Die approbierte Originalversion dieser Diplom-/Masterarbeit ist an der Hauptbibliothek der Technischen Universität Wien aufgestellt (http://www.ub.tuwien.ac.at).

The approved original version of this diploma or master thesis is available at the main library of the Vienna University of Technology (http://www.ub.tuwien.ac.at/englweb/).

MSc Program
Renewable Energy in Central and Eastern Europe

Current Trends and Long-term Perspectives of Grid-Integrated PV Systems

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
DI Demet Suna

Mag. Jan Dörrich
9613075

Vienna, 04.02.2010

Affidavit

I, Mag. Jan Dörrich, hereby declare

1. that I am the sole author of the present Master's Thesis, "Current Trends and Long-term Perspectives of Grid-Integrated PV Systems", 72 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool,

   and

2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 04.02.2010

____

Signature

Abstract

PV technology has highly developed over the last years. There has been a steady increase of cell efficiency and nowadays test cells reach an efficiency of more than 40 percent already. Although these modules are not produced in a large scale the developments look promising and many new technologies having its advantages and disadvantages are being developed. Today, large scale production is done with monocrystalline and multicrystalline silicon but thin film modules could be next soon.

Looking at the market developments Germany will have the biggest PV market in 2010. An ambitious feed-in tariff and political commitment brought Germany the first place by far. Other countries like USA, Japan and Spain are catching up fast, although announced subsidy caps in certain countries could change the picture significantly within the next years. At the moment it seems the USA has the most ambition to support its PV sector in the long run. Big question marks are China, India and Turkey. One has to see how the national supporting schemes work out there but irradiation and demand potentials are enormous in those countries.

The worldwide PV production was booming in the last years. The overall global capacity increased from 1,166 MW in 1999 to 14,370 MW in 2008 that is a capacity increase of more than 12 times in 10 years. Module costs have decreased over the last years and will continue decreasing. Best-practice production costs for c-Si modules under one Dollar per Watt could be possible by 2012. Generally the prices are still high above other energy sources but in some countries, with good pre-conditions, grid parity seems possible in the near future.

Despite the bright future, PV has to master many challenges on the way to a major player on the electricity market. High production prices, shortage of raw materials, increase of efficiency and cost of research and development are just a few of them.

Table of Content

List of Figures and Tables

List of Acronyms

AC	Alternate Current
a-Si	Amorphous Silicon
BIPV	Building Integrated Photovoltaic
BOS	Balance-of-System
CdTe	Cadmium Telluride
CIS	Copper Indium Diselenide
c-Si	Crystalline Silicon
DC	Direct Current
EEG	Renewable Energy Sources Act
EPBT	Energy Pay Back Time
EPIA	European Photovoltaic Industry Association
G	Gram
GHG	Green House Gas
GW	Gigawatt
GWh	Gigawatt Hour
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
Km	Kilometre
kW	Kilowatt
kWh	Kilowatt Hour
kWp	Kilowatt Peak
LCA	Life Cycle Assessment
LDC	Line Drop Compensator
Microns	Micrometer (10-6 meter)
mm	Millimetre
MNRE	Ministry of New and Renewable Energy
MW	Megawatt
MWp	Megawatt Peak
PCS	Power Conversation System
PV	Photovoltaic
PVPS	Photovoltaic Power Systems Programme
RES	Renewable Energy Source
STC	Standard Testing Conditions
SVR	Step Voltage Regulator

1. Introduction

Photovoltaic (PV) is a combination of two words: ‘photo’, meaning light, and ‘voltaic’, meaning electricity (from Italian inventor Alessandro Volta). Photovoltaic technology generates electricity from light and the term is used to describe the hardware that converts solar energy into usable power (EPIA & Greenpeace, 2008).

1.1 Motivation

Dealing with increasing energy prices and demand will be one of the biggest challenges for mankind in the near future. Introducing and adopting renewable energy sources will be crucial when dealing with this issue. PV can and must play an important role in this new energy mix. Solar energy sun has the most energy potential of all renewable energy sources and fossil fuels will eventually run dry. Public discussions of peak oil scenarios and the struggle for the remaining fossil resources are dominating the media coverage already for years.

The remarkable rise of fossil fuel prices can be observed in figure 1 for households and figure 2 for the industry. Figure 1 shows the consumer prices in Germany between 1991 and 2008. The electricity prices for households increased “only” 44 percent but the real challenge is the increase of the heating oil price which is almost 3 times as high as in 1991. Also the gas prices doubled in that period. Since the price indices increased by about 63 percent for that period, fossil fuels have clearly outperformed the regular price indices. The economy crises in 2008/09 mitigated the high fossil prices but it is expected that they will increase again in the near future. Taking this figures and having in mind that heating plus warm water is responsible for about two-third of the private energy consumption (which is still met in large quantities by fossil fuels) a shift to renewable energy is inevitable.

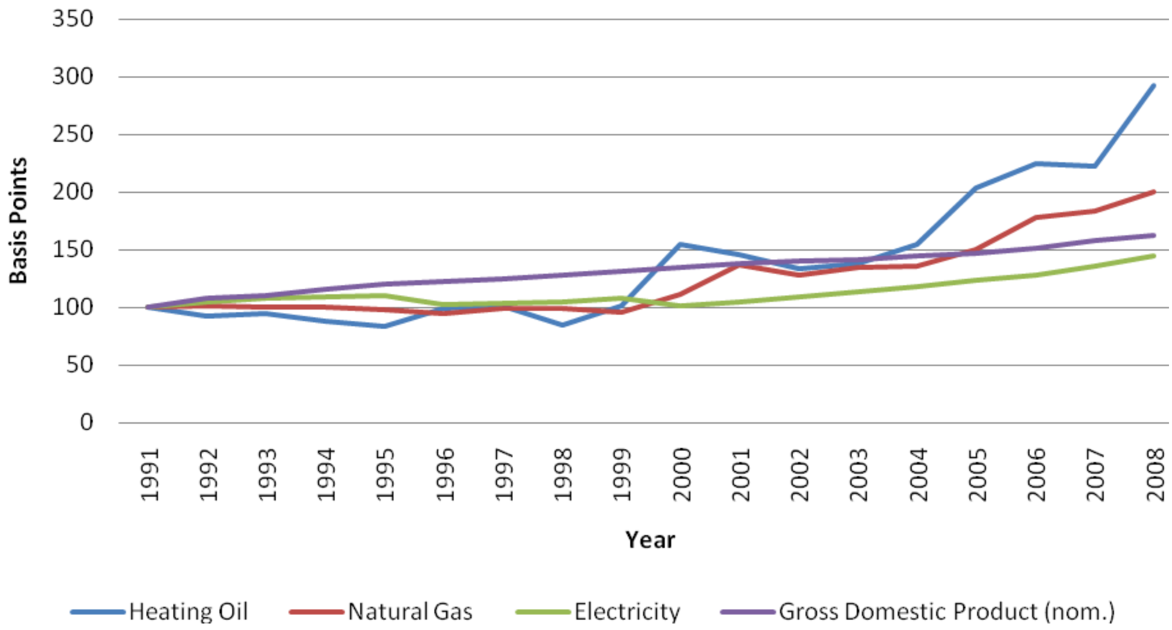


Figure 1: Development of Consumer Prices in Germany for Households (incl. VAT)
Source: Bundesministerium für Wirtschaft und Technologie, 2009

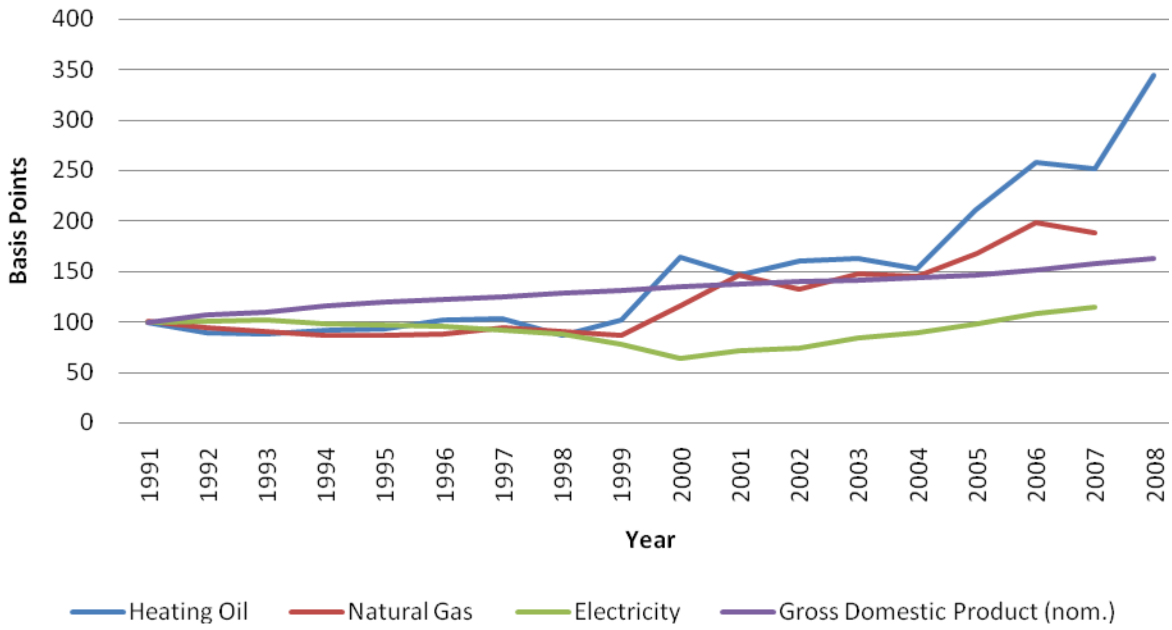


Figure 2: Development of Consumer Prices in Germany for Industry (excl. VAT)
Source: Bundesministerium für Wirtschaft und Technologie, 2009

Although PV is one of the most prominent renewable energy technologies and dependent on a worldwide abundant fuel source, the currently comparatively high level of cost of this technology is still a huge barrier for an accelerated deployment. However, the PV technologies comprise also a large potential for promise cost reduction while the fossil fuel prices are increasing.

Another main argument besides price stability and avoided risk of disruption in fossil fuel supply are the environmental benefits. PV systems will have a major contribution to GHG emission scenarios in the future.

The motivation of this paper is to show that PV technology can be an answer to upcoming energy shortages and environmental preconditions for a sustainable future.

1.2 Core Objective and Structure of the Paper

Core objective of the paper is to give its reader a comprehensive overview of the different PV technologies and developments. The focus will be on grid-integrated systems, explaining the grid integration and the different PV technologies in chapter 2. Chapter 3 and 4 explain the global development of the PV sector and compare the policies and prospects of selected countries, with emphasis on Austria. The big environmental advantages of PV are explained in chapter 5 but also an analysis of the economical criteria. The last chapters give an overview of the future of PV technology. It also tries to answer one of the most important questions of an energy source: When is grid parity possible?

1.3 History of Photovoltaic Systems

The underlying photovoltaic effect was discovered already in 1839 by the French physicist Alexandre Edmond Becquerel. Experimenting with metal electrodes and electrolyte he discovered that conductance rises with illumination. The British engineer Willoughby Smith and his assistance Joseph May discovered the photovoltaic effect in selenium in 1873. In 1876, with his student R. E. Day, William Adams discovered that illuminating a junction between selenium and platinum also has a photovoltaic effect. These two discoveries were a foundation for the first selenium solar cell construction, which was built in 1877. Charles Fritts first described them in detail in 1883 and he built the first module, a precursor of the photovoltaic module (Smith, 1995).

In 1905 Albert Einstein succeeded in explaining the photo effect correctly which brought him the Nobel Prize in 1921. After many other discoveries and developments Daryl Chapin, Calvin Fuller und Gerald Pearson succeeded to build the first silicon cells with an efficiency of more than four percent in 1954. At the end of the 1950’s the first photovoltaic applications were used in satellites. In the 60’s and 70’s essential developments could be achieved, mainly due to the demand of the aerospace industry (Perlin, 2002).

1.4 Off-Grid and Grid-Integrated Photovoltaic Systems

Worldwide there are two PV grid systems: grid-integrated and off-grid. According to EPIA & Greenpeace in 2010 about five percent of all worldwide installed PV systems will be off grid systems. In countries, which are associated with the Photovoltaic Power Systems Programme (PVPS) of the International Energy Agency (IEA), about 6 percent or 128 MW were installed in off-grid projects in 2007.

There are different classifications within a grid-integrated system. In centralized systems big PV plants feed electricity into the grid only on certain connection points. The technical requirements are different to decentralized systems. In a decentralized system you have many small electricity production sites with lower voltage which feed the energy into the grid at many connection points.

A major issue for urban PV development nowadays are building integrated PV (BIPV) systems, where the PV elements actually become an integral part of the building, often serving as the exterior weather skin. PV specialists and innovative designers in Europe, Japan, and the U.S. are exploring creative ways of incorporating solar electricity into buildings.

A BIPV system consists of integrating PV modules into the building envelope, such as the roof or the façade. By simultaneously serving as building envelope material and power generator, BIPV systems can provide savings in materials and electricity costs, reduce use of fossil fuels and emission of ozone depleting gases, and add architectural interest to the building. The so called “Solar Energy Architecture” will play a major role in the next decades in city development in many countries.

Grid-integrated PV systems are installed to provide power to a grid-connected customer or directly to the electricity network. An inverter is used to convert electricity from direct current (DC) as produced by the PV array to alternating current (AC) that is then supplied to the electricity network.

The typical weighted conversion efficiency of inverters is in the range of 95 percent, with peak efficiencies up to 98 percent. Inverters connected directly to the PV array incorporate a maximum power point tracker, which continuously adjusts the load impedance to provide the maximum power from the PV array. One inverter can be used for the whole array or separate inverters may be used for each string of modules. PV modules with integrated inverters can be directly connected to the electricity network but still play a very limited role (IEA PVPS, 2008b).

Grid-integrated centralized systems perform the functions of centralized power stations. The power supplied by such a system is not associated with a particular electricity customer, and the system is not located to specifically perform functions on the electricity network other than the supply of bulk power. These systems are typically ground mounted and functioning independently of any nearby development.

In off-grid applications, where no electricity grid is available, the system is connected to a battery via a charge controller. This stores the electricity generated for future use and acts as the main power supply. An inverter can be used to provide AC power, enabling the use of normal electrical appliances. Typical off-grid applications are found in electrification for remote areas (e.g. mountain huts like the Schiestelhaus) or rural electrification in developing countries. Small solar home systems in rural areas can cover basic electricity needs in single households. Sometimes these systems are connected to solar mini-grids, which provide enough power for several homes.

Off-grid PV system are sometimes called stand-alone systems and the typical size is around 1 kW. Defining such systems is becoming more difficult because of the development of mini-grids in rural areas by electricity utilities. Off-grid non-domestic installations were the first commercial application for terrestrial PV systems (IEA PVPS, 2008b).

In the past calculators and small electronic devices were often powered by PV. Due to improvements of the displays and other energy saving measures it is possible to power such devices for several years with one single battery. Therefore PV modules generating energy for these instruments decreased. On the other hand solar powered devices like parking meters, emergency phones or gauging stations in remote areas increased substantially over the last years. This is due to high connection costs to the grid and an increase in reliability of PV technology.

Projections of the share of grid-integrated systems are illustrated in figure 3. Although the dominance of grid-integrated systems is declining, they will still play a major role in the future. The focus of this paper is on this technology, due to the supremacy of grid-integrated systems.

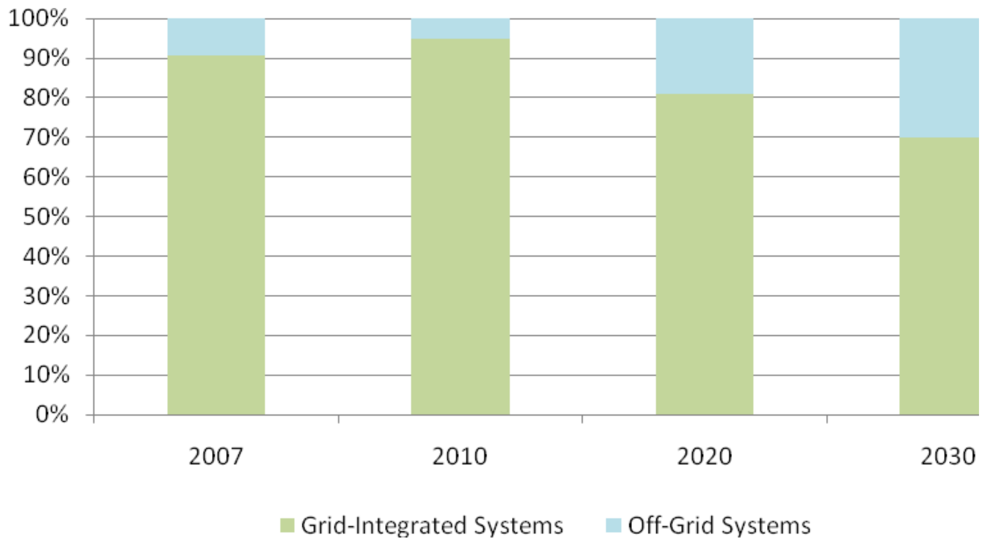


Figure 3: Projected Annual PV Installations by Application
Source: EPIA & Greenpeace, 2008

2. PV Technology and Grid Integration

In this chapter the pros and cons of different PV technologies are being explained.
It will highlight the most common technologies of today and also the status of research and development of new technologies which should either cost less or be more efficient. The difficulties of integrating PV electricity into the grid are discussed in the end of the chapter.

2.1 PV Technology

PV depends on the electrical properties of certain materials, known as semiconductors, which allow them to transform sunlight into electricity. These semi-conductor materials can be adapted to release electrons, the negatively charged particles that form the basis of electricity. While a number of materials have this semiconductor property, the one most commonly used in PV is silicon, an element most commonly found in sand. On its own, silicon is very resistant to electrical current, but its properties can be altered by doping it, or combining it with small amounts of other materials that make it receptive to either a positive or negative electrical charge (EPIA & Greenpeace, 2008).

All PV cells have two layers of semi-conductors, one positively charged and one negatively charged. When a positively charged layer of silicon is placed against a negatively charged layer of silicon, it forms an electrical field through which electrical charges can pass, generating DC. Sunlight, carrying solar energy, creates this charge. By connecting the silicon to a conductive metal, this charge can be concentrated into an electrical current, which can then be fed to any device that uses electricity. The flow of electricity increases with the intensity of the light. Therefore PV system can also generate electricity on cloudy days. PV doesn’t need bright sunlight in order to operate and days with clouds can even result in higher energy yields than days with a completely cloudless sky due to the reflection of sunlight (EPIA & Greenpeace, 2008).

PV cells are generally made either from crystalline silicon (sliced from ingots, castings or from grown ribbons) or from thin film, deposited in thin layers on a low-cost backing. In 2008 about 90 percent of the cell production has involved crystalline silicon.

Figure 4 shows the market share of the most common technologies since 1999. The share of cadmium telluride increased steadily over the last couple years due to the fact that this material can be used for thin film cells. Future plans and hopes have a strong focus on the thin film technology either based on silicon or other materials.

To reduce the high material losses in the production phase of crystalline silicon wafers, different ribbon growing methods (German “Bandziehverfahren”) have been developed. Thin films are dragged out of the silicon smelter directly. The silicon ribbons have already the thickness which is needed for the wafers. The flat ribbons only need to be cut into single pieces, most commonly with the help of lasers. The cost reduction potential for this process is quite high.

A special ribbon growing method is the so called edge defined film fed growth (EFG). This process could become very important in the future because the material loss when cutting the wafers can be avoided. Nevertheless until now amorphous silicon (a-Si) is the only thin film technology which made a breakthrough to mass production and which could be established on the market (Schott, 2009).

