV, the products are still found to be in an underdeveloped state and not yet suitable for efficient use as energy source. In Norway there are no economic incentives for use of solar cells but even abroad the modules offered to the market need to be developed further, making them simpler to design as an integral part of the building, simpler to install and simpler to maintain. It is expected that PV in combination with glass surfaces will be the first area of practical application.
>
> *Snøhetta Arkitekter, Oslo. Contact: Architect Astrid van Veen (19.10.2010)*

In spite of the fact that the southern parts of Norway receive the same amount of solar energy as northern Germany, where BIPV is commonplace, the prevailing cost structures in Norway, lack of comparable incentives and competence, and low user interest have prevented the development of an integrated commercial market. This demonstrates clearly the real effect of the German subsidy schemes.

There are signs that several building component manufacturers in Norway are following developments closely to see when customers are ready to apply the new PV technology to their projects. They are also looking for opportunities to meet the increasing interest and demand of the avant-garde consumer groups.

A few regional window producers have on their drawing boards some modules/sections that may be offered when or if the demand makes it viable. Also, some prefabricated house building companies follow BIPV developments for components and have drawing board sketches of modules that may be offered, but with no realized cases so far.

The producer of well reputed roof-mounted window systems, Velux in Denmark, is in the process of developing a real BIPV module that can, in principle, be plugged into the electrical system of a house. Velux has also invited some of the companies mentioned earlier to cooperate in a new and exciting development but that project is still on a confidential basis. But even Velux sees a bigger market in Norway for solar thermal than for PV, since heating water gives a more direct benefit with lower installation cost.

For integration of PV elements in the building construction, the roof and the south-facing walls represent the best alternatives. Ideally, the solar panels should be aligned in such a way that the solar rays continuously hit the panel at normal incidence angle. Devices that track the solar movement throughout the day and year are commercially available, but these are not useful for integrated building components. As a compromise, roof elements inclined at an optimal fixed angle can be computed based on the local conditions and the energy use profile. Fixed vertical wall elements, or panels fixed at an angle for solar shading, may also be used although the yield will be less than optimal.

Shading or impurities on the panel surface can have significant effect on the amount of energy delivered by a PV system. Snow will also have the same effect, making flat rooftop systems less suitable during winter in colder climates. In order to harvest the optimal energy output, the position of the building and the inclination of the panel areas need to be adapted for BIPV use.

By offering roof-mounted windows and pre-wired systems for PV generation to the market, along with increased knowledge and awareness among architects and technical consultants, we may gradually see a change of attitudes in Norway. However, this is likely to occur only if the price is within an acceptable range.

6.3 Simplified and cheaper installation

As discussed earlier in this report, the cost of installation normally supersedes the material cost of the components. By offering more completely integrated systems, installation should become simpler and relatively cheaper.

The solar panels are normally either encapsulated in glass or deposited on a flexible surface. In both cases these surfaces represent durable building cladding materials, which can be integrated as a useful part in the weather protection of the building and as such reduce the material cost of the building by combining both purposes.

Glass for skylights would be used in any case, and PV modules may replace necessary shading of direct sunlight. The PV integrated Velux windows mentioned above are examples of such a combined function.

Whole prefabricated construction modules with preinstalled PV systems would also be an excellent way to save the outside skin cost of a building and benefit from the collection of solar energy. Through the installation of mass produced wiring systems in prefabricated elements, it should technically be possible to reduce the installation cost significantly. Building component producers have demonstrated interest in such ideas. [MRI1]

This type of system would be most advantageous for bigger buildings where larger areas could be allocated for electricity generation. The generated power could be used directly for the occupants own energy needs such as lighting, ventilation or cooling in schools, offices shopping centers etc. This would cut the energy bill directly. The cost saving would be limited to a direct reduction of the utility invoices and would be unaffected by the current Norwegian disincentives.

6.4 Economic justification for the use of BIPV

The main European driving force for using BIPV and the interest in increased access to renewable energy resources is the reduction of greenhouse gasses and a reduced dependence on fossil fuels. The day it can be demonstrated that the use of BIPV also makes economic sense for the end user will be a turning point for the use of PV in Norway. It has become a clear political priority that Norway, like the rest of Europe, should advance that date by providing subsidy incentives. The lesson learned from the European countries is that the economic justification is the strongest driving force for increased use of renewable solar energy.

Due to the variability of energy generation from solar radiation, connection to the local energy grid represents the most flexible solution. A supermarket, school or office building may use its large surfaces to produce PV energy for their needs during daytime, but the use of the perishable electric current may become much more flexible by being connected to the grid.

For example, connecting the PV system to a hydroelectric system and pumping water up during hours of excess production (low consumption), the energy may be released through the dam during high demand times. This allows the generated energy to be used when it is needed in an optimal manner. Norway has ideal conditions for such systems, with the advantage that the hydroelectric production in the region exceeds local demand and can be sold on a wider international grid. But even installing these types of systems will not move forward until there is a sufficient real return from the investment.

7 Concluding remarks

The development of photovoltaic technology during the last couple of decades has led to a substantial PV market in several countries around the world. While PV globally now contributes only about 0.1% of the total electricity production, the IEA projects an increase to 5 % by 2030 and 11 % by 2050. Since the total consumption of electricity is also expected to grow, the installation of PV systems is projected to have massive annual growth rates in the years to come.

The initial investment cost represents the bulk cost of PV systems, where the modules are expected to have a service life of at least 25 years. These costs are still high and not yet competitive with energy from other (traditional) sources. It is the need to increase the access to sustainable and secure energy, the desire to use more renewable resources and the need to reduce the CO_2 emissions that are the motives for most public incentives and subsidies.