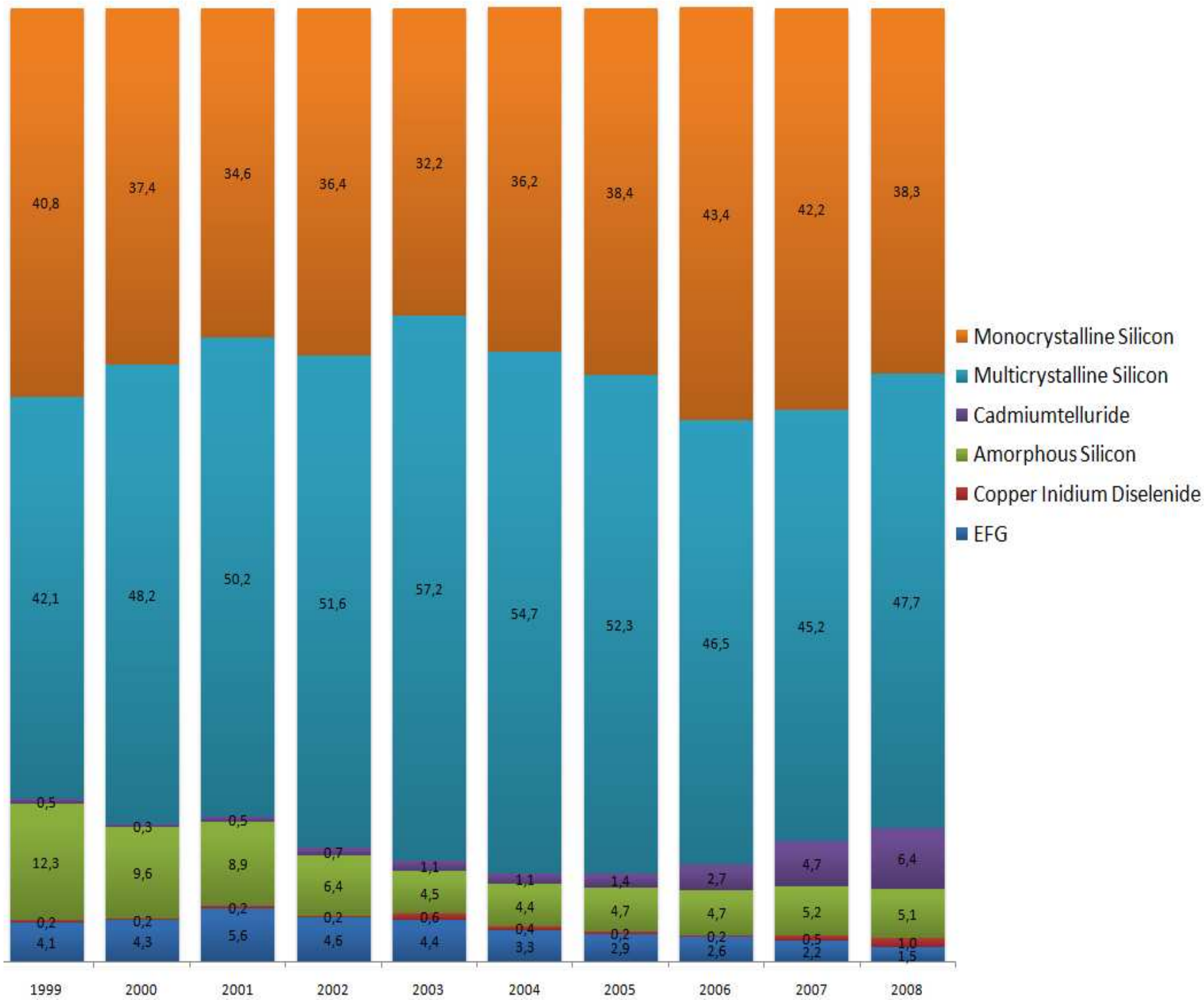


Figure 4: Market Share of Different Solar Cell Technologies
Source: Photon, 4/2009

PV cells are typically clustered and incorporated into a unit, usually by soldering them together under a sheet of glass. These modules are robust, reliable and weatherproof and can be adapted in size to the proposed site, and quickly installed. EPIA reports a general guaranteed power output by the module producers of 80 percent of the nominal power, even after 20-25 years (EPIA & Greenpeace, 2008).

When a PV installation is described as having a capacity of certain kWp (Kilowatt peak), this refers to the output of the system under standard testing conditions (STC), allowing comparisons between different modules. Watt peak is a convenient measure because the output of typical devices varies widely with levels of sunshine and other conditions. Mean output will typically be much lower than peak output; however if a system has been installed in an appropriate situation, peak output should be achieved under good conditions. Even under these conditions not all the peak output will be delivered to the user. Some power will be lost in the conversion of DC (produced by the PV cells) into AC required for household use.

The expected mean production of electrical energy of a newly build grid-integrated PV system has increased continuously over the last years due to technical improvements. Today you can expect an output between 700 and 1,000 kWh per kWp and year. For older systems the output is between 550 and 820 kWh per kWp and year. For an effective output of 1 kW PV cells of about 8-10 square meter are needed. This means for a new system you can expect an effective energy yield of 70-125 kWh per square meter and year (Dietrich, 2006). These figures are for Austria and obviously differ with varying irradiation.

2.1.1 Crystalline Silicon Wafers and Thin Film Technology

The basic input material for monocrystalline silicon ingots, multicrystalline silicon ingots or multicrystalline silicon ribbons is highly purified silicon or virgin silicon. The process is the same as for producing semiconductor grade silicon. A process known as Crystal Growing transforms multicrystalline silicon into samples with a singular crystal orientation, known as ingots. The ingots need to be cut into bricks or blocks and then sawn into thin wafers, whereas the ribbons are cut directly to wafers of desirable size.

The most expensive part of the silicon production is the purification process. Today silicon is purified based on chemical gaseous. The most common method is the Siemens process where high-purity silicon rods are exposed to trichlorosilane at 1,150 °C. The trichlorosilane gas decomposes and deposits additional silicon onto the rods, enlarging them according to its chemical reactions, producing multicrystalline silicon. There are attempts to replace the current expensive chemical purification process by cheaper alternatives like metallurgical purification but no methods are available for the mass market right now (IEA PVPS, 2008b).

The key current production countries are Germany, the USA, China and Japan. The selling price of solar photovoltaic grade silicon in 2007 was at least two to three times the price in 2003, with increases of 20 percent to 25 percent each year (IEA PVPS, 2008b). In 2009 the price for long-term silicon contracts has fallen suddenly about 50 percent from a year before and came close to the spot market price of $ 67 per kg, or about $ 0.50 per Watt (Wang, 2009).

The economy crisis has made it difficult for developers in 2009 to borrow money for installing large solar energy projects in Europe and the United States. Many solar wafer and cell makers who signed long-term contracts in 2007 and 2008 have either renegotiated or cancelled their contracts when silicon cost $ 300 per kg at the spot market and $150 per kilogram for long-term contracts (Wang, 2009). Some project developers should be benefiting from these price declines but on the long run it is expected that silicon prices will increase again.

The silicon ingots are of two types: monocrystalline and multicrystalline. In monocrystalline silicon (also called single crystal silicon) the crystalline framework is homogenous, which can be recognized by an even external colouring. Large single crystals are exceedingly rare in nature and are also difficult to produce in the laboratory. The wafer is sliced from single-crystal boules of grown silicon. These wafers or cells are then cut as thin as 170 microns (0.2 mm) and less. Research cells have exceeded 24 percent efficiency (compare figure 6) and a commercial module of monocrystalline silicon of reached 22 percent (Sunpower Corporation module).

Multicrystalline silicon (or polycrystalline silicon) is composed of a number of smaller crystals or crystallites and is a material consisting of multiple small silicon crystals. The cells can be recognized by a visible grain and multicrystalline silicon is sliced from blocks of cast silicon. These wafers or cells are both less expensive to manufacture and less efficient than monocrystalline silicon cells. Research cells approach 20 percent efficiency, and commercial modules approach 15 percent (Solarserver, 2010).

An interesting trend is the decrease of wafer thickness, strongly motivated by the rising price of silicon feedstock and an ongoing focus on improving manufacturing yield (IEA PVPS, 2008b). Thinner wafers mean less silicon needed per solar cell and therefore lower cost. The average thickness of wafers has been reduced from 320 microns in 2003 to 170 microns in 2008. Over the same period, the average efficiency has increased from 14 percent to 16 percent. By 2010, the aim is to reduce wafer thickness to 150 microns whilst increasing efficiency to an average of 16.5 percent (EPIA & Greenpeace, 2008).

Another technology mentioned above is thin film modules which raised high expectations in the last years. Thin film uses coating technologies where extremely thin layers of photosensitive materials are being deposited onto a low-cost backing such as glass, stainless steel or plastic. The big advantage of this technology is lower production costs compared to the more material-intensive crystalline technology. The disadvantage is substantially lower efficiency rates. There are three types of thin film modules commercially available at the moment. These are manufactured from amorphous silicon (a-Si), copper indium diselenide (CIS) and cadmium telluride (CdTe). All of these have active layers in the thickness range of less than a few microns (e.g. CIS devices are approximately the same as the thickness of a human hair, making it very flexible and lightweight). The costs are also lower because less labour is needed for production compared to the assembly of crystalline modules, where individual cells have to be interconnected (EPIA & Greenpeace, 2008).

Several new companies are working on the development of thin film production, based on a roll-to-roll approach. This means that a flexible substrate, for example stainless steel, is coated with layers in a continuous process. The successful implementation of such a production method will offer opportunities for significantly higher throughput in the factory and lower costs. EPIA (2009) expects a growth in the thin film market share to more than 20 percent of the total production of PV modules by 2010.

Among the commercially available thin film technologies, a-Si is the most important in terms of production and installation, with 5.1 percent of the total market in 2008 (compare figure 4). Multicrystalline thin film on glass is a promising thin film technology, which is now entering industrial production. Microcrystalline technology, in particular the combination of amorphous silicon and microcrystalline silicon, is another approach with encouraging results.

A production capacity outlook is illustrated in figure 5. In 2009 about 82 percent of the production capacity is covered by c-Si modules. Until 2013 EPIA (2009) expects this number to drop to 75 percent and thin film production to increase to 25 percent.

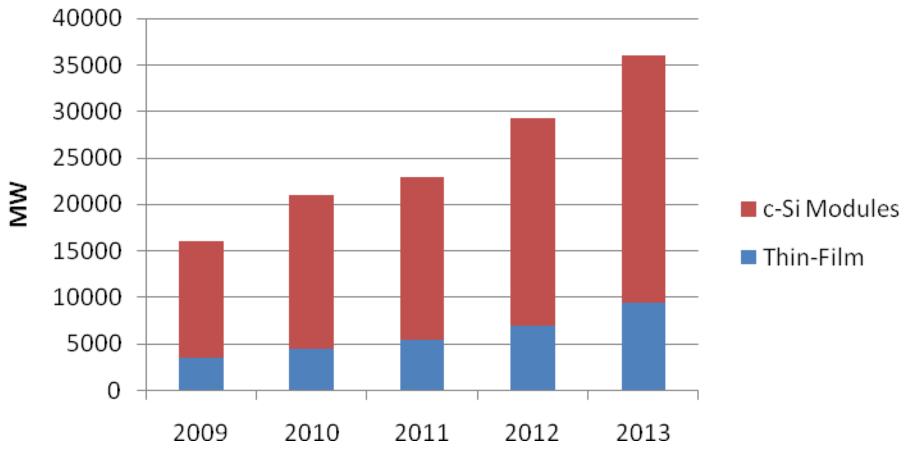


Figure 5: Production Capacity Outlook – Crystalline Technologies vs. Thin Film
Source: EPIA & Greenpeace, 2008

2.1.2 Other Cell Types

For reasons mentioned above recent research and developments efforts are trying to replace the expensive PV cells out of silicon with thin film modules out of different materials. Besides the research with the material Cadmium Telluride, testing with “Sulfosalze” using a method called “Ionenzerstäubung” is being done. With this method newly developed semiconductors efficiencies of almost one percent have been reached. Now scientist are about to optimize the “Sulfosalze” and coordinate the reactions of the different layers. Although these developments are in status of fundamental research right now, the use of the very abundant available “Sulfosalze” could revolutionize the production of PV cells (science.orf, 2008).

Researchers calculated that the costs of a well-engineered thin film cell would be the half of a silicon produced PV cell. If this thin film technology would be produced on the basis of “Sulfosalze” the costs would be another 25 percent lower. It is not expected that this technology will hit the market very soon due to problems with low efficiency but this could change within the next years (science.orf, 2008).

There has been a steady increase of cell efficiency over the last decades for almost all technologies. Multijunction concentrators reach an efficiency of more than 40 percent already (compare figure 6). Although these modules are not produced in a large scale the figures look promising for the future. Today, large scale production is done with monocrystalline and multicrystalline silicon but thin film modules could be next soon. Figure 6 illustrates the development of the efficiency of the different technologies over the last decades.

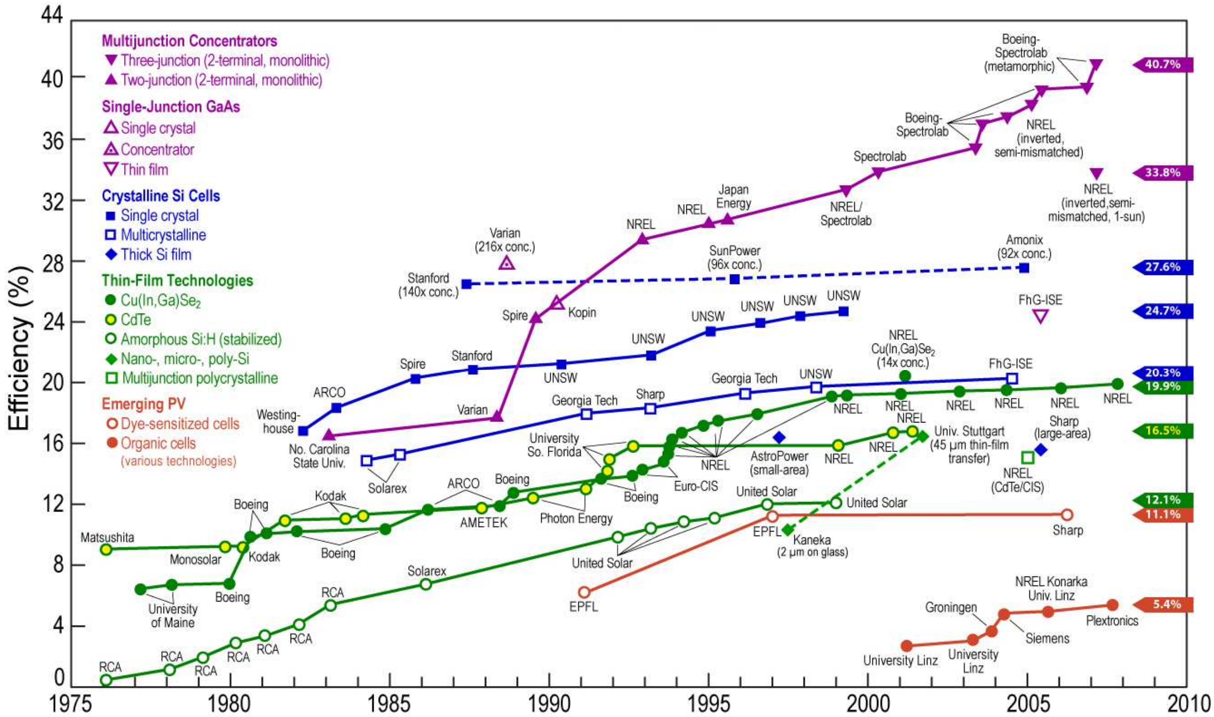


Figure 6: Development of Cell Efficiencies until 2008
Source: NREL, 2009

Regardless of the optimization of the production processes there are natural limits (loss mechanisms) of crystal silicon regarding efficiency. This leads to a theoretical maximum level of efficiency of 28 percent for crystal silicon (Solarserver, 2010).

Another very important factor besides the efficiency is the production cost per Watt. Although thin film modules have a lower efficiency they are generally cheaper to produce. This could have a major implication for PV producers in the upcoming years. No matter which technology will be dominating in the future, a study of the U.S. Department of Energy (US Dept. of Energy, 2008) shows generally a very positive trend. Many PV technologies will have production costs under 1 $/W by 2015 (compare figure 7).

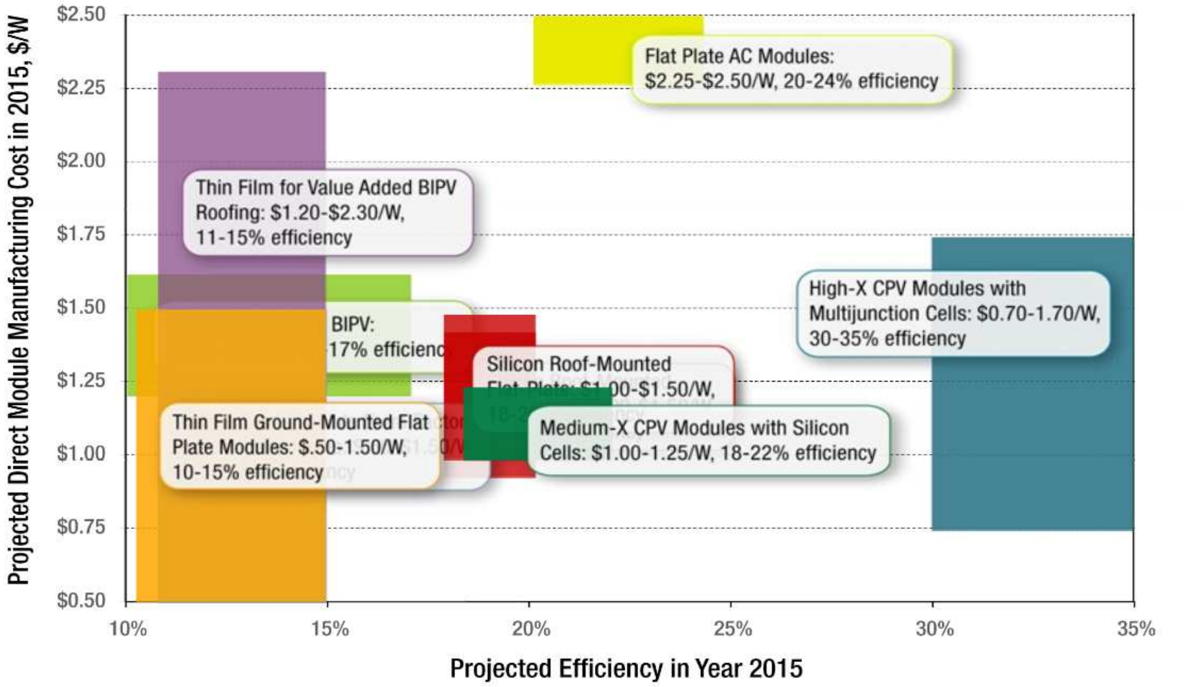


Figure 7: Projected Efficiencies and Costs of PV Systems in 2015
Source: U.S. Dept. of Energy, 2008

Another PV technology is concentrator cells. These cells work by focusing light on to a small area using an optic concentrator with a concentrating ratio of up to 1.000. The small area can then be equipped with a material made from semi-conductors like a multi-junction gallium arsenide type. They reach efficiencies of up to 30 percent and in laboratories of up to 40 percent (EPIA & Greenpeace, 2008). The two main drawbacks with concentrator systems are that they cannot make use of diffuse sunlight and must always be directed very precisely towards the sun with a tracking system.

2.1.3 Inverters

Since PV systems produce direct current (DC), inverters are used to convert the power into alternating current (AC). This is essential for grid connection in order to feed electricity into the distribution network. Inverters usually have a capacity between a few kW (3-6 kW are most frequently used) and a few hundred kW for large-scale systems (EPIA & Greenpeace, 2008).

Typically there are three types of solar inverters in use (wikipedia, 2010a):

- Stand-alone inverters: These inverters draw its DC energy from batteries charged by PV modules and are often used in isolated systems or remote areas.
- Grid tie inverters: Grid-tie inverters match the phase with a utility-supplied sine wave. For safety reasons, they are designed to shut down automatically upon loss of utility supply. These inverters can’t provide a backup power during a utility breakdown.

- Battery backup inverters. Battery backup inverters are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid.

2.2 Grid Integration

This chapter gives a brief overview of the difficulties and technical preconditions that are needed to feed solar electricity into a grid. Figure 8 shows how electricity generated by solar cells in roof-mounted PV modules is transformed by an inverter into AC power suitable for export to the grid network. The solar radiation is absorbed and transformed into electricity by the PV module (1). After that the PV module combiner or junction box (2) gathers the electricity of the different modules and transports it via the DC cable (3) to the DC disconnector (4). The disconnector is a current safety installation right before the inverter module (5) which transfers the DC into AC. At last AC is fed in (6) and goes via the safety fuse (7) into the plugs or the grid.

The householder/generator can either sell all the output to the local power utility or use the solar electricity to meet the demand in the house itself. The additional surplus can then be fed into the grid. Larger systems usually feed the generated electricity straight into the grid but a self use is also possible. Different technical issues have to be considered depending on the capacity and the grid.

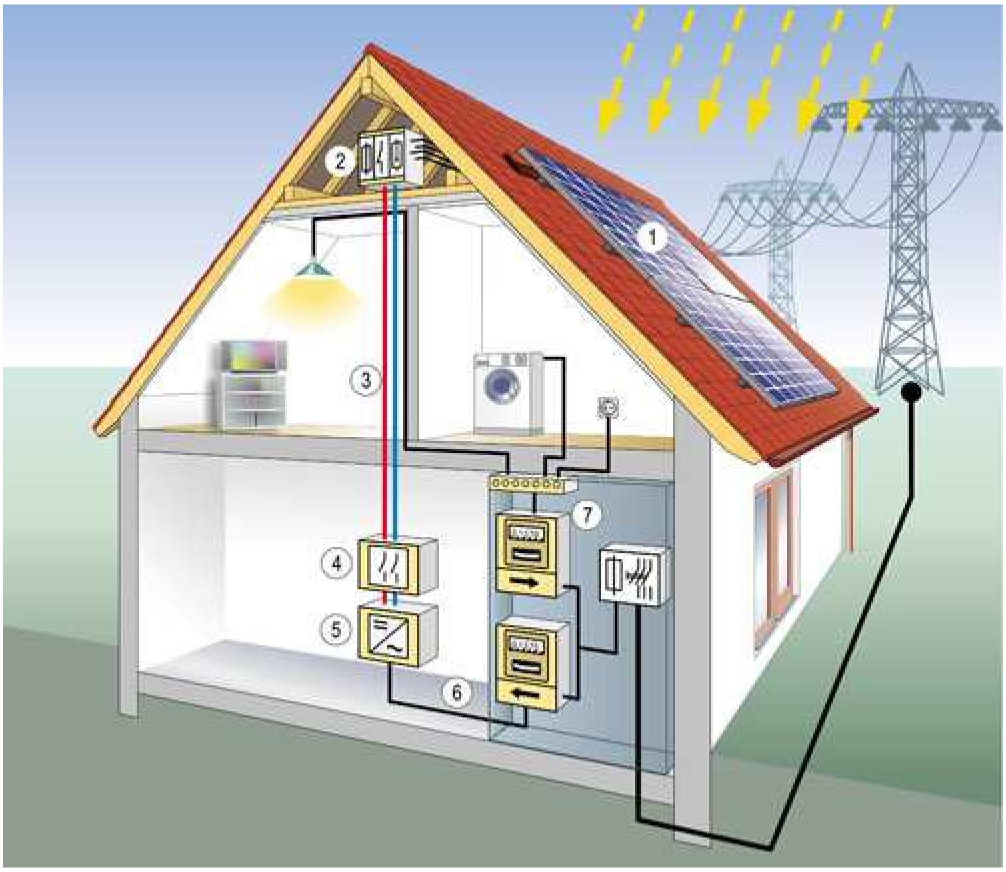


Figure 8: Example of a Grid-Connected PV System
Source: solar-individuell, 2010

For grid integration five technical terms are especially important (IEA PVPS, 2008c):

- Overvoltage/Undervoltage
- Harmonics
- Unintended Islanding
- Peak Power Supply
- On-Site Generation

Overvoltage and Undervoltage

When the voltage in a circuit or part of it is raised above its upper design limit, this is known as overvoltage and the opposite is called undervoltage. Similar to water, electricity current flows from a higher voltage point to a lower voltage point. Line voltage generally decreases as it goes to further end. Electronic and electrical devices are designed to operate at a certain maximum supply voltage, and considerable damage can be caused by voltage that is higher than that for which the devices are rated. Therefore the voltage must be kept in a certain range usually defined by laws or guidelines. In order to control the voltage within the range, utility companies apply various technology countermeasures (IEA PVPS, 2008c).

Harmonics

Harmonics are electric voltages and currents that appear on the electric power system as a result of certain kinds of electric loads. Harmonic frequencies in the power grid are a frequent cause of power quality problems. Usually electricity supplied from the grid is AC but some electronic devices and appliances need DC power or AC at a different frequency. Grid loads such as appliances and computers use power electronics technologies to change the grid AC to the desired current waveform. In this process, those devices generate “harmonics” that may distort the grid waveform. *Harmonics can be defined as a component integral multiple of the fundamental waveform* (IEA PVPS, 2008c). Harmonics can be avoided by installing filters. When a filter is defect or in severe harmonic situations the devices could overheat and even catch fire (IEA PVPS, 2008c).

Unintended Islanding

In every transmission and distribution line electricity is usually constantly flowing. In order to disconnect the distribution lines, breakers and reclosers are designed to stop supplying power. Otherwise in cases of environmental influences (e.g. lightning) or other technical failures (e.g. collapse of an electrical tower) serious accidents could happen. Every distributed power generator (including PV) is designed to stop supplying the power in such cases. This condition is called unintended islanding. One of the biggest concerns of unintended islanding is an increasing risk of accident due to an electric shock of the worker who tries to repair the network. This could lead to severe injuries when the generator keeps supplying the power to the load unintentionally (IEA PVPS, 2008c).

Peak Power Supply

Usually the electricity demand increases in daytime and decreases in night time. The imbalance between power demand and supply leads to fluctuation of grid frequency or voltage, and it could damage demand side equipment. Since PV generates electricity in the daytime, PV can contribute to supplying the peak load, especially when using PV systems for cooling. On the one hand utilities can benefit from the peak demand reduction from PV power. On the other hand also PV owners can benefit due to higher peak prices during the day, although the effect is limited. In many countries the demand remains relatively high in the evening and the limited irradiation during winter days in regions of higher latitudes are also quite significant (IEA PVPS, 2008c).

On-Site Generation

Grid losses are around 6 percent per 100 km for the most common European transmission voltages (wikipedia, 2010b). In many countries large power plants are constructed far away from the point of demand. Since PV can be integrated or mounted on any building requiring electricity these losses could be minimized. Especially for industry buildings this is an interesting option. On the other hand the incorporation of PV has a significant visual impact on the building design. On-site PV is a major issue considering the feasibility stage of projects and progressed on some, in order to give the construction industry experience of such technologies and increase public awareness (IEA PVPS, 2008c).

3. Global Developments

This chapter gives an overview of global developments of PV technology. It explains the distribution of the worldwide cell production and the global market developments. An outline of the history and future of PV power capacity is also given. At the end of the chapter the PV market potentials of selected countries are being analyzed. These include the biggest markets today and some promising ones of the future.

3.1 PV Cell Production Worldwide

The worldwide cell production has increased significantly over the last years. As illustrated in figure 9 the MW capacity increased almost 40 percent between 2005 and 2006, almost 69 percent between 2006 and 2007 and already 85 percent between 2007 and 2008. It is expected that the PV industry is prepared to deliver large quantities of modules and to follow the future PV demand in the short-term. To continue this success story the PV industry requests certain policy frameworks, low administrative barriers and easy procedures to connect PV to the grid.

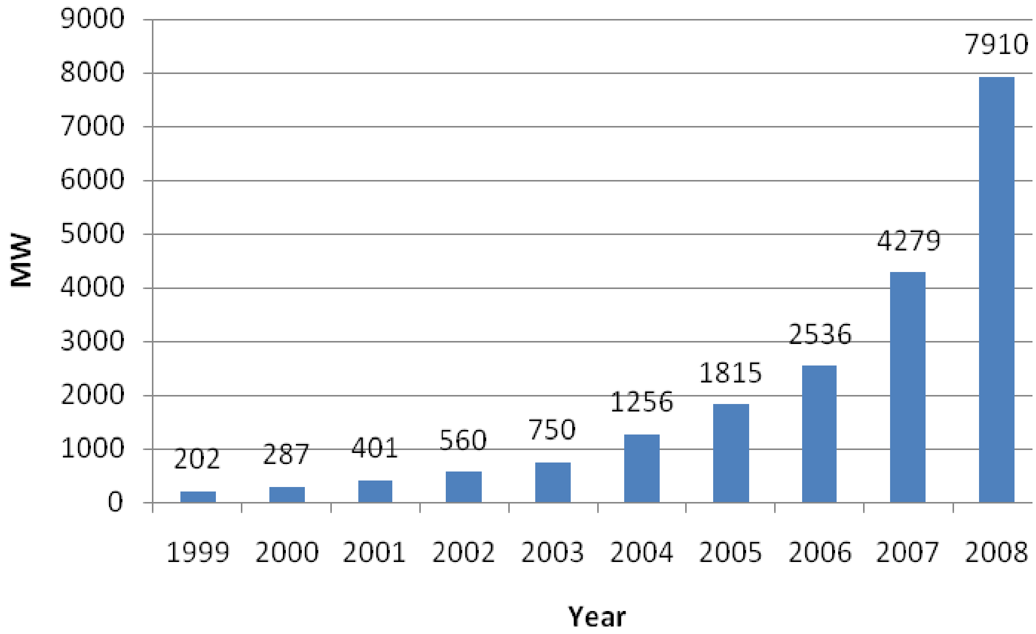


Figure 9: Development of Worldwide Annual Solar Cell Production
Source: Photon, 4/2009

EPIA (2009) expects a continuing increase of the PV production capacity over the next years. As illustrated in figure 10 an annual production capacity of more than 22,000 MW until 2013 could be possible, although there are some question marks as investments in new production capacities will only take place if the PV demand increases as expected by the industry.

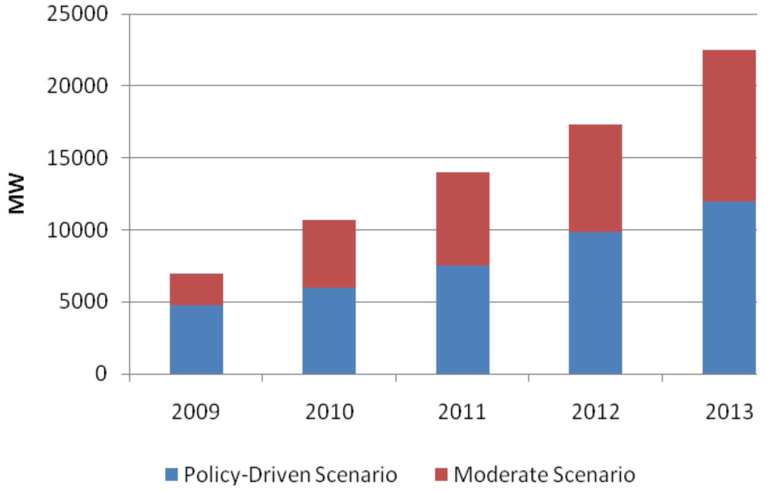


Figure 10: Projected Global Annual PV Market Development in MW
Source: EPIA, 2009

In order to make better predictions EPIA designed two market development scenarios: A policy driven one with higher feed-in tariffs and subsidies and a moderate one with more basic assumptions. Comparing these two scenarios there are quite significant differences which indicate the importance of a sound policy framework. For a moderate scenario “only” about 12,000 MW of production capacity will be needed. There is still high uncertainty when it comes to predictions. Comparing other scenarios the market forecasts for 2010 vary already significantly ranging from 6.8 GW (Navigant Conservative Scenario), 7 to 10 GW (EPIA Scenarios) and on the high-side 17 GW (Photon Consulting Scenario).

In the recently published eighth ”Annual Photovoltaic Status Report” the European Commission's Joint Research Centre (JRC) has reported that a massive increase in PV production capacity is underway and that worldwide production capacity for solar cells would exceed 38 GW by the end of 2010. The report also notes that production volumes in 2008 increased by 80 percent as compared to 2007, reaching 7.3 GW of potential output with China, Taiwan and Europe all adding significant capacity (Jäger-Waldau, 2008).

The key problem is that market demand will be significantly below production capacity levels. When comparing figure 9 and figure 10, the production capacity in 2008 (7,910 MW) is already above the PV market demand of 2009 (which was 5.96 GW in 2008 according to Solarbuzz, 2009). That discrepancy of supply and demand could increase significantly within the next years.

Due to these overcapacities and with the temporary end of the silicon shortage, it is expected that module prices will fall back on their historical learning curve observed over the last 3 decades. This curve showed a 20 percent module price reduction each time the cumulative PV power installed was doubled. In the first half of 2009 a first price decrease was already visible (EPIA, 2009).

Figure 11 illustrates the worldwide PV cell production in 2008. China was number one in cell production with a capacity of more than 2,500 MW followed by Germany (1,460 MW) and Japan (1,269 MW). The overall cell production in 2008 was almost 8 GW.

Comparing 2007 to 2008 there have been substantial increases in the production capacities of certain countries. Germany's production increased from 842 MW to 1,460 MW, Japan from 922 MW to 1,269 MW and the USA from 265 MW to 431 MW but the most impressive increase was in China from about 1,000 MW to 2,589 MW (IEA PVPS, 2008b).

If the module price decrease is passed on to the final customer and leads to a decrease in PV system prices, the generation cost of PV electricity could compete even sooner with conventional retail electricity prices from the grid.

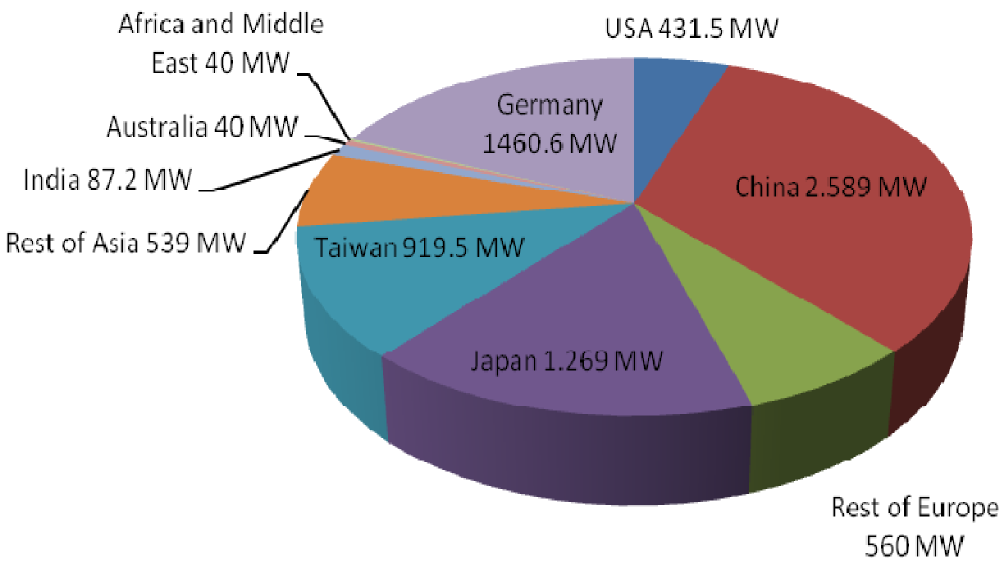


Figure 11: PV Cell Production Worldwide in MW in 2008
Source: Photon, 4/2009

Figure 12 gives an overview of the biggest PV cell producers worldwide in 2008. Biggest producer in 2008 was the German company Q-Cells followed by the Japanese Sharp and Chinese Suntech.

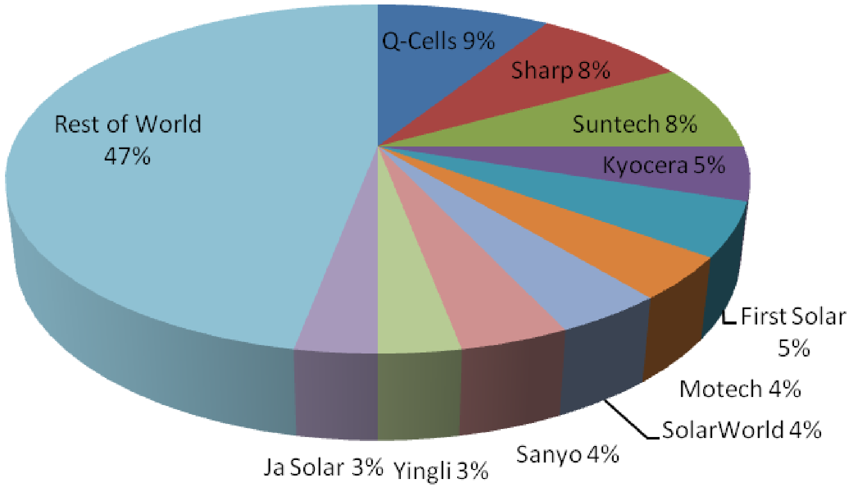


Figure 12: Top 10 PV Cell Producers 2008
Source: EPIA & Greenpeace, 2008

3.2 Overview of Global Market Developments

Solarbuzz (2009) predicts that the European PV markets, the United States grid-integrated PV market and the major Asian and Pacific PV markets will account for 96 percent of the global PV demand in 2010.

After extremely challenging industry conditions in 2009 due to the economic crisis, excess manufacturing capacities (as illustrated above) could still be an issue in the future. Solarbuzz (2009) expects the PV industry to return to a growth path in 2010, resulting in a global market of 7.4 GW in that year, even with a 2 GW demand reduction in Spain after a major policy adjustment. This is a rather conservative scenario compared to other scenarios mentioned above (7 to 10 GW EPIA scenarios and the 17 GW Photon Consulting scenario).

Nevertheless the global market could reach 7.4 GW in 2010 (up from the 5.95 GW in 2008). This results to a more than doubling of the US market size to well over 1 GW in 2010 together with a German market size of 3.2 GW (Solarbuzz, 2009).

Solarbuzz (2009) expects that a major global factory-gate module price reduction in the first half of 2009 could establish the foundation for a rapid demand growth in feed-in tariff driven European markets in 2010. European country markets are very heterogeneous and characterized by a wide variation in customer and application segments. There are also many different barriers to market development. Germany, Italy and Spain are still the dominating PV countries in Europe and will claim an 83-88 percent market share in Europe by 2010. The new emerging European PV markets will contribute 2.9 GW to the overall market demand by 2013 (Solarbuzz, 2009).

In the Asian and Pacific region Australia, China and India will soon join Japan and South Korea as major regions contributing to the global market demand within the next 5 years. Right now China and especially India are mainly manufacturing hubs. This will change substantially and they will be become an engine for the PV market demand growth in this region. The projects in the pipeline for this region have already surpassed 7 GW in 2009 (Solarbuzz, 2009). Japan is also ready to return to growth in 2010 after four years of downturn.

67 distinct project proposals over one MW in India and 45 identified MW-scale project proposals in China highlight the development of these countries. Additionally over 70 distinct funding programs and incentive policies at the national and local level collectively in India and China (targeting systems smaller than one megawatt) point out the effort to become

major players in the region. Therefore these countries represent a significant market opportunity over the next five years (Solarbuzz, 2009).

Figure 13 illustrates a PV market share forecast for 2010. The largest market will be Germany followed by the USA. Italy is predicted to be in third place already.

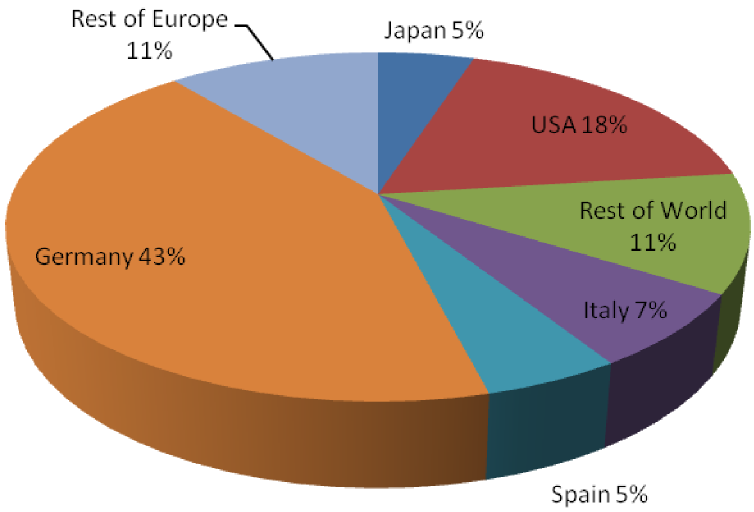


Figure 13: PV Market Share Forecast for 2010
Source: Solarbuzz, 2009

3.3 Total Photovoltaic Power Installed

Although the solar PV market has been booming over the last decade the demand for solar installations has dropped in 2009 due to the recession and credit crunch, as well as government incentive cutbacks in Europe. Solar panel inventories have built up, and competition has intensified for the reduced available business, driving prices down across the solar PV supply chain. The demand for solar installations is expected to come charging back in 2010 as new government incentives in the U.S., Europe, and China gain traction. By the end of 2008, the global cumulative capacity was approaching 15 GW. In 2009 Europe was in the first place regarding capacity with more than 9 GW (representing over 65 percent of the global cumulative PV installed capacity). Japan (2.1 GW) and the US (1.2 GW) are following behind, representing 15 percent and 8 percent, respectively, of the global cumulative PV power installed (EPIA, 2009).

The historical development of the global cumulative PV power is shown in figure 14. The overall capacity increased from 1,166 MW in 1999 to 14,370 MW in 2008 that is a capacity increase of more than 12 times in 10 years.

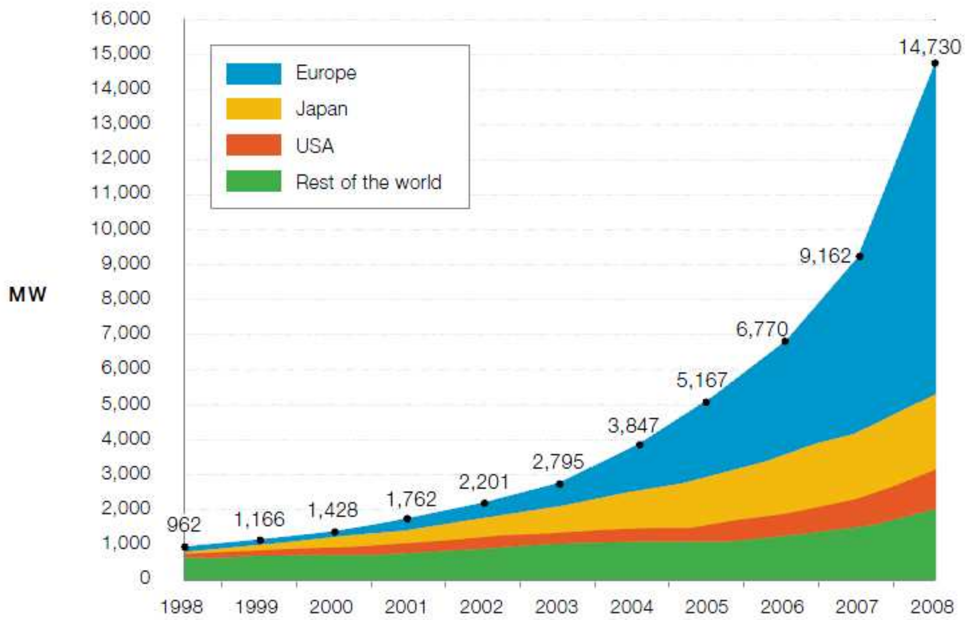


Figure 14: Historical Development of Global Cumulative PV Power Installed per Region
Source: EPIA, 2009

The world solar PV market grew to 5.95 GW in 2008, reaching a record high and representing a growth of 110 percent over the previous year. Europe was also number one when it comes to demand and accounted for 82 percent of the world demand in 2008. Germany was displaced from the top position by Spain's 285 percent growth and the US advanced to number three. Rapid growth in Korea allowed it to become the fourth largest market, closely followed by Italy and Japan. Overall 81 countries contributed in 2008 to the 5.95 GW world market. In 2008, the global PV market growth has more than doubled compared to 2.4 GW in 2007 but this has definitely changed in 2009 (Solarbuzz, 2009).