With further development of components and systems, followed by increased market volumes, parity with other energy sources is projected within relatively few years (depending on local availability of sunshine). Norway has only about half of the insolation of areas closer to the equator. In spite of this disadvantage, Norwegian companies operate in the forefront of technological development and as suppliers in the initial parts of the value chain.

The abundance of clean, renewable and inexpensive energy from hydroelectric power available in Norway has historically reduced the need to promote large-scale development of other renewable energy systems for the domestic energy market. This ample energy resource has, combined with advanced metallurgical and process technologies in the production of silicon as a raw material, led to the development of the region's important role in the global PV industry.

Technological platforms from other industrial sectors have also provided the basis for additional Norwegian ventures operating within the PV industrial sector. Use of in-house electronic technology and experience from power supply to telecom installations globally was the platform for the inverter design. Adopting locally produced abrasive material for silicon slicing proved to be an industrial winner. Know-how from environmentally advantageous industrial processes was the technological platform for the sludge treatment company that operates worldwide from its base in Agder.

The main opportunities in Agder in the near future appear also to come from application of advanced competitive technology adapted to the specific needs of the PV industry in the initial part of the value chain. Research and development in regional research institutions and universities is a precondition for following the rapidly advancing technology. Given that this focus is in place today, and with the present open access to the necessary skills and know-how, there is no reason that Norway cannot continue to be on the front line of global production.

The conclusion we must draw from the initial evaluation is that the gaps in the later stages of the value chain are large and that the market, in the near term, is not likely to change without a change in the national framework. This may give us medium term opportunities but the incentives and motivation for builders is usually too limited for a quick build-up in PV use. Until the systems have reached a cost closer to parity with other main sources of energy, there will be a limited volume in Norway for markets closer to the consumer.

Architects and consultants seem to await the deployment of more developed 'plug-in' components that can reduce the installation costs. There might be some segments in this latter part of the value chain that could be a niche for local initiative and production at this time. Another niche might be buildings where architects plan to use expensive facade materials; in this case BIPV would become a competitive alternative. For opportunities on a larger scale, one should look to the wider European market or wait for government incentives.

Major advances in increased efficiency of the PV cells and reduction of the manufacturing costs are projected by even the gloomiest technology roadmaps and industrial analyses. Most roadmaps and projections actually argue for very convincing and optimistic scenarios and these types of paradigm shifts normally represent new opportunities. In fact, every earlier baseline estimate for PV deployment we have reviewed for this study has undershot the actual deployment. This may indicate that there are unseen technical synergies or hidden cost benefits that are routinely overlooked. But as the opportunities, viability and sustainability of PV increases, so too will the competition increase as the market becomes bigger and more attractive.

The bulk of research on photovoltaic technology in Norway is now focused on groundbreaking cell technology and on elements for increasing their effectiveness. At the University of Agder there is also ongoing research on End use of photovoltaic technology in Norway. Together with Teknova and local industry partners operating in the photovoltaic segment, a broad PV competency pool is gathered in Southern Norway. The first Solar Energy Seminar was arranged in Kristiansand in June 2011, with special focus on the solar industry and investment cases. The Agder region now has a unique opportunity to position itself and take a leading role in terms of solar industry in Norway. This could be a strong case also for including other segments, such as BIPV, in a strategic mid- to long-term planning process.

As mentioned at the outset of this report, this is a review of PV solar power technology and development. The question remains, however, where does Agder go from here? In our estimation, there are two concrete steps that should be taken to build upon this review.

The first step is to assemble a team composed of the relevant public and private actors to identify Agder’s energy needs and goals within 1-5 year, 5-15 year and 15+ year timeframes. These needs and goals should be specified in accordance with regional parameters, such as integratability, durability, return-on-investment, seasonality, practicality and other key factors.

Next, each available energy technology should be scored along the same parameters to identify the most relevant technologies ready for deployment now and the most promising technologies for the medium and long terms. This will lay the groundwork for the development of a regional roadmap.

The use of this approach is common for companies, industrial organizations and governments involved in the PV sector. This roadmap will provide the most important regional actors with a common framework for evaluation, comparison and investment in the Agder region. Key here is that the roadmap is developed with the input of all of the relevant actors as the basis for concerted action. With this common understanding, it will be possible to make the next step in building cooperation and commitment and to put in place a broader and more integrated energy profile for the region.

The second concrete step builds upon the first. Here the goals and opportunities identified above must be analyzed in the context of action. We recommend that an action matrix be developed wherein specific regional actors are assigned concrete deliverables for pursuing objectives within their areas of responsibility. The timeframes for these actions should coincide with the short, medium and long term timeframes in the roadmap.

This stage will require commitment to a common future for the region. The actors should initially be separated into public sector, private sector and the research sector. The matrix can be subsequently further subdivided based on, for example, specific firm's position in the energy value chain, or their role as producer, supplier, customer or financier.

Timeframe /Actor	1-5 years	5-15 years	15+ years
Public	*1. aa* *2. bb* *3. cc*	*4. ddd* *5. ee* *6. ffff*	*7. ggg* *8. hhh* *9. jjjj*
Private	*10. aa* *11. bb* *12. ccc*	*13. ddd* *14. eee* *15. ffff*	*16. ggg* *17. hhh* *18. jjjj*
Research	*19. aa* *20. bb* *21. ccc*	*22. ddd* *23. ee* *24. ffff*	*25. ggg* *26. hhh* *27. jjjj*

This stage is where analysis moves into synthesis. Responsible actors must be delegated specific actions to be followed up within a given timeframe in order to deliver the desired roadmap outcome for the region. This lays the basis for ongoing cooperation and reevaluation of Agder region's concerted efforts to meet the needs of the region and exploit the opportunities up-and-coming energy technologies offer. It is in this step that goals and objectives are translated into coherent deliverable outcomes.

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