The world solar cell production reached 6.85 GW in 2008 (up from 3.44 GW in 2007) and the overall capacity utilization rose to 67 percent in 2008 from 64 percent a year earlier. The 123 percent growth for thin films in 2008 on the supply side (to 0.89 GW) confirms the production potential and future expectations of this technology. China and Taiwan continued to increase their share of global solar cell production. Their market increased 44 percent in 2008 compared to 35 percent in 2007 (Solarbuzz, 2009).

The shortage of multisilicon supply to the solar industry seems to come to an end and was eased in 2008. In MW-terms the multisilicon supply increased by 127 percent. Number one producer of multisilicon was the United States which accounted for 43 percent of the world's supplies. The average global wafering capacity increased 81 percent and grew to 8.30 GW (Solarbuzz, 2009).

Overall the PV industry generated $ 37.1 billion in global revenues in 2008, which was an increase of 11 percent compared to 2007 (Solarbuzz, 2009).

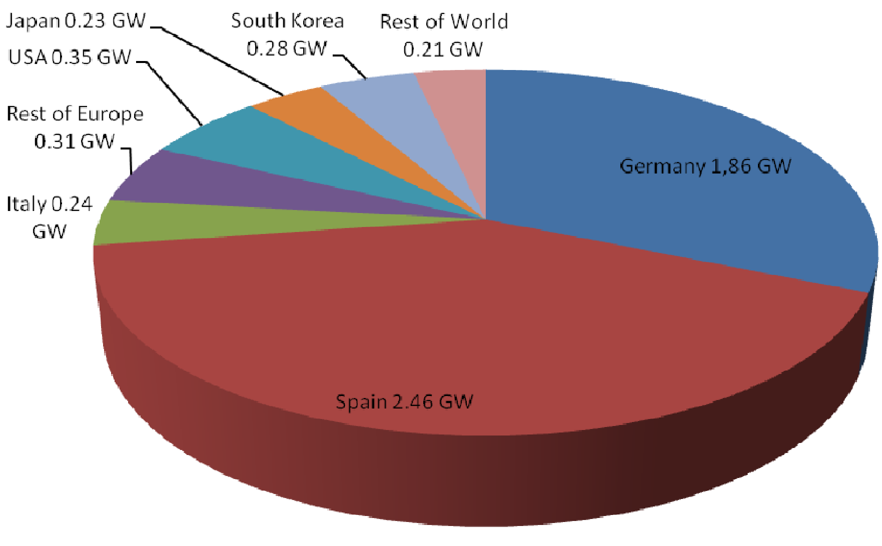


Figure 15: PV Market Demand in GW in 2008
Source: Solarbuzz, 2009

Figure 15 illustrates the relations of the global PV market demand in 2008. The most capacity has been installed in Spain followed by Germany. The total demand in 2008 was 5.95 GW and the trend to grid-integrated systems continued. This reflects the growth in investor-owned large-scale PV power systems being developed in response to feed-in tariff frameworks in place in a number of countries. Roughly 90 percent of this generating capacity consists of grid-integrated electrical systems.

3.4 PV Trends of Selected Countries

This chapter gives an overview of the most important PV countries and of countries which could be interesting for PV investments in the future. It focuses on the different supporting schemes and their role for development of the sector.

3.4.1 Germany, USA and Japan

Germany, USA and Japan will represent about two-third of the PV market in 2010 according to Solarbuzz (2009) and therefore are being summarized under this chapter. They represent the strongest or most developed markets and give an indicator for future developments.

Germany will take back its number one position in 2010 as the most mature market and is still clear number one in cumulative installed PV power worldwide. Success factors are a proven feed-in tariff scheme, good financing opportunities, high potential for future development, good availability of skilled PV companies and good awareness of the PV technology. The Spanish PV market took over the lead regarding newly installed capacity in 2007 but due to a yearly subsidy cap, which has been set at 500 MW for 2009, has lost this top position to Germany again (EPIA, 2009).

Nevertheless it seems that the booming years for the German PV market are over and market growth will probably slow down in 2010. One reason is that the degression rates of the feed-in tariffs will be increased by 1 percent if the German PV market develops to a size larger than 1.500 MW in 2009, which is expected for 2010. Another reason could be the lack of investments in new grids. Too many PV operators could endanger grid stability and make new investments necessary. Considering this fact and that the price of PV systems will decrease accordingly with the feed-in tariff degression rates, the annual German PV demand could be up to 4 GW by 2013 if the present support scheme is maintained, (EPIA, 2009).

In the USA the pace of growth for PV will primarily be determined by financing, permitting and regulatory issues, rather than by product supply or PV subsidy constraints. These factors impacted the market size over the last four years. 97 percent of the market size in 2010 is already backed up by identified funding sources, projects under development and renewable portfolio standard driven demand. 60 large planned projects are already listed which contribute to a 2.3 GW demand in 2010 which provides the basis for rapid demand growth in the US (Solarbuzz, 2009).

The US federal tax credit for installing both residential and commercial PV systems has been extended in 2008 for 8 years through December 31, 2016.

The key provisions of the investment tax credit are (gosolarcalifornia, 2010):

- A 30 percent federal investment tax credit for both residential and commercial solar installations has been extended for 8 years through December 31, 2016.
- This credit eliminates the $ 2.000 cap on the tax credit for the purchase and installations of solar electric on residential properties.
- Utilities may now benefit from the credit as eligible tax credit recipients.
- The possibility for the authority to issue clean renewable energy bonds is extended through 2009.

Besides Europe and America also Asia has a state with long traditions in PV technologies. Japan is expected to become a GW market in 2010 for a policy-driven scenario and in 2012 for a moderate scenario (as shown in figure 16). Japan has set ambitious objectives to reach 14 GW of installed PV power by 2020 and 53 GW by 2030. There are many indicators for a good PV development in Japan. PV technology is well established and widely integrated in the building environment. Until now the development of the Japanese PV market has been dominated by residential systems. This has changed and there have been many announcements to build multi-MW PV plants, which is very promising for the future. The existing support mechanisms at national and regional levels have been reinforced recently. Investment subsidies and a new power purchase programme have been announced for public, commercial and industrial grid-integrated applications. An energy technology innovation plan called Cool Earth 50 has been developed which is looking towards 2050, with a long-term strategy for PV cells to achieve conversion efficiencies of 40 percent (EPIA, 2009).

Outlook

The US PV market has grown from 168 MW in 2001 to 1,110 MW by 2008, growing at a yearly rate of 31 percent during the period 2001-08. The significant growth witnessed by the US PV sector could be attributed to the strong support from the US Government in terms of tax credits. The recent extension of tax credits with effect from 1st January, 2009 until the year 2016, will further drive the US PV market towards the growth trajectory. Considering this, the US Solar PV market is expected to grow at a higher yearly rate of nearly 50 percent in the coming years. The US could reach a total installed capacity of more than 75 GW by the year 2020 (Aarkstore Enterprise, 2009).

Germany will still be the strongest PV market worldwide in the near future but a decrease of subsidies could change this scene in the long run. Right now it looks like the USA could take over the lead by 2013 as illustrated in figure 16. The reason for that is US policy driven scenario compared to an expected moderate scenario in Germany in the future. Japan's PV market will grow significantly in the next years but the neglects of the last years put Japan behind the US market and far behind the German one.

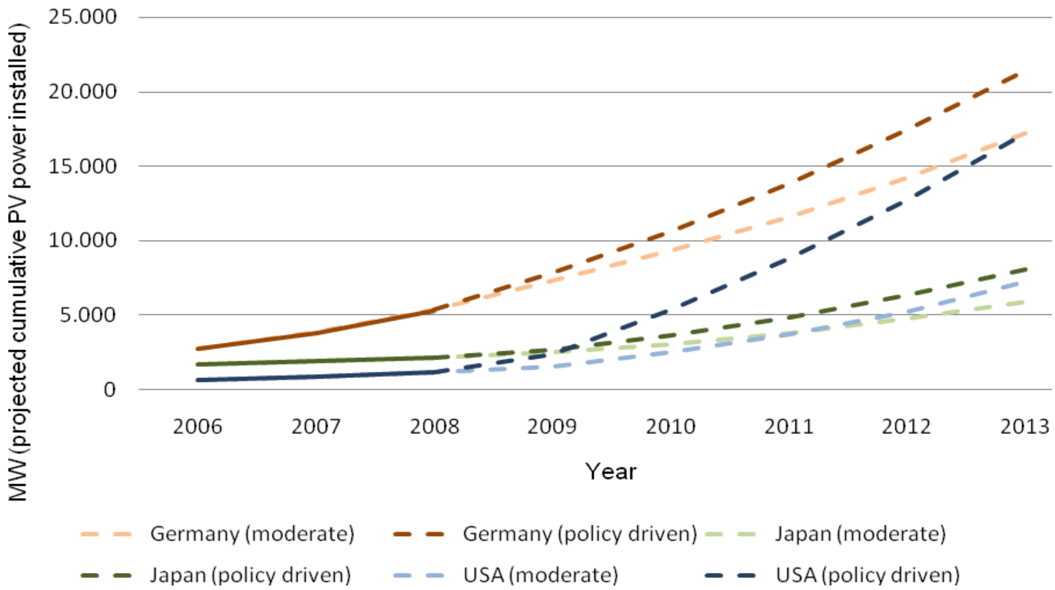


Figure 16: PV Market Overview and Development of Germany, Japan and USA
Source: EPIA, 2009

3.4.2 Italy and Spain

Spain and Italy have about the same geographical preconditions for PV installations. Comparing these two countries give a good overview of how different feed-in tariffs and subsidies can influence the development of a PV industry.

In Spain 2,605 MW were connected to the grid in 2008, reaching a cumulative PV power installed of 3,317 MW at the end of 2008, more than 95 percent of which were large-scale ground-mounted systems (Comisión Nacional de Energía). Whereas the Italian PV market rose to a cumulative capacity of 430 MW at the end of 2008, 338 MW of which was installed in 2008 alone (EPIA, 2009).

The world’s largest PV park is located in Spain near the town of Olmedilla (Castilla La Mancha). It was constructed in September 2008 and has a capacity of 60 MWp which generates about 85 GWh of electricity per year (pvresources, 2010).

Legislation

Italy introduced a feed-in law for renewable energies in July 2005 and the last decree from February 2007 has finally developed the PV market. Besides high sun irradiation, Italy offers a very attractive support scheme, mixing net-metering and a well-segmented premium feed-in tariff (EREC, 2009a).

In January 2009 the Italian government made an amendment to the law and extended the net metering to PV systems up to 200 kW. The PV system owner can now valorise the electricity he produces himself at the same price as the electricity he consumes traditionally from the grid. The PV system owner gets a credit (unlimited in time) for the value of the excess electricity which is fed into the grid. On the total electricity produced by the PV system, the owner also gets additionally to the valorisation of the electricity itself, the premium feed-in tariff. The present feed-in tariff scheme is valid until the end of 2010. Under these conditions a continuous growth of the Italian PV market can be expected (EPIA, 2009).

As mentioned above Spain decreased its annual installed capacity due to the large growth of the PV market in 2008. The Spanish government has put in place a strict cap, which allows only a 500 MW annual market from 2009 to 2011. The system of quarterly calls for projects has limited the Spanish market to 375 MW in 2009 (EPIA, 2009).

Electricity generation in Spain has two different regimes, which follow a fairly simple structure. Any energy that comes under the traditional label, such as oil and coal, goes into the ordinary regime bracket and all renewable energy sources go under the special regime label (EREC, 2009b).

It is in the special regime that the feed-in tariff promotion mechanism is implemented. Spain's feed-in tariff incorporates both fixed total prices and price premiums added to the electricity market price. Tariffs will be revised every four years taking into account whether objectives have been achieved for different types of energy and the evolution of costs. These revisions will not affect plants that are already in operation. The new tariffs are based on whether the installation is on buildings or on the ground. Installations are also classified in Type I and Type II based on their position, construction material and use (EREC, 2009b).

The Spanish feed-in tariffs are right now around 0.41 €/kWh for PV systems under 100 kW and 0.21 €/kWh over 100 kW. An amendment to the decree allowed the Spanish PV market to see an impressive growth in 2007 and especially in 2008. The decree has been in force since September 28, 2008. The new feed-in tariff establishes a quarterly pre-registration mechanism. The regulated tariff for each official announcement will be calculated according to the existing demand within the previous announcement, with a decrease in the remuneration if the quarterly cap is totally covered. This mechanism can lead to a decrease of the tariff between 10 percent and 16 percent per year depending on the market segment. Tariffs are still granted for 25 years. The system will probably be revised in 2011 according to the new PV targets to be set within the Renewable Energy Plan 2011-2020 (EREC, 2009b).

The Italian feed-in tariff is paid by the Ministry of Economy and Finance via an organization called GSE (Gestore dei Servizi Elettrici) and changes according to the plant size and level of building integration. The incentives are granted for 20 years up to a limit of 1,200 MW (EPIA, 2009). The rate suffers a decrease of 2 percent until 2010 when a new law issued by the Minister of Economic Development will determine new tariffs for PV plants starting their work after 31 December 2010. From January 2009, the Italian government extended the net-metering to PV systems up to 200 kW and modified the calculation method. The new net-metering is based on the balance of the value of the energy fed into the grid and the value of the expenditure to buy electricity from the grid. If, over a time period, there is an excess of electricity fed into the grid, the PV system owner gets a credit (unlimited in time) for the value of the excess of electricity. This measure is very attractive for the residential, public and commercial sectors. The Italian feed-in tariffs vary from 0.48 €/kWh for building integrated PV

(BIPV) in the range of 1-3 kWp to 0.35 €/kWh for non-integrated systems above 20 kWp (EREC, 2009a).

Summarizing the different legislation policies shows that the Italian policies incentivize the energy production, while Spanish policy gives an incentive to the energy sale. A study by the University of Las Palmas concludes that small photovoltaic plants (up to 5 kW) are more profitable in Italy, while in Spain, large farms win in profitability. As a result of that, the accumulated PV power in Spain in the last two years shows an increase of the 363 percent in front of the 46.6 percent for the same item in Italy (Diaz-Reyes, 2008).

Outlook

In a policy-driven scenario the EPIA (2009) expects that the Italian PV market reaches the GW scale by 2011, assuming that the administrative procedures will be harmonised at regional level, that the net metering will have a strong impact on the demand for PV systems and that the new feed-in tariff will have no cap limitation and will remain consistent with the existing one (compare figure 17).

The global financial crisis will have a negligible impact on the Italian Solar PV market. This is because the market is strongly supported by the government in terms of feed-in tariffs for solar PV installations in the country. The feed-in tariffs for PV in Italy has also been raised, thereby making the Italian solar PV market a lucrative investment hub. The rise in tariffs accompanied with the enormous growth potential of the country for solar PV development will lead to a high number of solar PV installations in the country. Considering the positive outlook of the Italian Solar PV market, the cumulative installed capacity is expected to grow at a compound annual growth rate of around 48 percent in the future years to reach nearly 50 GW by 2020 (Aarkstore, 2009).

If the strict cap of 500 MW annual PV market is not removed by the Spanish government the PV capacity increase in the next years will be rather restrained as shown in figure 17. Seeing the solar potential in Spain and the high national renewable targets, in a policy-driven scenario EPIA expects a removal of the cap which would allow a GW market by 2013. Other forecasts believe that in the long run, the Spanish Solar PV market will gradually grow and reach total capacity of 33,738 MW by 2020 (Aarkstore, 2009).

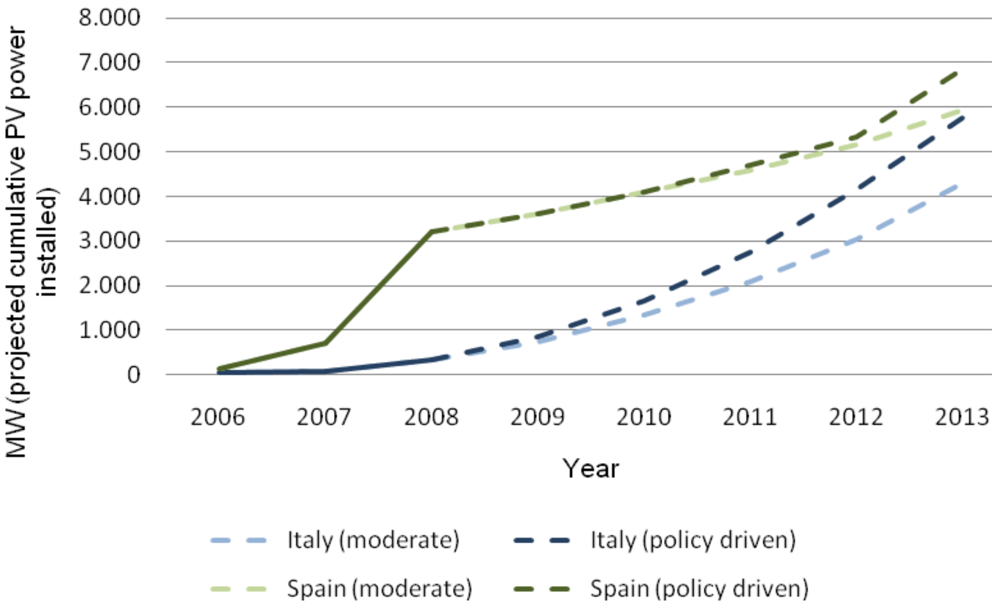


Figure 17: PV Market Overview and Development of Italy and Spain
Source: EPIA, 2009

3.4.3 Croatia and Turkey

Croatia and Turkey could be very interesting markets for PV investments in the future. Although both PV markets and their framework requirements are not really developed yet, the solar irradiation potential and the vicinity to big European markets could change the picture.

Croatia

In 2009 the PV capacity in Croatia is rather low with only 0.78 MWp including 0.12 MWp grid-integrated. Nevertheless Croatia is the official candidate member state of the EU since 2004. It recovered from the collapse of former Yugoslavia and is the second country, after Slovenia, with the strongest, market-oriented economy and stable democratic political system. Croatia has ratified the Kyoto Protocol and lowered successfully its carbon emissions. With the RES sector in development, Croatia is an interesting country for investors. Solar electricity generation has vast potential due to good irradiation of Croatian territory with the maximum PV output potential reaching 1,450 kWh/kWp. The Croatian government set a non-ambitious target of 45.66 MWp of PV capacity installed by 2020 (PV-NMS-NET, 2009).

One of the main barriers for constructing PV plants in Croatia is a long and complicated procedure for obtaining all relevant permits, which often results with repetitive demands for the same documents. It is also necessary to establish a real electricity market in Croatia and resolve the question of uncertainty after the feed-in tariff contract expires, which is after twelve years (PV-NMS-NET, 2009).

It seems that procedure is not the only barrier to implementation of PV. A case study by the University of Zagreb (Ognjan, 2009) showed that in current conditions, PV systems in Croatia are simply non-profitable. Comparing the system’s costs, the prices of PV modules and inverters are similar to European prices (total value of 5 €/Wp). Therefore crucial difference exists in the other costs (1.5 €/Wp or 23 percent of total investment), which includes mounting, grid connection equipment, permits and documentation and similar. The case study showed also that investment costs are one of the two most influential factors for profitability. Investment subsidies of 30-40 percent of total investment with current twelve year tariff could help project profitability. This would either cover 50 percent of costs of PV modules or all other costs plus inverter costs (Ognjan, 2009).

The most attractive in Croatian incentive system are its feed-in tariffs. There are three levels: 0.50 EUR/kWh for systems smaller than 10 kWp, 0.45 EUR/kWh for systems bigger than 10 kWp but smaller than 30 kWp and 0.31 EUR/kWh for the rest. Feed-in tariffs are guaranteed over 12 years and are adjusted on a yearly basis. The weakness of Croatian RES market lies in its grid accession procedure which is complicated and lengthy (PV-NMS-NET, 2009).

However duration of the tariff proved to be the second most influential factor in profitability calculation. Therefore another option could be to extend the duration of the tariff to at least 20 years and to give a smaller investment subsidy. PV systems have a future in Croatia, but there is a need for detailed analysis of the existing related legislation and of possible improvements. Removing the 1 MWp limit, simplification of the procedure and additional support from the state are key factors for higher penetration of PV in Croatia (Ognjan, 2009). Also a better support from the state and raising awareness among population of such technologies is crucial for higher implementation of PV technologies, as they are the most expensive technology, but also the closest to households, who could help overall Croatian economy and reduction of CO2 emissions.

Turkey

The total installed PV capacity in Turkey in 2008 is estimated to be about 1 MWp. The largest plants are Türk Telekom (262.5 kWp), Mu Muğla la University (94 kWp) and Marmaris KIPA, Kuşadas KİPA (60 PA kWp) (Çolak, 2008). PV Tech (2009) states that the capacity in 2009 increased to about 2 MWp.

The PV sector is very small, approximately 30 companies provide work for only a small number of employees. The main business types are importer, wholesale supplier, system integrator and retail sales. The companies serve in the installation, engineering and project development sectors. The PV modules, inverters and charge controllers are mainly imported to Turkey (Çolak, 2008).

There is abundant solar energy potential available in Turkey with an irradiation of 1,300 kWh/m^2 but Turkey doesn't have a reasonable legal structure which encourages the production of PV energy and selling the excess energy to the grid (Çolak, 2008).

Whether Turkey will join the EU in the near future or not is still a political question and depends also on fulfilling the different criteria. Nevertheless the economic cooperation between both has definitely been intensified over the last decades. Turkey has started negotiations to become an EU member in 2005 and is already an associated member since 1963. The energy chapter has been opened in 2006 and the EU spotted important insufficiencies. Turkey has not ratified the Kyoto Protocol and there are no national limits for

GHG emissions. Energy from renewable sources account for more than 10 percent to the total energy consumption. This could change since Turkey is among European countries with the most irradiation. It has a PV electricity output potential of 1,650 kWh/kWp for the majority of it's territory (PV-NMS-NET, 2009).

Unfortunately reliable data for Turkey is rare. In 2005 Turkey started to support the PV market and adopted a feed-in tariff law which is organized by the Energy Market Regulatory Authority. The feed-in tariff rate is based on the average of the wholesale price announced in the previous year which was 0.08 EUR/kWh for industry, 0.09 EUR/kWh for domestic consumption and 0.1 EUR/kWh for the service sector in 2008. Although since the Market Financial Reconciliation Centre guarantees a minimum of 0.05 EUR/kWh over a 10-year period, the majority of RES producers sold their electricity to this institution instead (PV-NMS-NET, 2009).

In 2009 finally a feed-in tariff for solar energy of 0.28 EUR/kWh was agreed for the first ten years and 0.22 EUR/kWh during the next ten years. This should ensure the start of a healthy development of the market without the risk of overheating as it was witnessed in Spain (solarfeedintariff, 2010).

Besides the feed-in tariff there is also a quite interesting incentive scheme. The Turkish law on RES established a quota system for each legal entity, holding a retail sale licence for electricity. They have an obligation to purchase a specified amount of electrical energy from RES. In order to support new installations certified producers' installations cannot be older than 10 years. *The quota is based on a comparison between the amount of energy sold by that retail sale license holder, in the previous calendar year, and the total electric energy offered for sale by all retail sale license holders in Turkey* (PV-NMS-NET, 2009).
If state owned properties are used for renewable energy generation, you can get an 85 percent discount on all costs related to these properties (PV-NMS-NET, 2009).

Outlook

The perspective of Croatia and Turkey joining the EU are a realistic one and likely to influence far-sighted investors' decisions. Strategic and growing, Turkish and Croatian markets should not be neglected while analysing the renewable energy sector in Europe. The knowledge about solar electricity potentials as an alternative energy source is still rather limited. The use of solar power for thermal applications like hot water is well known but the possibility to generate electricity is rather unknown. The basis has to be created for promoting PV technology all over the country. This could be done by promoting low cost systems for producing PV panels and the usage of PV power systems (IEA PVPS, 2008a).

Turkey is located in a relatively advantageous geographical position for solar energy and areas receive an average of 7.2 hours of sunlight per day. Some experts and companies think that the recent introduction of a solar feed-in tariff by the Turkish government could be the beginning of a solar boom in Turkey. As mentioned above the tariffs work by offering fixed, premium rates for small scale energy producers feeding electricity into the national grid. Turkey has the opportunity to use solar energy but has not realized its potential yet and this could change with the new system. The new rates are designed to offset the costs of producing electricity by PV and have already proved to be a useful mechanism in attracting investment. Experts therefore believe that the tariff legislation along with the abundance of sunshine will contribute to the growth of the Turkish PV sector over the next ten years (solarfeedintariff, 2010).

Jim Mellon, a solar investment expert, even predicts that Turkey will be looking to benefit from what he described *as "an industry which will be bigger than the internet and that investors should keep a close watch on developments there*"(solarfeedintariff, 2010).

As for Croatia the perspectives are not as bright as for Turkey. A better support scheme from the state could improve those perspectives and the vicinity to EU states is certainly a plus.

3.4.4 Emerging Markets

China and India are one of the largest emerging markets. Due to their population size and the need for energy sources the PV technology could be (or in the case of China is already) very important for future developments.

China

Driven by the global market PV industry in China has developed quickly over the past years. For a long time China's annual production of solar cells has composed only 1 percent of the whole world’s annual production. In 2005 this fraction increased already to 8 percent, which is less than only those of Japan and Europe. China has been one of the fastest countries in the development of PV industry and therefore attracts international investors' interest (Dou, 2007). The Chinese domestic market grew by 100 percent in 2007 compared to 2006 with 20 MWp of new capacity were installed during the year 2007, taking the cumulative installed capacity to 100 MWp in 2007 and to 145 MWp in 2008 (IEA PVPS, 2008b).

Due to its high potential for RES, its existing energy challenge and the presence of important players in the PV sector, many experts are expecting China to initiate a support policy for PV. In the policy-driven scenario (illustrated in figure 18), it is expected that China will be one of the top PV markets by 2013 alongside Europe and the US (EPIA, 2009). However China has to face many challenges when it comes to implementing PV technology.

With the recognition and commitment of Chinese government to developing renewable energy technology, it can be expected that the domestic solar energy and application market will expand rapidly in the near future. Although today the structure of the electricity market in China does not allow for traditional grid parity economics for solar. The base-load generation will continue to be dominated by coal and natural gas. China is extracting almost a quarter of the worldwide coal resources and this is not going to change in the near future due to China's strategic use policy. Additionally there is almost no competition among the generation providers since the electricity rates and retail level are set by the state. Only where solar electricity costs can directly be compared with other electricity generation costs (like diesel generation) the cost argument is also in china possible (Miller, 2009).

Due to a different energy strategies compared to many other countries the Chinese government pushes for high amounts of installed capacity, with the long-term goal of bringing down high capital costs. The majority of China's electricity companies are state-owned, and because of this structure and the strategic nature of the electricity industry, energy

infrastructure development is not necessarily executed based primarily on economic considerations. Power projects do not have to be immediately profitable to be built.
The Chinese government is heavily involved in the electricity sector and wants to achieve two targets. It wants to push installed capital costs of new technologies down to approach base-load capital cost and it supports domestic manufacturers and domestic economic growth (Miller, 2009).

Due to a limited grid capacity and with current overcapacity in the Chinese generation market, grid interconnection is a major concern for newly installed generation capacity. It is likely that newly installed solar PV capacity will face significant delays. Some producers may even be unable to connect to the grid in the near future. This was already the reality with recently installed wind parks. There are two reasons for this development. No sufficient standards for interconnection procedures across the grid regions and a general lack of experience on the side of the developers. Until this grid connection and integration problem is not solved the number of independent project developers will be rather low (Miller, 2009).

On the other hand China is already taking over a leading role regarding manufacturing facilities as part of broader economic development plans. Many module production facilities are being built all over the country and adding to the huge Chinese PV boom, at least regarding the production (Miller, 2009).

India

India has a high potential for decentralised PV applications (grid-integrated and off-grid) due to its huge population where many people live in rural areas far away from centralized electricity connection. With its economy growing and the resulting immense energy demand, India could become a significant PV market in the coming years. On the other hand local or regional initiatives to support PV are not very developed. Therefore it is expected that the Indian market will develop slowly. This could change immediately if an appropriate support programme such as a feed-in tariff mechanism is put in place. Under this conditions EPIA (2009) expects that the Indian PV market could increase to 600 MW by 2013 as illustrated in figure 18.

Wind currently dominates RES of power generation in the country but solar PV is expected to outpace wind in the long run. Today PV constitutes an insignificant part of India’s installed power generation capacity with estimates of around 100 MWp, with grid connected solar PV generation at a mere of 2.12 MWp (SEMI, 2009).

Although grid connected solar generation in India is currently very small the Ministry of New and Renewable Energy (MNRE) is targeting a capacity of 50 MWp by 2012 through an incentives program established in 2008 and equivalent to feed-in tariffs (SEMI, 2009).

Under the so called Generation Based Incentives the following feed-in tariff is being used:

- A combined MNRE provision plus a state utility feed-in tariff sums up to about 0.30 US $/kWh.
- The tariff is guaranteed for 10 years.
- There is a capacity cap of 50 MWp by 2012 for the incentive scheme (SEMI, 2009).

The Indian PV industry while welcoming the announcement of a feed-in tariff scheme for grid connected PV, has expressed its concerns that the scheme, as it stands, needs to be expanded in scale and requires review and rework to make it more attractive to investors (SEMI, 2009).

Sathya Prasad, president of SEMI India (association of semiconductor equipment and materials producer) expects the biggest potential in India for off-grid systems in the many rural areas, based on real needs for lighting and electrification, powering irrigation pumps, providing backup power for the growing network of cell towers, as well as other urban applications. By making available this off-grid source of power, many of the 450 million people in India who now rely on kerosene and other fuels to light their homes could enjoy a significantly higher quality of life (SEMI, 2009).

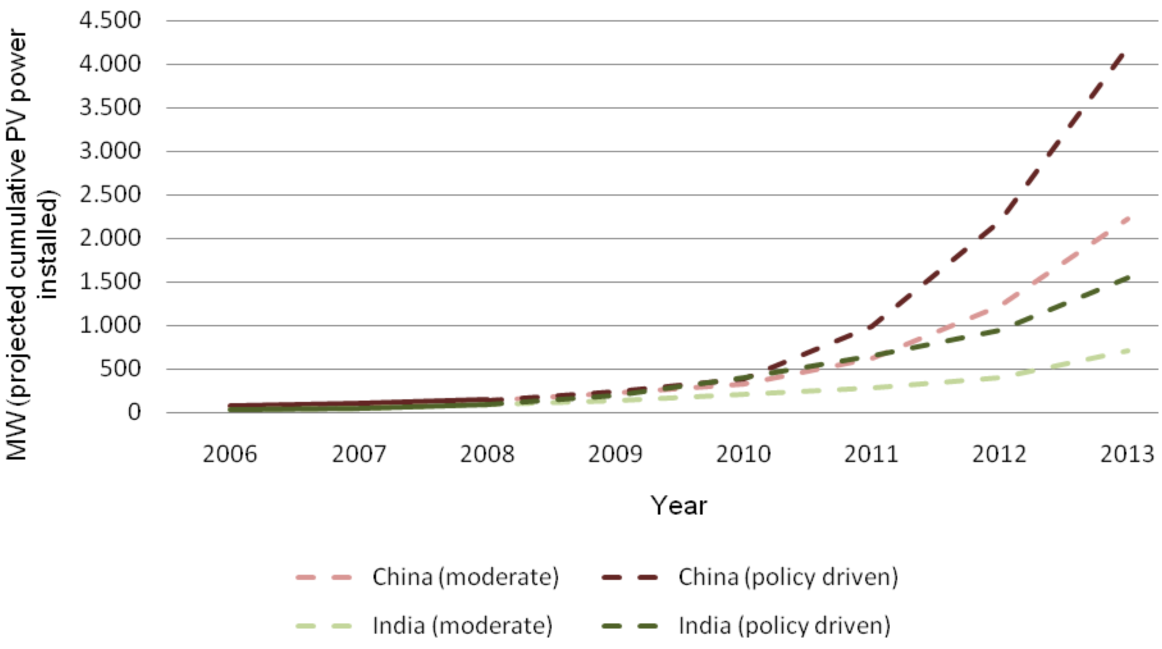
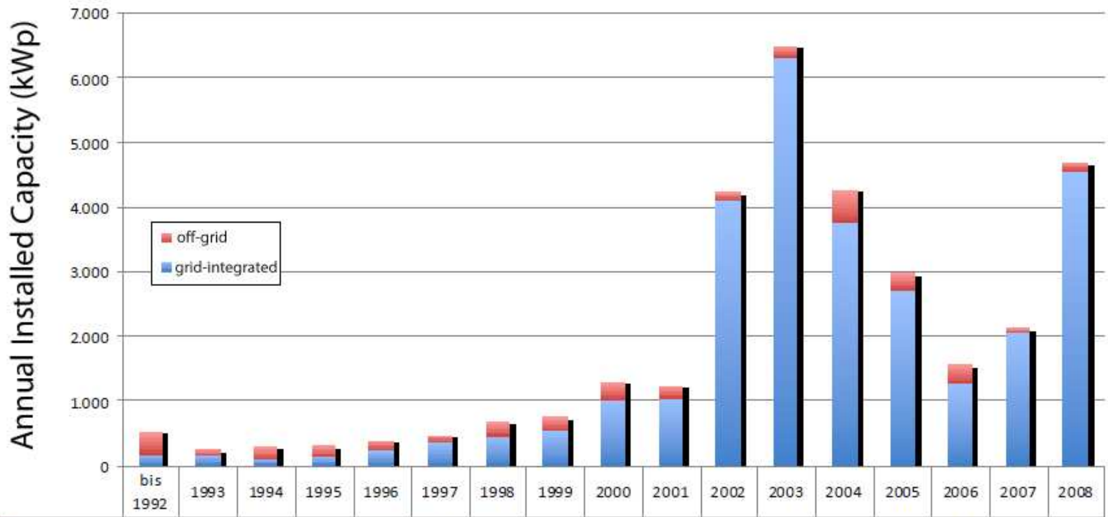


Figure 18: PV Market Overview and Development of China and India
Source: EPIA, 2009

4. Austrian PV Market

Until 2007 the size of the Austrian domestic PV market has declined three years in a row regarding annual installed capacity. Since 2007 there has been a slight increase compared to the previous year. Nevertheless the Austrian PV market is still far away from the peak of 6.5 MW capacity installed in 2003. Off-grid and grid-integrated PV systems with a total power of more than 4.6 MW were installed in 2008, which represents a 121 percent growth of the domestic market compared to the year before. The cumulative installed PV capacity in Austria reached more than 32 MW at the end of 2008. Grid-integrated applications dominate the market and account for about 88 percent of the cumulative installed capacity (compare figure 19 and 20). The market development of PV shows a rise of the home market of 2,116 kWp in the year 2007 to 4,686 kWp in the year 2008 (see figure 19), which corresponds to a growth of 121 percent. Despite this observation, the PV home market is still far from its historical maximum related in the year 2003 with 6,472 kWp. The total cumulated Austrian PV equipment in operation in 2008 was 32,387 kWp.



	bis 1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
off-grid	338	85	167	165	133	104	201	200	256	186	127	169	514	250	274	55	133
grid-integrated	187	159	107	133	245	365	452	541	1.030	1.044	4.094	6.303	3.755	2.711	1.290	2.061	4.553

Figure 19: Annual Installed PV Capacity in Austria
Source: pvaustria, 2010

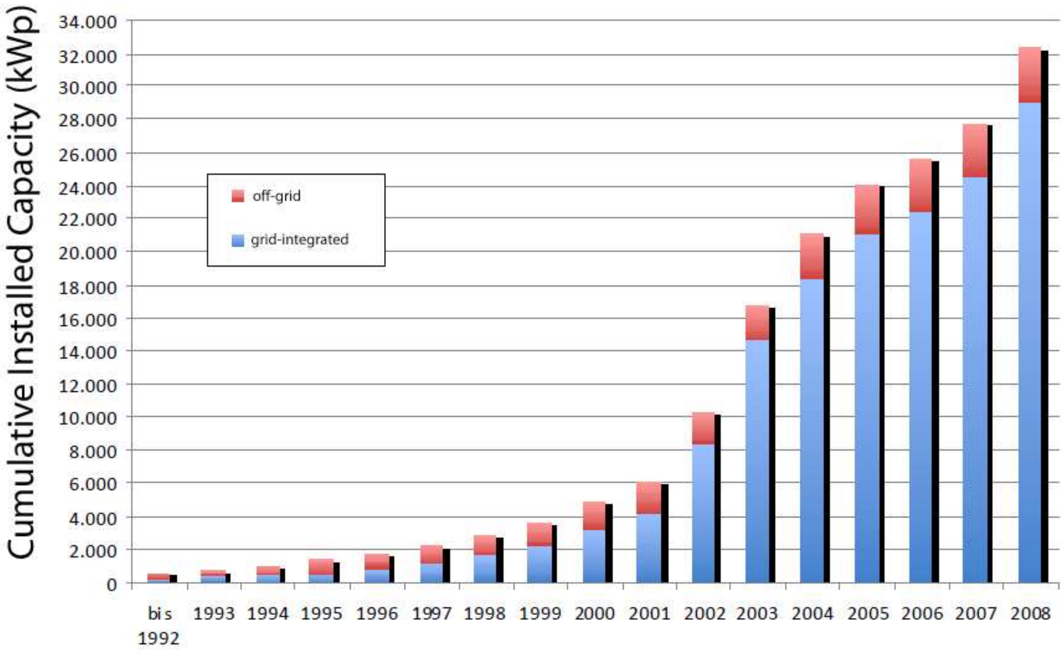


Figure 20: Cumulative PV Output in kWp in Austria
Source: pvaustria, 2010

The photovoltaic modules installed in Austria had a middle electricity production of approximately 29 GWh. This corresponds further to a saving of CO2-emissions at a value of approximately 29,200 tons of CO2. The export quota of photovoltaic modules amounts to 94 percent. The strongly growing production departments of the mover systems and the inverters show even higher export quotas close to 100 percent. In the range of the photovoltaic industry 1,762 full time jobs have been registered in the year 2008 (pvaustria, 2010).

Austria has been top regarding solar generated energy for a long time. The growth rates of the last years suggest a bright future for the Austrian PV industry but still the PV market is becoming Europe's tail end. In Austria only 0.4 percent of the overall produced electricity is generated out of PV systems, only Romania, Estonia and Lithuania generate less energy from solar power (pvaustria, 2010). The government subsidies for PV systems are regulated in the green electricity law. This law exists since 2002 and has been amended many times. The last big amendment was in 2008 and has been approved on Sept. 23, 2009 by the Austrian government which is also the date it has come into effect.

There are two subsidy systems available in Austria:

- Nationwide Investment Subsidies
- Nationwide Feed-in Tariffs

Newly erected private PV systems with a capacity below 5 kWp get a one-time investment subsidy of up to 60 percent of the investments costs. The problem is that only 18 million Euros have been available overall (19 million Euros overall, one million for PV components). The consequence for 2009 was that the 18 million Euros have been given away only after a few hours. Many private projects have not been built because of the lack of subsidies (pvaustria, 2010).

Some federal states in Austria support PV systems with one-time subsidies. Lower Austria for example grants subsidies up to 50 percent of the investment costs, although these funds are quite limited and both subsidies combined from the state and the federal states must not exceed 60 percent. The subsidies for rooftop and stand alone systems are 2,500 €/kWp, for building integrated systems they are 3,200 €/kWp, with the limitation that the overall state and federal subsidies must not exceed 60 percent of the investment costs (pvaustria, 2010).

On Sept. 23, 2009 the Austrian government passed an amendment to the green electricity law. The subsidies for the smaller systems have been increased to 35 million Euros. Nevertheless many experts doubt that this will be enough to improve the situation for the Austrian PV market. A feed-in tariff without a cap as established in many European countries would increase the PV share faster.

The feed-in tariffs for contracts signed in 2009 have been announced on Feb. 23, 2009. The tariffs for electricity made out of PV systems are right now 45.98 Cent/kWh for systems up to 5 kWp, 39.98 Cent/kWh between 5 kWp to 10 kWp and 29.98 Cent/kWh for systems above 10 kWp.

The PV lobby is still very critical about the green electricity law. The amendment improves the situation only marginal and is not able to push the Austrian PV sector to an international level. The amount of 2.1 Million Euro for feed-in tariffs for 2009 was already completely distributed on July 16.

The most relevant changes due to the amendment regarding the feed-in tariffs are:

- For new PV system there are now 2.1 Million Euros available each year.
- Only PV systems with a capacity above 5 kWp will be supported under the green electricity law and will get feed in tariffs.
- PV systems with a capacity below 5 kWp will only be supported via the climate and energy funds with investment subsidies.

- There is a formal easement regarding the application process. For PV systems it is not necessary any more to file an application for a recognition order as green electricity plant and also the necessary permissions are not needed anymore.
- Projects which couldn't get any subsidies in the first year are ranked before all new applications for additional three years
- The running time of the subsidies has been extended to 13 years (pvaustria, 2010).

Comparing different nations, Austria is far behind when it comes to supporting PV technology and there seems to be no major changes in the future. The PV lobby demands a new start of negotiations regarding the green electricity law. The main request is to stop the construction volume cap for new PV systems.

When comparing the feed-in tariffs with Germany, the leading country regarding PV market, it becomes obviously that the problems are not the tariffs itself but the subsidy cap. Germany pays 43.01 Cent/kWh for systems smaller than 30 kW (EEG 2009) and Austria pays even 45.98 Cent/kWh. Nevertheless the policy environment for developing the domestic Austrian PV market remains complex and ineffective. The planning uncertainty and the lack of subsidy capital is the reason why the Austrian PV market has become quite insignificant. Figure 21 illustrates the development of the German PV capacity. Comparing the German (figure 21) and Austrian development (figure 19) the poor Austrian market development is apparent.

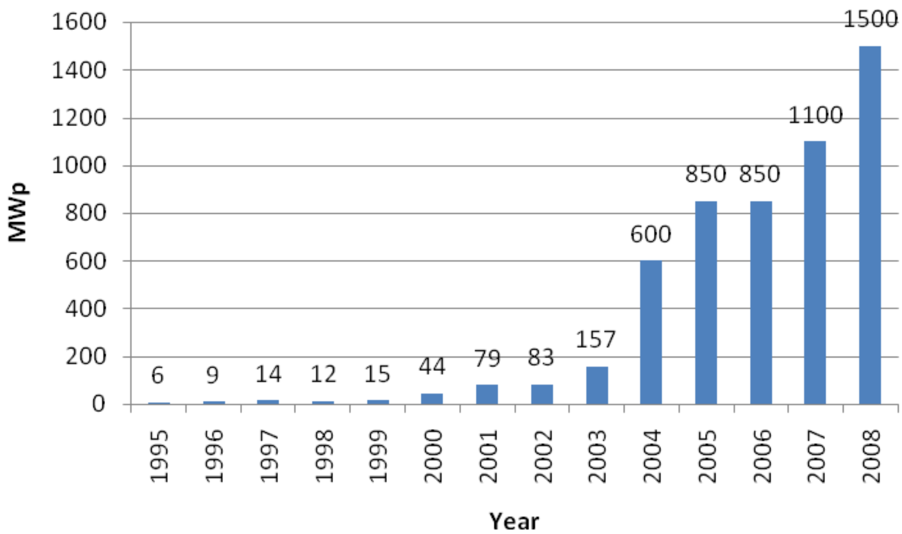


Figure 21: Annual Installed PV Capacity in Germany
Source: BSW-Solar, 2009

Despite these poor perspectives there is one major trend regarding Austrian PV projects in recent years: Optimal architectural integration of building integrated PV systems in newly constructed and refurbished buildings. Several installations with PV innovatively and aesthetically integrated into the building design were developed (IEA PVPS, 2008b). This could be a second chance for the Austrian PV industry.

5. PV Values and Market Deployment Strategies

One of the main arguments for PV technology is the environmental sustainability. This chapter explains the ecological benefits of this renewable energy. Nevertheless there are some disadvantages of PV compared to other technologies, especially economical wise. The second part of the chapter will focus on the economical challenges of using the sun as an energy source.

5.1 Environmental Values

The biggest environmental value of solar PV systems is that there are no emissions of green house gases (GHG) during their operation. There are also no environmental safety concerns associated with conventional generation technologies like nuclear fallout or explosion risk and there is no pollution in the form of emissions, exhaust fumes or noise. On the other hand PV systems are quite energy intense in the production phase but these indirect emissions of GHG are significantly lower than the avoided emissions. At the end of the life cycle is the decommissioning which is also quite unproblematic for PV systems (EPIA & Greenpeace, 2008).

There are three main environmental benefits of PV systems according to the IEA (2009):

- *Reduction of greenhouse gas emissions.*
- *The potential to greatly reduce pollution associated with electricity services.*
- *A significant contribution towards sustainability.*

Sustainability is commonly quoted as the ability of the particular production system to sustain the production level over long times. The World Commission on Environment and Development defines sustainability as *"forms of progress that meet the needs of the present without compromising the ability of future generations to meet their need"* (World Commission, 1987). For energy systems this means the exploitation of primary energy resources for energy utilization will not cause significant ecological damage for future generations.

5.1.1 Energy Payback Time

The energy balance of a PV system is expressed by the Energy Payback Time (EPBT), *which is the time it takes for the PV system to generate the amount of energy equal to that used in its production.* The life cycle assessment (LCA) provides a conceptual framework for a detailed and comprehensive comparative evaluation of environmental impacts as important sustainability indicators. An LCA considers not only the direct emissions from PV construction, operation and dismantling, but also the environmental burdens and resources requirement associated with the entire lifetime of all relevant upstream and downstream processes within the energy chain. Naturally all means of electricity generation create polluting emissions when the entire life-cycle is taken into account. In the case of PV systems, manufacturing is very energy intensive, resulting in the emissions that accompany the use of standard grid electricity (De Wachter, 2008).

According to different studies (De Wachter, 2008), the EPBT of a PV system varied between 1 and 6 years. One outcome of these studies was that the larger the energy yield of the PV system is, the faster the energy consumed during its manufacturing phase is gained back. This means the EPBT depends heavily upon the average irradiation at a particular manufacturing site. The studies were conducted on monocrystalline silicon PV panels in four different geographic regions and produced the following results:

- In the Netherlands an average EPBT of 3.5 years was reported (average irradiation of 1,000 kWh/m^2/year)
- In Switzerland the EPBT varies between 3 and 6 years (with an average irradiation of 1,100 kWh/m^2/year)
- For a rooftop installation in Southern Europe an EPBT between 1.7 to 2.7 years has been calculated (average irradiation of 1,700 kWh/m^2/year)
- For ground-mounted installations in the U.S the EPBT was only 1.1 years (average irradiation of 1,800 kWh/m^2/year) (De Wachter, 2008).

Assuming a 30-year system life, PV systems will provide a net gain of 26 to 29 years of pollution-free and greenhouse-gas-free electrical generation (US Dept. of Energy, 2004).

Figure 22 illustrates the energy payback of different components and systems. As explained above the EPBT can vary significantly.

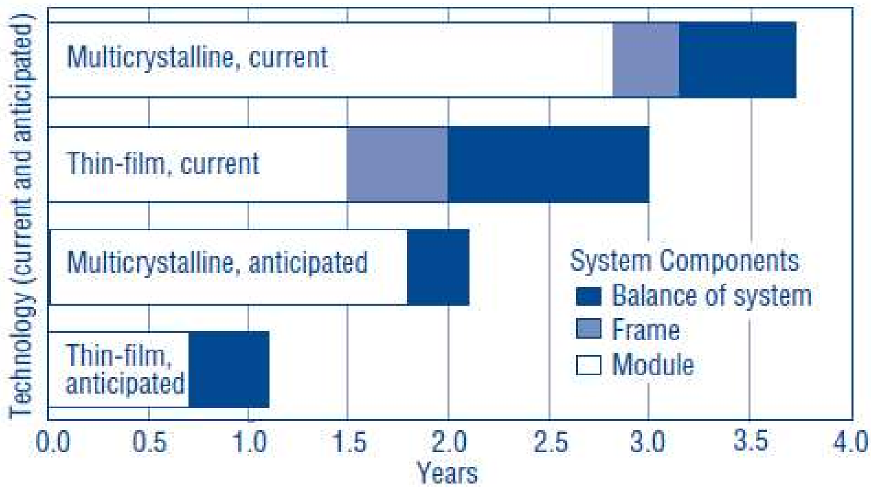


Figure 22: Energy Payback for Rooftop PV Systems
Source: US Dept. of Energy, 2004

The balance of system (BOS) is defined as all components of a PV system other than the PV panels. This includes wiring, switches, support racks, an inverter, and batteries in the case of off-grid systems. In addition the BOS may also include design costs, land (especially in the case of free-standing systems), site preparation, system installation, operation and maintenance costs, and other related costs.

5.1.2 Emission Reduction

The existing profile of electricity production in different countries influences the amount of GHG which could be saved significantly. EPIA and Greenpeace (2008) state that PV technology could save an average of 0.6 kg CO2 per kWh.

Other scientists found out that PV technologies generate far less life-cycle atmospheric emissions per GWh than conventional fossil-fuel generation technologies. According to their studies at least 89 percent of the harmful emissions into the atmosphere could be prevented if conventional grid electricity was to be replaced by PV electricity (De Wachter, 2008).

The GHG emissions over the life-cycle of a PV panel are strongly related to the EPBT. They can mainly be allocated to the use of electrical energy during the manufacture of PV panels. Consequently, those emissions differ for the same PV panel according to the energy mix that is used for generating electricity in that particular location.

Studies with three different energy mixes and for four different types of PV panels (multi-Si, mono-Si, ribbon silicon, thin film CdTe), show that the CO2 emissions vary between 21 grams CO2-eqivalent/kWh for the thin film CdTe to 45 grams CO2-eqivalent/kWh for mono-Si. The thin film CdTe panels demonstrate the best results, but differences between PV systems are small in comparison with the difference of PV systems and conventional fossil-fuel based generation. The average CO2 emission for power generation is 470 grams CO2-equivalent/kWh (De Wachter, 2008).

Figure 23 illustrates the GHG emissions of PV systems based on three silicon technologies, compared to a number of other energy technologies. The PV systems are installed on a roof top in Southern Europe with irradiation of 1,700 kWh/m²/year and have a 30 year life time.

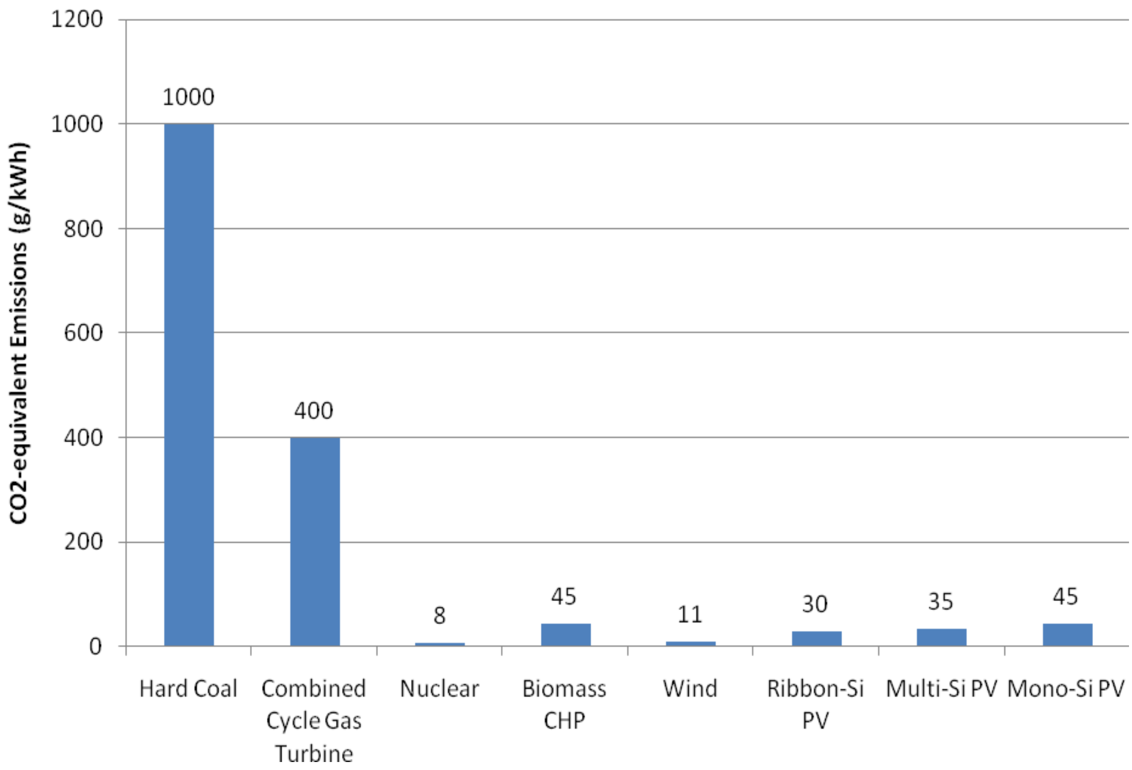


Figure 23: GHG Emissions of Different Energy Technologies
Source: Alsema et al., 2006

In addition heavy metals are emitted directly during the manufacturing process of PV systems, or via the use of grid electricity during the manufacturing process. Here again thin-film CdTe PV panels present the best results, even for cadmium emissions. This type of PV cell requires much less electrical energy for its manufacture, so it produces fewer heavy metal emissions attributed to the use of grid electricity. The higher direct cadmium emissions occurring during its manufacturing process are being compensated by the lower energy consumption (De Wachter, 2008).

The trend in the environmental impact of PV manufacturing is decreasing even further and the energy efficiencies are increasing. As a result, the EPBT and the life-cycle environmental profile of PV panels can be expected to continue to improve in the upcoming years.

In the future a 'PV breeder' scenario also has to be considered which could cut the current GHG emissions of PV life-cycles more or less in half. PV breeders get a large part of the electrical energy for the PV manufacturing out of PV panels (De Wachter, 2008).

Although there are no CO_2 emissions during operation, a small amount does result from the production stage as explained above. Depending on the technology PV emits 21–43 g CO_2-equivalent/kWh compared to the average Austrian energy mix of 229 g CO_2-eq./kWh. Energy from hydro power emits 25 g CO_2-eq./kWh and from natural gas 247 g CO_2-eq./kWh (oekb, 2010). Comparing these figures it becomes obvious that PV is very effective when substituting conventional generation methods. Thermal coal power in Europe has even average emissions of up to 1000 grams CO_2-equivalent/kWh. By substituting PV for coal power, huge savings could be achieved. In Austria with its large hydro power percentage, savings are much smaller and could even be negative when substituting large hydro power stations. Whereas by replacing off-grid systems like diesel generators, CO_2 savings of about 1 kg/kWh could be achieved. Another important factor in the LCA is the decommissioning of PV systems. Recycling PV modules and reusing the materials can additionally reduce the GHG emissions (EPIA & Greenpeace, 2008).

Scenarios by EPIA and Greenpeace (2008) predict that solar PV could have reduced annual global CO_2 emissions by just over 1.6 billion tonnes by 2030. This reduction is equivalent to the output of 1,600 average cars driving 1000 km each or 450 coal-fired power plants with an average size of 750 MW. The according cumulative CO_2 savings from PV between 2005 and 2030 could reach a level of 9 billion tonnes.

Nevertheless data from 2007 for Austria show that the costs per avoided CO_2 ton compared to other renewable energy sources (RES) are still quite high (compare figure 24) but if governments adopt a wider use of PV in their national energy generation, solar power can make a substantial contribution towards international commitments to reduce emissions of GHG and their contribution to climate change.

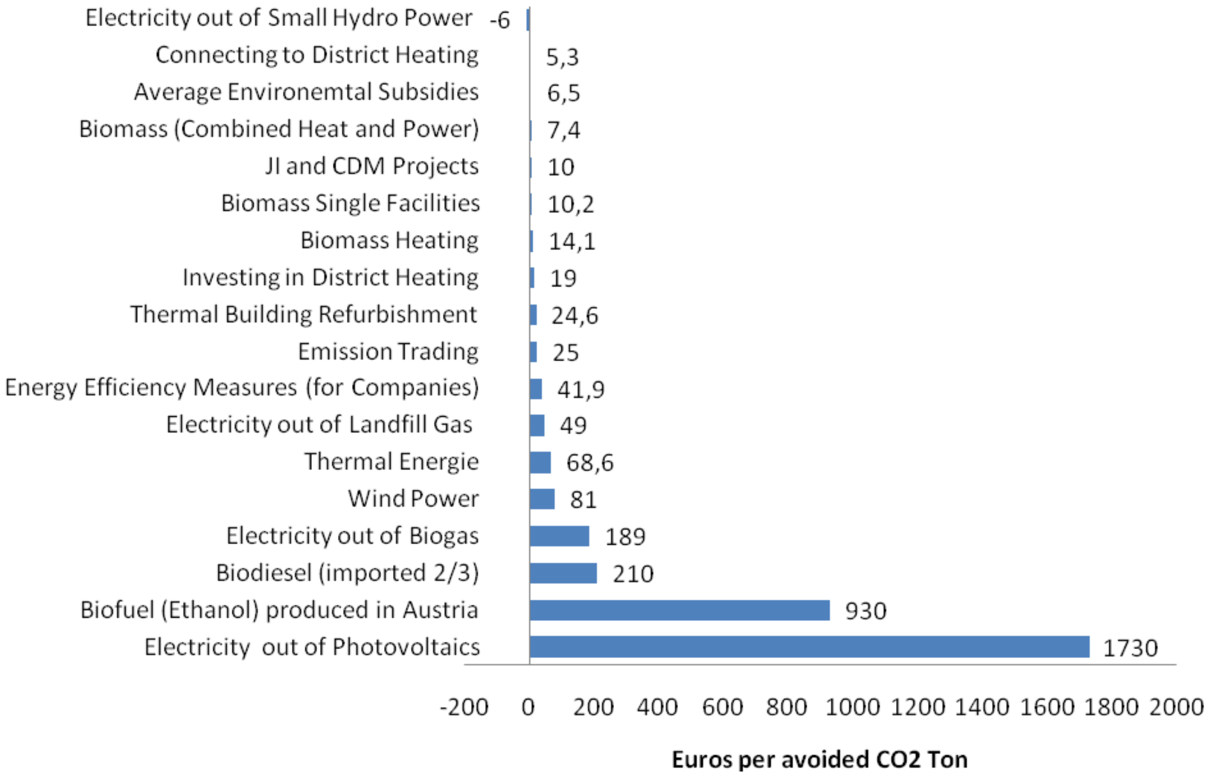


Figure 24: Costs per Avoided CO2 Ton (€/ton) for Different RES
Source: Streissler, 2007

5.2 Market Strategies

The question when and if a technology can compete with others is often linked to cost factors. This sub-chapter will highlight the challenges PV has to handle to become a mainstream energy source. It will also show that PV is on the right track but the path to go is still long.

5.2.1 Economical Criteria of PV Utilization

The market value of the solar PV market reached an annual € 20-25 billion in 2008 (EPIA, 2009). Competition among the major manufacturers has become increasingly intense, with new players entering the market as the potential for PV opens up. The PV industry has become a mature industry sector. Integration along the whole supply chain or at least multinational partnerships, joint ventures and long-term supply agreements has taken place. This is a new development and is in contrast to the earlier stages of industry development. In the past most companies had made one or two products for a limited number of markets. For the future experts believe that that the smallest businesses may disappear altogether and that vertical integration of the industry will be the norm. The small to medium players will have to specialize in PV niche markets if they don’t want to get absorbed by others (IEA PVPS, 2008b).

In 2008, EPIA (2009) estimates that over 130,000 people were employed directly by the European PV industry and 60,000 people indirectly. The PV sector is particularly promising in terms of job and local wealth creation.

An example of a typical modern PV business is Norway’s Renewable Energy Corporation (REC). REC is one of the leading vertically integrated players in the solar energy industry. Their business is carried out in three divisions. REC Silicon and REC Wafer are among the world's largest producers of polysilicon and wafers for solar applications. The third division (REC Solar) is a manufacturer of high performance solar cells and modules, and is also engaged in project development activities in selected segments of the PV market. Also the production facilities are globally located. The silicon materials plants are in the USA, the wafer and cell production is located in Norway and solar modules are produced at a manufacturing plant in Sweden. A new manufacturing complex for wafers, cells and modules is being built in Singapore which will open in the first Quarter of 2010 (IEA PVPS, 2008b).

Industries which support the PV sector are also expanding. Commodity suppliers, chemical industry, machinery industry, glass industry, electronic device producers, plastics and polymer industries, equipment suppliers, and many more are producing specialized equipment for the PV manufacturing industry. This has become a significant business on its own (IEA PVPS, 2008b).

Still the PV industry has to become more profitable to be able to challenge conventional energy sources and also other RES. In Austria PV still has a long way to go, as shown in figure 25, but as described in the next chapters, PV systems are on the threshold to grid parity in other countries.

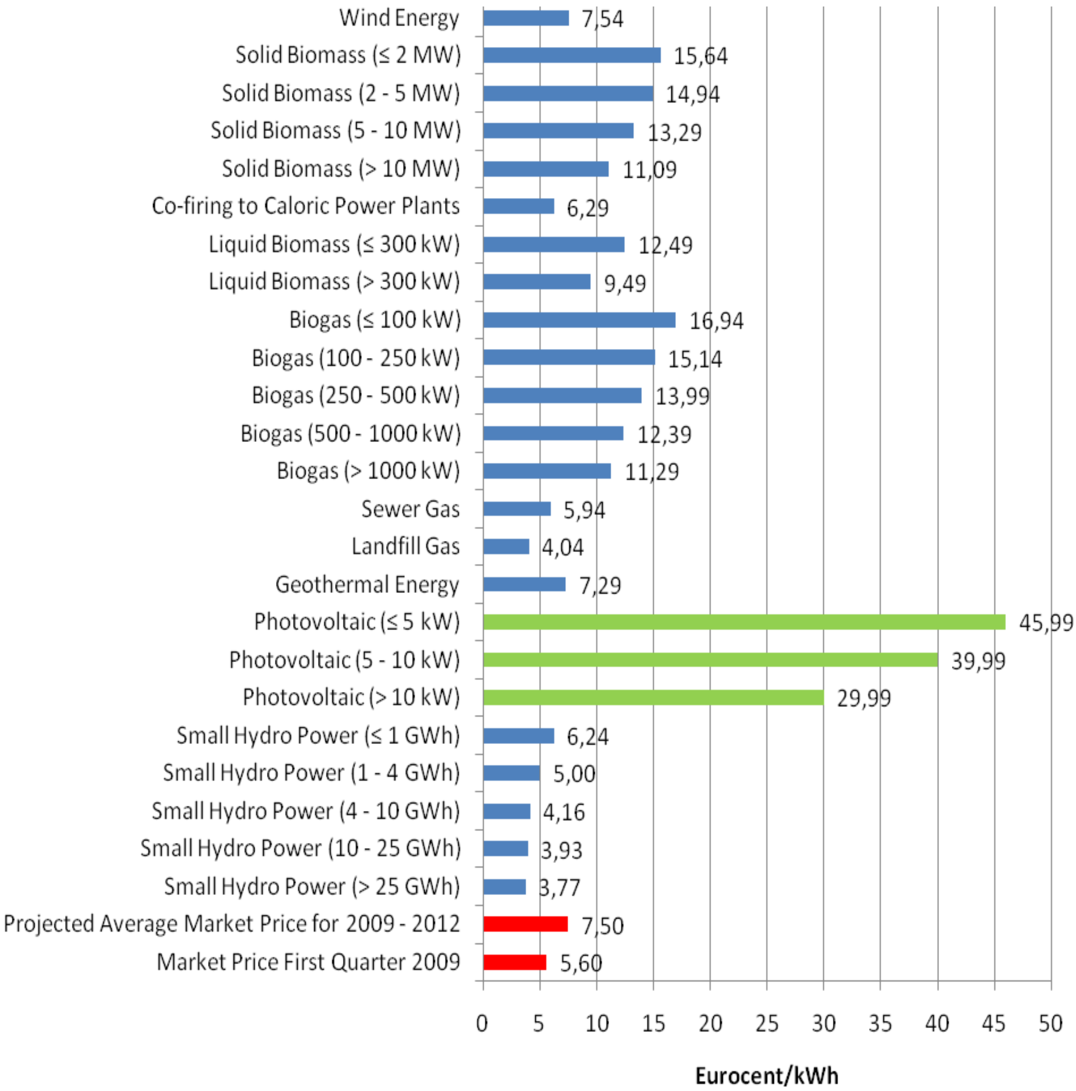


Figure 25: Generation Cost of RES in Austria
Source: Bachhiesl, 2009

In the face of increasing oil and gas prices and its' effect on market prices for electricity the Bundesverband Eneuerbare Energie (2008) expects an average market price for electricity between 2009 and 2012 of 7.5 Eurocent/kWh for Austria. The price will be 6 Eurocent at the beginning and considerably above 8 Eurocent/kWh by 2012.

5.2.2 Prices of PV Components

The historical learning curve of PV modules showed over the last 3 decades a 20 percent module price reduction each time the cumulative PV power installed was doubled. This development was stopped in 2007 but is expected to continue now due to the end of the multicrystalline silicon (more silicon production capacities and lesser demand due to the economic crisis of 2008). Cost reduction potentials for the crystalline silicon methods are related to automatization, increase of productivity and increase of cell efficiencies. If these cost reductions are passed on to the final customer and leads to a decrease in PV system prices, the generation cost of PV electricity could compete even sooner with conventional retail electricity prices from the grid (EPIA, 2009).

A survey by Solarbuzz (2009) shows, that in the summer of 2009 the numbers of price decreases for PV compounds have exceeded the increases already over a period of seven months. The drop in retail prices has started in February 2009 and the reductions are reflective of price reductions from the manufacturers at the factory gate. This survey included all the retailers, which are just over 70 worldwide.

Another conclusion of this survey is that the reductions in the first half of 2009 are a function of a major structure shift in demand, most notably a less attractive PV policy in force in Spain than prevailed in 2008. This cut in demand in Spain had a significant effect on the global PV market. The companies tried to readjust their distribution and to shift to other countries.
This market break has been overcome by a mix of government policies and building end customer demand. The level of market activity and projects in the pipeline have been picking up again around the world in the second half of 2009.

By the end of 2009 there have been 327 solar module prices below € 2.64 per Watt which represent more than 22 percent of the total survey. Comparing these figures with June 2009 they represent an almost six percent increase of companies who sold their modules below € 2.64. The lowest retail price for a multicrystalline silicon solar module was € 1.31 per Watt from an US retailer. The lowest retail price for a monocrystalline silicon module was € 1.78 per Watt, from an Asian retailer. Solarbuzz (2009) also identified the lowest thin film module price at € 1.16 per Watt from an Asian-based retailer.

Due to the production process it is typical to expect thin film modules to be at a price discount to crystalline silicon, as explained above. Comparing these figures it is important to have in mind that not all models are equal. The brand, technical attributes and certification can make a difference and all prices are based upon the purchase of a single solar module and are exclusive of sales taxes.

Around 40-50 percent of the overall cost are BOS cost. Still the module cost represents around 50–60 percent of the total installed cost of a PV system and therefore the solar module price is the key element in the total price of an installed solar system. Figure 25 illustrates the development of the average solar module prices (this is the price for the purchase of a single module - a number significantly higher than often quoted "factory gate" prices) between 2006 and 2009. The prices are exclusive of value added taxes which are between 8-20 percent of the prices depending on the country or region. Generally Europe has the highest value added taxes (e.g. 20 percent in Austria).

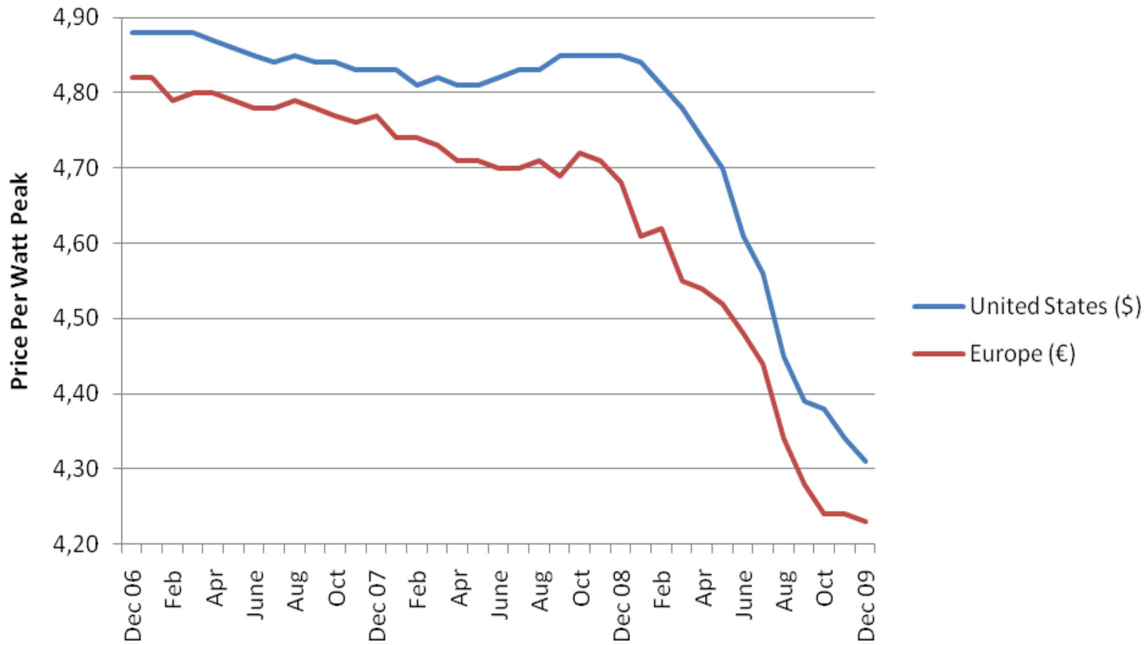


Figure 26: Solar Module Retail Price Index
Source: Solarbuzz, 2009

Over the past 12 months prices are still declining. The ratio of decreases to increases in both the November and December result are similar. For the year as a whole, the retail price index in the United States is down 53 Dollar Cents per Watt, while the European index is down 45 Eurocents from Dec. 08 to Dec. 09.

In addition to retail prices, construction prices are also a very important indicator and signal for a technology. Macroeconomic challenges in 2008 and 2009 have many solar executives and investors focusing on cost structures. Based on years of cost research, including tracking, for many solar power companies it is clear that the metric of one Dollar per Watt will become increasingly important in the coming years. In 2008, the sum-of-average fully-loaded cost of an a-Si module (including all costs at each step of the supply chain, excluding only profit) was under $ 2/W and best practice was under $ 1.40/W. Between 2009 and 2012, a-Si module cost structures will continue to decrease, falling below $ 1.50/W on average and under $ 1/W for best practice (Song, 2009).

In 2008 the average fully-loaded cost of a thin film module was under $ 2.30/W and best practice was nearing $1.50/W. Between 2009 and 2012, thin film module cost structures are expected to continue to decrease, falling below $ l.50/W on average and under $ 1/W for best practice according to Photon Consulting (Song, 2009). Considering BOS the average fully-loaded non-module system cost was under $ 2.70/W and best practice was below $ 1.40/W in 2008. Between 2009 and 2012, BOS costs will continue to decrease, nearing $ 2/W on average and $ 1/W for best practice.

Photon Consulting (Song, 2009) predicts that these cost structures of $ 1/W for modules and $ 1/W for BOS will enable the best practice cost of solar electricity in sunnier areas to fall below $ 0.10/kWh by 2012. As a result, solar sector costs will be competitive with roughly 8,000 TWh per year of grid electricity, equivalent of roughly 8,000 GW of installed solar capacity.

Being able to offer solar electricity for $ 1/W or less would be outstanding and groundbreaking for the whole sector. Nevertheless there are several important issues and barriers, which have to be taken into consideration.

- First of all the cost of solar power is far below the price, making it difficult for outsiders and consumers to evaluate the true cost (no real cost transparency).
- Because profit margins are high and compound along the supply chain, there is a big difference between the sum of average costs at each step of the supply chain and the current costs of all solar companies. This means the sum-of-average Cost are smaller than the corporate costs.
- There are big cost differences across the companies. These spreads are driven by both feedstock cost and processing cost differences.
- Companies with higher cost structures have to be very careful. With the price far above cost, it is inevitable that price will eventually fall, creating big risks for companies with higher costs.

Despite the risks, the opportunity is huge. PV technology is already able to beat grid price in some locations and the addressable market is expanding exponentially, creating a big prize.

Several companies have established a cost leadership. The best-positioned companies to capture a share of this prize have distinctively low cost structures.

As the cost of PV declines, the addressable market grows quickly. An estimate of portion of electricity consumption in ratio to the costs of PV systems in the OECD is shown in figure 26.

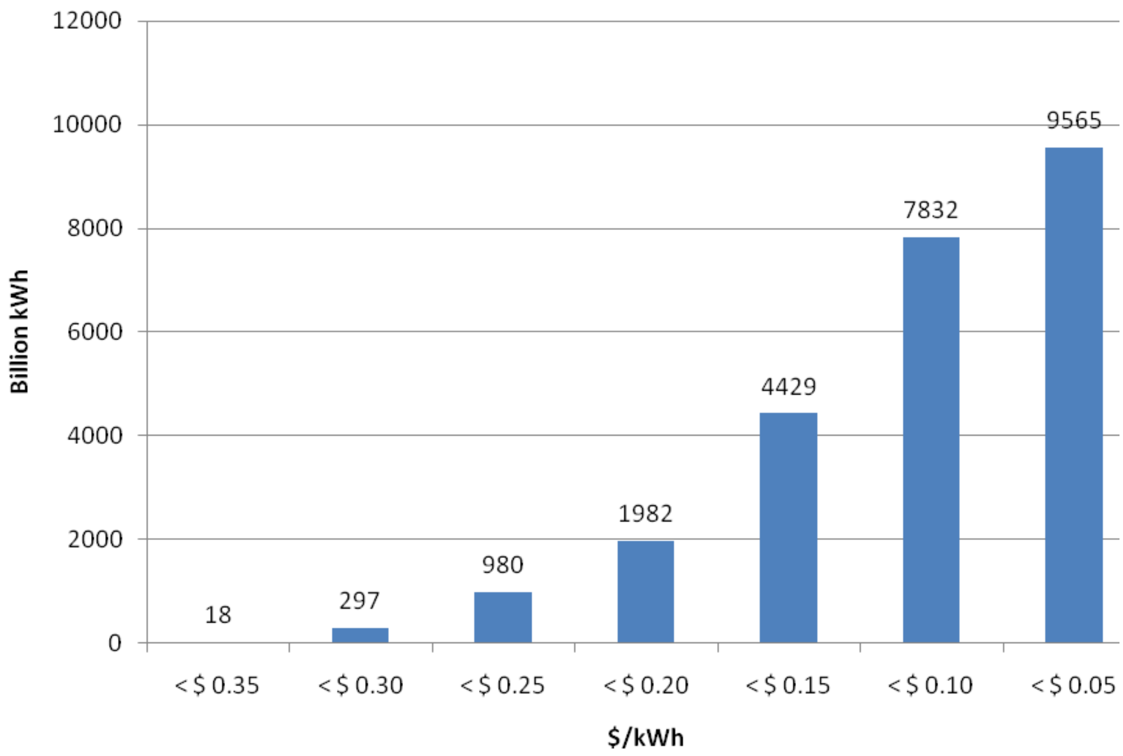


Figure 27: Addressable Market vs. Cost
Source: Song, 2009

The current worldwide PV generation is roughly 18 Billion KWh. If the price would decrease about 14.3 percent to 0.30 Dollar Cent per kWh the PV generation would increase 1650 percent to 297 Billion kWh (for comparison the OECD countries consume roughly 10 trillion kWh of electricity per year). These figures point out the significance of PV construction prices for the development of the sector.

6. Future Perspectives

This chapter describes the future perspectives of PV. The technology is on the track to costs of 1 Dollar per Watt and also towards grid parity. Although future scenarios described in chapter 7 illustrate that there could be considerable differences between the developments of PV.

6.1 One Dollar per Watt?

At the PV sector level the true cost of solar power is remarkably low now. As shown above the average cost is less than $ 2/W for c-Si modules and less than $ 5/W for systems. This includes all costs through the supply chain, excluding only profit. This equates to a levelized electricity cost without incentives of less than $ 0.25/kWh in sunnier environments. Best practice is already far lower, and three segments (c-Si modules, thin film modules and non-module BOS equipment) are approaching cost structures of $ 1/W.

On the other hand these sector-level benchmarks are far below many companies' cost structures. At the company level there is a major difference between what the costs could be and what the costs are for nearly all solar manufacturers. This means costs for many companies far exceed the sector average and best practice benchmarks. For Photon Consulting (Song, 2009) two main factors are accountable for that:

1. High feedstock costs: The feedstock costs are a main driver for high cost structures. Many companies are heavily depending on silicon feedstock and have no possibility to substitute. In 2008 the average cost of producing Si was less than $ 40/kg, but the average cost of Si for users was more than $ 130/kg. This highlights the large spread between cost of production and cost of use.

2. High processing costs. Typical low-cost cell processors have costs of under $ 0.4/W but many other competitors have processing costs 50 percent higher. For many companies the cost to convert a wafer into a cell (excluding wafer cost) is very expensive compared to competitors.

Today all solar manufacturers are exposed to either high feedstock cost or high processing cost. There is a strong competition which forces the manufacturers to establish cost leadership for specific steps of the supply chain. Nevertheless price reductions could occur very fast and this could endanger the success of a manufacturer quickly.

Figure 27 gives an overview of the average solar costs and their development for c-Si modules. The difference between average costs and best practice examples is significant. In the year 2007 average costs were 71 percent above best practice produced modules. The prediction for this ratio for 2012 is almost the same.

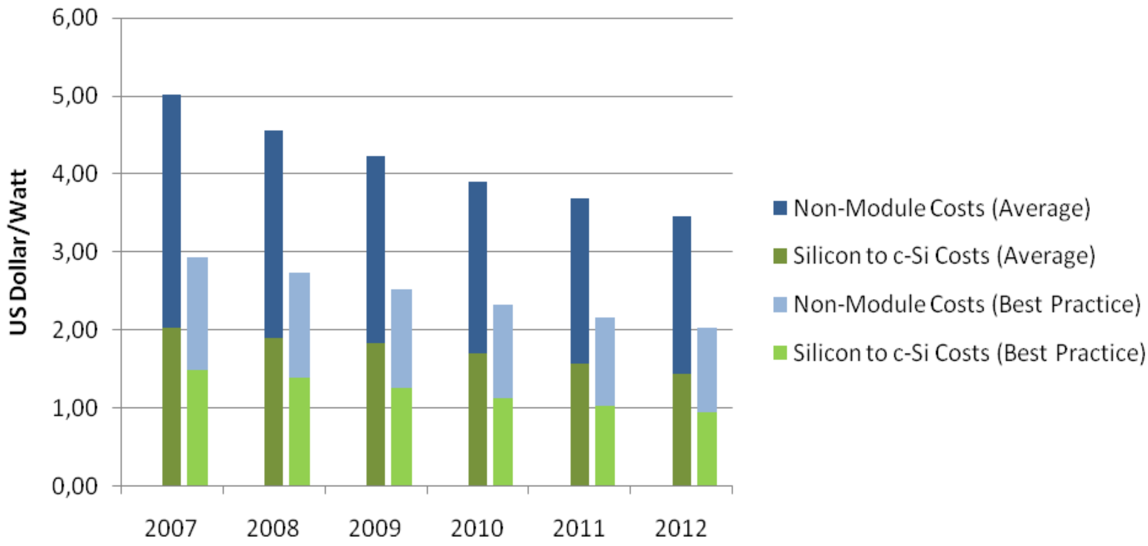


Figure 28: Average c-Si Module Costs
Source: Song, 2009

Average thin film modules have been 62 percent more expensive than best practice ones. This ratio will decline to 51 percent in 2012 as shown in figure 29 (non-module costs are included). In 2009 average thin film costs of 1.94 $/W are more than half the average all-in c-Si module costs of 4.23 $/W.

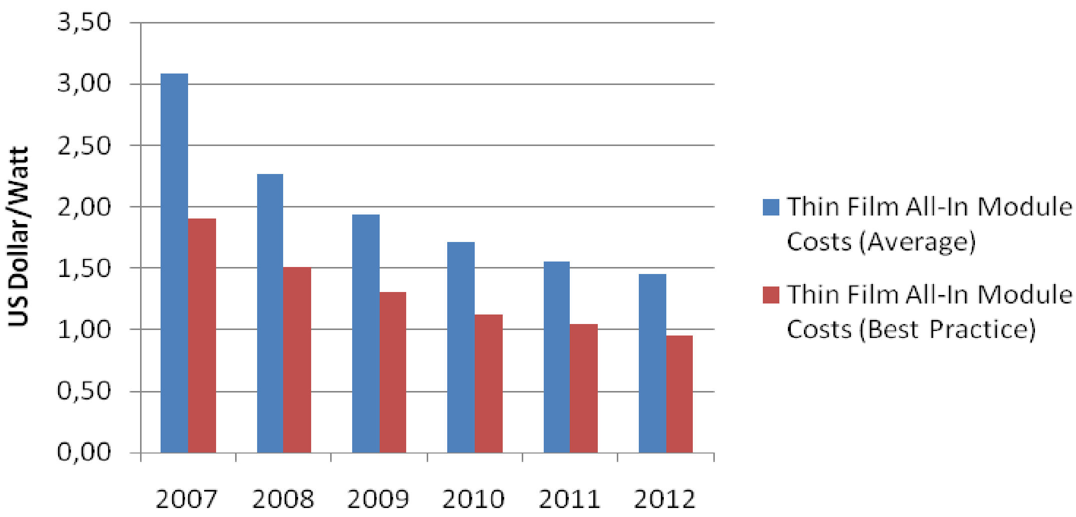


Figure 29: Average All-In Thin Film Module Costs
Source: Song, 2009

Table 1 gives a detailed overview of the overall system costs and its' development for c-Si modules. It points out that the cost decrease to one Dollar per Watt takes place in three areas of the solar sector: c-Si modules, thin film modules and BOS.

Silicon	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Average all-in Cost ($/kg)	36	38	41	43	43	41
Best Practice all-in Cost ($/kg)	27	28	23	19	17	16
Average Si Usage (g/W Silicon-to-Module)	9.1	8.3	7.7	7.0	6.6	6.2
Average all-in Cost ($/W)	0.33	0.32	0.31	0.30	0.28	0.25
Best Practice all-in Cost ($/W)	0.24	0.23	0.18	0.13	0.11	0.10
Ingot/Wafer						
Average Processing Cost ($/W)	0.42	0.40	0.39	0.35	0.32	0.30
Best Practice Processing Cost ($/W)	0.38	0.33	0.30	0.27	0.24	0.22
Cell						
Average Processing Cost ($/W)	0.62	0.55	0.53	0.49	0.45	0.41
Best Practice Processing Cost ($/W)	0.36	0.35	0.33	0.31	0.29	0.27
c-Si Module						
Average Processing Cost ($/W)	0.65	0.62	0.60	0.55	0.51	0.48
Best Practice Processing Cost ($/W)	0.50	0.47	0.44	0.41	0.39	0.36
Silicon to c-Si Module						
Sum of Average Costs ($/W)	2.02	1.89	1.83	1.69	1.57	1.44
Sum of Best Practice Costs ($/W)	1.48	1.38	1.25	1.13	1.03	**0.95**
Non-Module (c-Si)						
Average all-in Cost ($/W)	2.99	2.67	2.40	2.21	2.12	2.01
Best Practice all-in Cost ($/W)	1.45	1.35	1.27	1.20	1.13	**1.07**
Total System (c-Si)						
Sum of Average Cost ($/W)	5.01	4.56	4.23	3.90	3.69	3.45
Sum of Best Practice Cost ($/W)	2.93	2.73	2.52	2.33	2.16	**2.02**
Electricity						
Sum of Average Si-to-electricity Cost ($/kWh)	0.35	0.30	0.28	0.26	0.24	0.23
Sum of Best Practice Si-to-electricity Cost ($/kWh)	0.16	0.14	0.13	0.12	0.11	0.10

Table 1: c-Si Modules System Costs
Source: Song, 2009

In 2012 c-Si modules could be produced at costs below one Dollar per Watt for the first time.

6.2 Grid Parity

Another very important term for the PV sector is grid parity. For PV it represents the point at which PV electricity is equal to or cheaper than grid power.

The race to grid parity is mainly focused on the US market and there especially in the South-western states. Particularly two companies are trying to reach grid parity within 2010. The Californian company Sempra Energy started a 12.6 MW PV plant in El Dorado, Nevada in 2008. The official market reference price in the USA was about 11.12 US-Cent per kWh in 2008. It is said that Sempra is delivering its electricity just a little above the average price (Photon, 3/2009).

Another company, First Solar, could have reached grid parity already. A remarkable contract between First Solar and Southern California Edison was materialized. The Californian Energy Authority (California Public Utilities Commission) announced in July 2008 that electricity supplier will pay the PV plant operator less than 9.7 US-Cent (7.57 Eurocent) per kWh. For this reason this would be the first project which sells PV electricity under the average market price (produced conventionally). The mentioned 7.5 MW plant started its operation in October 2009 and can be extended up to 21 MW (Photon, 3/2009).

Analysts predict that First Solar will dominate the US market regarding price per kWh. Nevertheless neither First Solar nor Sempra are confirming these figures. First Solar assumes officially that the grid parity of PV electricity will be reached between 2010 and 2012 (Photon, 3/2009).

Not many contracts between electrical suppliers and PV operators are public and the production costs are often a very well kept secret. Therefore it will be hard to tell when a PV operator is actually able to offer electricity at a competitive price.

7. Future Scenarios

The last chapter analyses two future scenarios of PV technology. The IEA scenario could be seen as a moderate one emerging from a worldwide need to reduce GHG emissions. Although EPIA (2008) developed different scenarios, the so called moderate one is still much more optimistic than the IEA scenario. This could be seen as the desire of the PV industry but interestingly both scenarios simulate a similar future trend, although with a different timeline.

7.1. IEA Scenario

The IEA (2008) developed different scenarios in 2009 which are based on the 4th Assessment Report of the IPCC (Intergovernmental Panel on Climate Change) and recommend a global temperature increase of maximum 2.0–2.4 ℃ until 2050.

The basis is a reference scenario for growth in global electricity demand, against which the percentage contribution from PV power can be judged. This shows global demand for power increasing from 15,016 TWh in 2005 to 21,278 TWh in 2015 and 29,737 TWh in 2030.

The Act Scenario brings back CO2 emissions to 2005 levels by 2050 through a number of technological developments whereas the Blue Scenario is more ambitious, bringing emissions at 50 percent of the 2005 level by 2050. This implies of course higher investment costs, but also greater needs in technological and policy developments.

According to the Blue Scenario, about 46.5 percent of renewable energy sources will be needed by 2050 in the global power energy mix. 7 percent of the total electricity generated will come from solar PV by 2050 globally, which would represent about 30 GW/year of annual installed capacity and an area of 215 km^2 of solar panels (IEA, 2008).

Figure 30 illustrates the CO2 equivalent saving potential in 2050. The overall savings would be 1.32 Gt whereas the most savings could be achieved in China and India followed by North America.

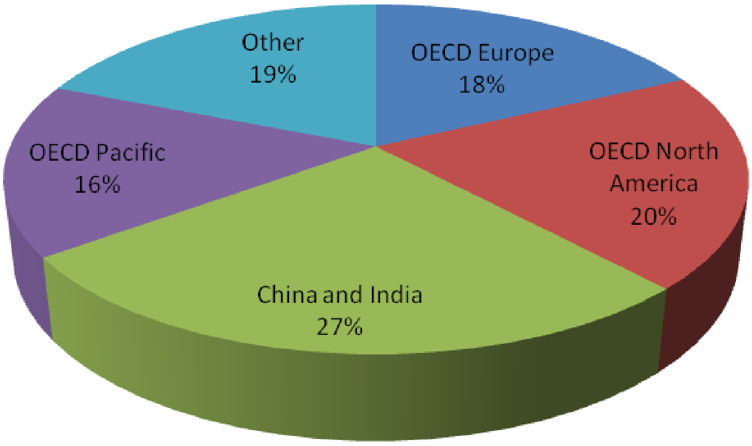


Figure 30: Ratio of CO2 Equivalent Saving Potential in 2050
Source: IEA, 2008

For the Blue Scenario a completely different energy system has to be implied. Short and medium term technology policies are needed and it will only be possible if the whole world participates fully.

PV systems in this scenario have a potential to reduce GHG by 3 percent. A timeline of the developments are illustrated in figure 31. Certain technology parameters have to be fulfilled to enable the Blue Scenario:

- c-Si modules efficiency has to be around 25 percent
- Thin film modules reach efficiencies of 20-25 percent and a lifetime of 30-35 years
- Third generation devices are fully developed and deployed (devices above 40 percent efficiency; ultra-low cost cells reach 10-15 percent efficiencies and a lifetime of 10-15 years)
- Fully integrated and multi-functional PV applications in buildings

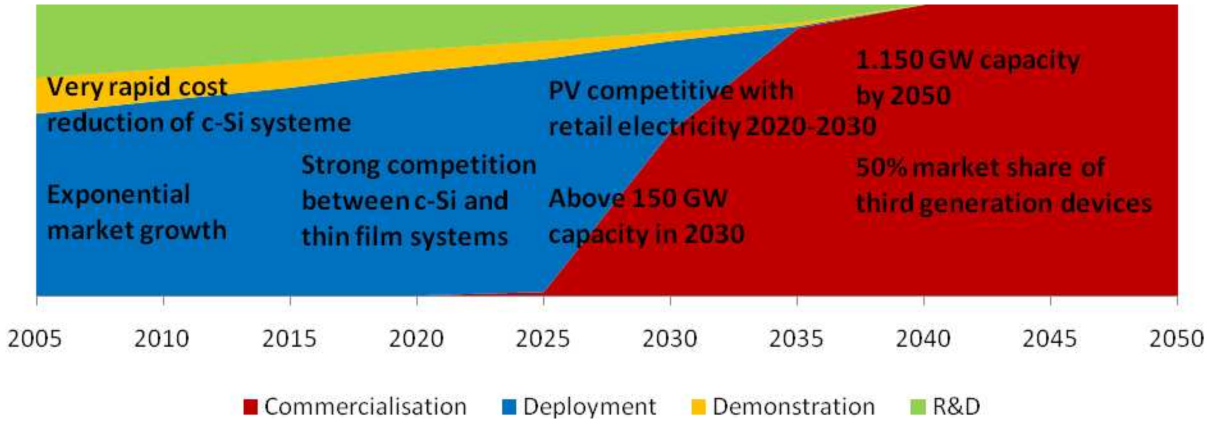


Figure 31: Timeline of the Technology Developments
Source: IEA, 2008

7.2 EPIA Scenario

EPIA has also developed different scenarios for PV systems. Unlike the IEA scenario the EPIA one is more focused on the market development and policy frameworks than the GHG objectives and the means to reach them.

EPIA's moderate scenario with moderate political commitment is characterized in this chapter. In this scenario insufficient additional global political support is given and therefore fast market deployment is difficult. Without the potential for economies of scale, PV production costs and prices will fall at a slower rate than in an advanced scenario, resulting in a lower level of PV deployment.

Expected market growth rates under this scenario are:

- Average growth rate 2007-2010 30 percent
- Average growth rate 2011-2020 21 percent
- Average growth rate 2021-2030 12 percent

Two assumptions are made for the expected growth in electricity demand over the first decades of the 21st century. The reference scenario of the IEA (see above) and an alternative scenario for future electricity based on the 2007 Energy [R]evolution Report of Greenpeace and the European Renewable Energy Council. It also takes into account the extensive use of energy efficiency measures in order to decrease final electricity consumption. This scenario shows global demand for power increasing from 13,675 TWh in 2003 to 14,188 TWh in 2010, 16,614 TWh in 2020 and 19,189 TWh (IEA 29,737 TWh) in 2030. The PV contribution is therefore higher under this projection.

The results of this scenario show that, even from a relatively low baseline, PV electricity has the potential to make a major contribution to both future electricity supply and the mitigation of climate change. The main figures are illustrated in table 2 for the whole scenario period up to 2030. A moderate scenario therefore shows that by 2030, PV systems could be generating approximately 1,291 TWh of electricity around the world. Under this scenario, the global installed capacity of solar power systems would reach 912 GW by 2030. About 74 percent of this would be in the grid-integrated market, mainly in industrialised countries. The total number of people supplied with household electricity from a grid-integrated solar system could reach approximately 564 million.

	2007	2010	2020	2030
Annual Installations in GW	2.4	5.3	35	105
Accumulated Capacity GW	9.2	21.6	211	912
Electricity Production in TWh	10	24	283	1,291
PV Contribution to Electricity Consumption (reference scenario of the IEA)	0.07 %	0.14 %	1.20 %	4.34 %
Grid Connected People in Million	5.5	14	136	564
Employment in Thousand People	119	252	1,462	3,718
Market Value in Billion €	13	24	97	204
Annual CO2 Savings in Mt	6	15	170	775
Cumulative Carbon Savings in Mt	27	61	839	5,333

Table 2: Projections of a Moderate Scenario
Source: EPIA & Greenpeace, 2008

These results are just for a moderate scenario. An advanced scenario based on the assumption that continuing and additional market support mechanisms will lead to a dynamic expansion of worldwide PV installed capacity would produce much better results. Market support programmes would create economies of scale and PV prices would fall faster as a result, leading to a further market push. Although such market programmes are designed to be only a temporary means of support, they are nonetheless crucial in initiating a stable commercial environment.

In order to meet the growth in demand projected in the scenario, companies along the PV value chain will need to upscale their production capacities. Table 3 gives a breakdown of the investments needed in the PV industry up to 2010 according to EPIA & Greenpeace (2008). The highest level of investment is required for silicon production and the upscaling of thin film production capacities. As explained in chapter 2.1.1 silicon prices have been on a record low in 2009 and therefore have positively influenced the demand. Nevertheless, overcoming the economic crisis of 2008/09, the prices will increase significantly within the next years making the sufficient supply of silicon a crucial precondition for further growth of the PV sector.

	2008	2009	2010	Total
Silicon	869	1,097	1,402	3,368
Wafers	604	708	1,104	2,416
Cells	345	404	631	1,380
Modules	345	404	631	1,380
Thin Film	606	1,011	788	2,406
Total	2,770	3,624	4,555	10,950

Table 3: Investment in New Production Capacities in Million Euros
Source: EPIA & Greenpeace, 2008

Taking the accumulated capacity EPIA expects 912 GW by 2030 in a moderate scenario. The IEA Blue Scenario expects a capacity of above 150 GW in 2030 and 1,150 GW in 2050. EPIA expects a PV contribution to the electricity consumption of more than 4 percent by 2030 and IEA estimates 7 percent in 2050. Although there are significant differences in the two scenarios, it is obviously that PV systems will increase considerably over the next decades. The only question is the starting point of the exponential growth.

8. Summary and Conclusion

Although PV is one of the most prominent renewable energy technologies and dependent on a worldwide abundant fuel source, the currently comparatively high cost of this technology is still a huge barrier for an accelerated deployment. However, the PV technologies comprise also a large potential for promised cost reduction while the fossil fuel prices are increasing.

Besides established silicon technologies, thin film, a non silicon based technology holds significant growth potential. This technology has the advantage that it is completely based on non silicon material so the chances of it being hindered by polysilicon market fluctuations are negligible. Many experts and companies believe that thin film could leverage PV into a real mass market. The market share of this technology has steadily increased in recent years. The significant growth prospects of this technology have triggered many companies to enter the non silicon based thin-film market. Correspondingly, with new companies setting up their non-silicon production lines in the coming years, the market share for this technology is expected to increase at a faster pace in the near future.

The worldwide PV production was booming in the last years. The overall global capacity increased from 1,166 MW in 1999 to 14,370 MW in 2008 that is a capacity increase of more than 12 times in 10 years.

Countries like Germany, the USA, Spain and Japan have already established a strong PV market. They will have a market share of more than 70 percent in 2010 and are good examples of the vast potential of solar electricity generation. Emerging countries like China and India have also realized these opportunities and are setting up the infrastructure for a competitive PV industry. Regardless of irradiation conditions, countries around the globe are discovering PV as a renewable energy source, able to find answers for crucial future challenges.

Germany will have the biggest PV market in 2010. An ambitious feed-in tariff and political commitment brought Germany the first place by far. Other countries like USA, Japan and Spain are catching up fast, although announced subsidy caps in certain countries could change the picture significantly within the next years. At the moment it seems the USA has the most ambition to support its PV sector in the long run. Big question marks are China, India and Turkey. One has to see how the national supporting schemes work out there but irradiation and demand potentials are enormous in those countries.

Different scenarios predict a significant increase of PV technology within the next decades. The persistent argument that PV is much too expensive for a mass market is increasingly invalidated. The lowest retail prices at the end of 2009 for PV modules have been € 1.78 for monocrystalline silicon modules, € 1.31 for multicrystalline silicon modules and € 1.16 for thin film modules. Module costs have decreased over the last years and will continue decreasing. Best-practice production costs for c-Si modules under one Dollar per Watt could be possible by 2012. Generally the prices are still high above other energy sources but in some countries, with good pre-conditions, grid parity seems possible in the near future. Some PV experts believe that certain plants in the USA are already able to produce PV electricity at grid parity. Conservative scenarios predict that the PV contribution to the electricity consumption could account for more than four percent by 2030, policy driven ones come to even higher results.

Despite the bright future, PV has to master many challenges on the way to a major player on the electricity market. High production prices, shortage of raw materials, increase of efficiencies and cost of research and development are just a few of them. Already in the seventies after a short boom the PV industry went into an almost permanent hibernation until the nineties. Without a long term political commitment and continuing development of the technology, this extraordinary market development of the PV industry in the last years could still be at stake.

References

Aarkstone, 2020: Aarkstore Enterprise, “Global Solar Photovoltaic Market Analysis and Forecasts to 2020”, 2009

Alsema et al., 2006: Alsema E.A., de Wild Scholten M.J, “Environmental Impacts of Crystalline Silicon Photovoltaic Module Production”, Paper presented at 13th CIRP Intern. Conf. on Life Cycle Engineering, Leuven, 31 May- 2 June 2006

Bachhiesl, 2009: Udo Bachhiesl Udo, Stigler Heinz, „Zweckmäßigkeit unterschiedlicher Förderinstrumentarien für Erneuerbare Energien“, Vortrag Wien 12.02.2009, IEWT 2009

Bundesverband Erneuerbare Energie, 2008: Bundesverband Erneuerbare Energie, „Ökostromgesetz neu im Rahmen einer neuen Strompolitik für Österreich“, Wien, 4. April 2008

Çolak, 2008: Çolak Metin, “Photovoltaic Applications in Turkey; Status and Prospects”, Ege University, Solar Energy Institute and Faculty for Engineering, 2008

De Wachter, 2008: De Wachter Bruno, “Environmental impact of the PV life-cycle”, Article at www.leonardo-energy.org, May 2008

Dou Charlie, 2007: Dou Charlie, “Opportunity and challenge of China PV market”, 2007

Diaz-Reyes, 2008: Diaz-Reyes, Giammatteo, Deniz-Quintana, “Photovoltaic Energy Promotion in Europe: Italy and Spain, two visions, one aim”, Univ. of Las Palmas de Gran Canaria, Las Palmas, 2008

Dietrich, 2006: Dietrich Sylvio, „PV Profit 2.2 – Wirtschaftlichkeit von Photovoltaik-Anlagen“, 3. Auflage, Verlag Solare Zukunft, Erlangen 2006

EPIA, 2009: EPIA, “Global Market Outlook for Photovoltaics until 2013”, 2009

EPIA & Greenpeace, 2008: EPIA & Greenpeace, “Solar Generation V”, 2008

EREC, 2009a: EREC, “Renewable Energy Policy Review Italy”, European Renewable Energy Council, March 2009

EREC, 2009b: EREC, “Renewable Energy Policy Review Spain”, European Renewable Energy Council, March 2009

IEA, 2008: International Energy Agency, “Energy Technology Perspectives - Scenarios & Strategies to 2050”, 2008

IEA PVPS, 2008a: IEA PVPS, “Annual Report 2007 Turkey”, 2008

IEA PVPS, 2008b: IEA PVPS, “Task 1 – Trends in Photovoltaic Applications”, 2008

IEA PVPS, 2008c: IEA PVPS, “Task 10 – Visualization Tool for Photovoltaics Operating on Electric Grids”, Ehara Tomoki, Mizuho Information & Research Institute, Inc., Japan 2008

Jäger-Waldau, 2008: Jäger-Waldau Arnulf, “PV Status Report 2008”, Renewable Energy Unit, EU Commission, 2008

Miller, 2009: Miller Matt, Larkin Matthiah, “China PV Market Development”, GTM Research, 2009

NREL, 2009: Kurz S., “Opportunities and Challenges for Development of a Mature Concentrating Photovoltaic Power Industry”, Technical Report, NREL/TP-520-43208, Revised November 2009

Ognjan, 2009: Ognjan Diana, Robić Slavica, Debrecin Nenad, “Profitability and the Feasibility of the Photovoltaics in Croatia – Analysis of Technical, Economical and Legal Aspects”, University of Zagreb & HEP Renewable Energy Sources Ltd, 2009

Perlin, 2002: Perlin John, “From Space to Earth – The Story of Solar Electricity”, First Harvard University Press, Cambridge, Massachusetts, 2002

Photon, 3/2009: Photon, Das Solarstrom Magazin, March 2009

Photon, 4/2009: Photon, Das Solarstrom Magazin, April 2009

PV-NMS-NET, 2009: PV-NMS-NET, “Status of Photovoltaics 2008 in the European Union New Member States”, 2009

Schott, 2009: Schott Solar AG, “Wafer vom Band: Hoher Wirkungsrad, halb so viel Silicium”, Article, Oct. 21, 2009

SEMI, 2009: Semiconductor Equipment and Materials International India, “The Solar PV Landscape in India – An Industry Perspective”, 2009

Smith, 1995: Smith Charles, “History of Solar Energy”, Technology Review, July 1995

Solarbuzz, 2009: Solarbuzz, “Details Mid-Range Global PV Market Forecast of 7.4 GW in 2010”, San Francisco, June 2009

Song, 2009: Song Joonki et al., “The True Cost of Solar Power Race to $1/W”, Photo Consulting, 2009

Streissler, 2007: Streissler Christoph, “Kostenvergleich der Klimapolitischen Maßnahmen”, Arbeiterkammer, Vortrag Sozak, 09.10.2007

US Dept. of Energy, 2008: US Department of Energy, “Technology Commercialization Showcase 2008 – Solar Energy Technologies Program Accelerating the Future of Solar”, John Lushetsky, 2008

US Dept. of Energy, 2004: US Department of Energy, “PV FAQs”, The National Renewable Energy Laboratory, January 2004

Wang, 2009: Wang Ucilia, “Contract Silicon Price Falls 50 Percent Close to Spot Price”, Greentechsolar Article, July 28, 2009

World Commission, 1987: United Nations, “Report of the World Commission on Environment and Development”, General Assembly, 96th plenary meeting, 11th Dec. 1987

(BSW-Solar, 2009): http://www.solarwirtschaft.de/entscheider/marktdaten.html

(Bundesministerium für Wirtschaft und Technologie, 2009):

http://www.bmwi.de/BMWi/Navigation/Energie/energiestatistiken,did=180924.html
(gosolarcalifornia, 2010): www.gosolarcalifornia.org/csi/tax_credit.html, 05.01.2010
(oekb, 2010): http://www.oekb.at/de/unternehmen/nachhaltigkeit/oekologie/seiten/umrechnungstabelle-emissionen.aspx, 23.02.2010
(pvaustria, 2010): www.pvaustria.at, 05.01.2010
(pvresources, 2010): www.pvresources.com/en/top50pv.php, 05.01.2010
(pvtech, 2009): www.pv-tech.org/tariff_watch/_a/turkey/
(science.orf, 2008): www.science.orf.at/science/news/153260, APA Report of Nov. 7, 2008
(solarfeedintariff, 2010): www.solarfeedintariff.co.uk/2009/05/sharp-solar-predict-turkey-solar-boom/, 05.01.2010
(solar-individuell, 2010): www.solar-individuell.de/photogrundprinzip.html, 05.01.2010
(solarserver, 2010): www.solarserver.de/wissen/photovoltaik-e.html, 05.01.2010
(wikipedia, 2010a): www.en.wikipedia.org/wiki/Solar_inverter, 24.02.2010
(wikipedia, 2010b): www.de.wikipedia.org/wiki/%C3%9Cbertragungsverlust, 05.01.2010