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Technology and market future prospects of photovoltaic systems

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Abstract
During the past 20 years there has been a significant growth of the solar photovoltaic (PV) technology and today is considered by many countries as an important technology for the future. Many countries have already established or are in the process of establishing support programs to encourage the adoption of this new technology following in this way the examples of the major players of the PV market. In this work, an investigation of the technology and market future prospects of PV systems is carried out. In particular the PV key benefits are presented and the various PV solar cell technologies are described and compared. Emphasis has been given to the current and future PV solar systems market demand including their current and future economics. Solar PV has two big challenges that need to be resolved. Production costs need to go down before it becomes economically sustainable, while production capacity must continue to grow in order for PV to become a significant player in the global energy market.
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1. Introduction
Photovoltaic (PV) systems convert energy from the sun directly into electricity. They are composed of photovoltaic cells, usually a thin wafer or strip of semiconductor material that generates a small current when sunlight strikes them. Multiple cells can be assembled into modules that can be wired in an array of any size. Small PV arrays are found in wristwatches and calculators, the largest arrays have capacities in excess of 20MW.
In recent years the PV industry has been experiencing a dramatic growth at a global level. Continuous increase of conventional fuel costs as well as growing pressure to turn towards Renewable Energy Sources (RES) are the main drivers behind this rapidly expanding industry which since the start of the decade has achieved continuous annual growth of around 30%. At a global energy output level, the PV industry is still lagging behind other RES technologies, such as, hydropower and wind energy. This is due to the high costs associated with the manufacturing of PV solar modules, costs that will however steadily diminish as a result of continuous advancements in technology [5].
PV systems are cost-effective in small stand alone (off-grid) applications, providing power, for example, to rural homes in developing countries, off-grid cottages and motor homes in industrialized countries, and remote telecommunications, monitoring and control systems worldwide. Water pumping is also a notable off-grid application of PV systems that are used for domestic water supplies, agriculture and, in developing countries, provision of water to villages. These power systems are relatively simple, modular, and highly reliable due to the lack of moving parts. PV systems can be combined with fossil fuel-driven

generators in periods of little sunshine (e.g., winter at high latitudes) to form hybrid systems. PV systems can also be tied to isolate or central grids via a specially configured inverter. Unfortunately, without subsidies, grid connected (on-grid) applications are rarely cost-effective due to the high price of PV modules, even if it has declined steadily since 1985 [6]. Due to the minimal maintenance of PV systems and the absence of real benefits of economies of scale during construction, distributed generation is the path of choice for future cost-effective on-grid applications. In distributed electricity generation, small PV systems would be widely scattered around the grid, mounted on buildings and other structures and thus not incurring the costs of land rent or purchase. Such applications have been facilitated by the development of technologies and practices for the integration of PV systems into the building envelope, which offset the cost of conventional material and/or labor costs that would have otherwise been spent.

The residential rooftop application of PVs is expected to provide the major application of the coming decade and to provide the market growth needed to reduce prices. Large centralized solar PV power stations able to provide low-cost electricity on a large scale would become increasingly attractive approaching 2020.

In this work, an investigation of the technology and market future prospects of PV systems is carried out. In particular the PV key benefits are presented and the various PV solar cell technologies are described and compared. Emphasis has been given to the current and future PV solar systems market demand including their current and future economics.

In section 2, the PV technology status is discussed and in section 3, the PV system types and their benefits are described. The PV market demand is presented in section 4 including projections on PV economics. The conclusions are summarized in section 5.

2. The PV technology

Solar energy is the energy force that sustains life on earth for all plants, animals and people. The earth receives this energy from the sun in the form of electromagnetic waves, which the sun continually emits into space. The earth can be seen as a huge solar energy collector receiving large quantities of this energy which takes various forms, such as direct sunlight, heated air masses causing wind, and evaporation of the oceans resulting as rain which can form rivers. This solar potential can be trapped directly as solar energy (solar thermal and/or PV) and indirectly as wind, biomass and hydroelectric energy.

Solar energy is a renewable source that is inexhaustible and is locally available. It is a clean energy source that allows for local energy independence. The sun's power that is reaching the earth annually is typically about 1000W/m^2, although availability varies with location and time of year. Capturing solar energy typically requires equipment with a relatively high initial capital cost. However, in some cases, over the lifetime of the solar equipment, these systems can prove to be cost competitive, as compared to conventional energy technologies.

The solar energy industry is divided into mainly two markets, the PV market and the solar thermal market. The solar thermal technology uses the heat radiated from the sun, for purposes such as heating water or power generation. On the other hand PV solar cells use the properties of particular semiconducting materials to convert sunlight energy to electricity. The PV industry is far larger than the solar thermal market.

Solar electricity produced by PV solar cells is one of the most promising options yet identified for sustainably providing the world's future energy requirements. Although the technology has, in the past, been based on the same silicon wafers as used in microelectronics, a transition is in progress to a second generation of a potentially much lower-cost thin-film technology. Cost reductions from both increased manufacturing volume and such improved technology are expected to continue to drive down PV cell prices over the coming two decades to a level where the cells can provide competitively priced electricity on a large scale [19].

2.1 Basics of PVs

Electricity can be produced from sunlight through a process called "photovoltaics", which can be applied, in either a centralized or decentralized way. "Photo" refers to light and "voltaic" to electrical voltage. The term describes a solid-state electronic cell that produces direct current (DC) electrical energy from the radiant energy of the sun.

The basic steps from the PV solar cell to a fully operating PV system are presented in Figure 1. PV solar cells are made of semi-conducting material, most commonly silicon, coated with special additives. When light strikes the cell, electrons are knocked and become loose from the silicon atoms and flow in an in-built circuit producing electricity. Individual solar cells can be connected in series and in parallel to obtain desired voltages and currents. These groups of cells are packaged into standard modules that protect the cells from the environment. PV modules are extremely reliable since they are solid state and there are no moving parts.

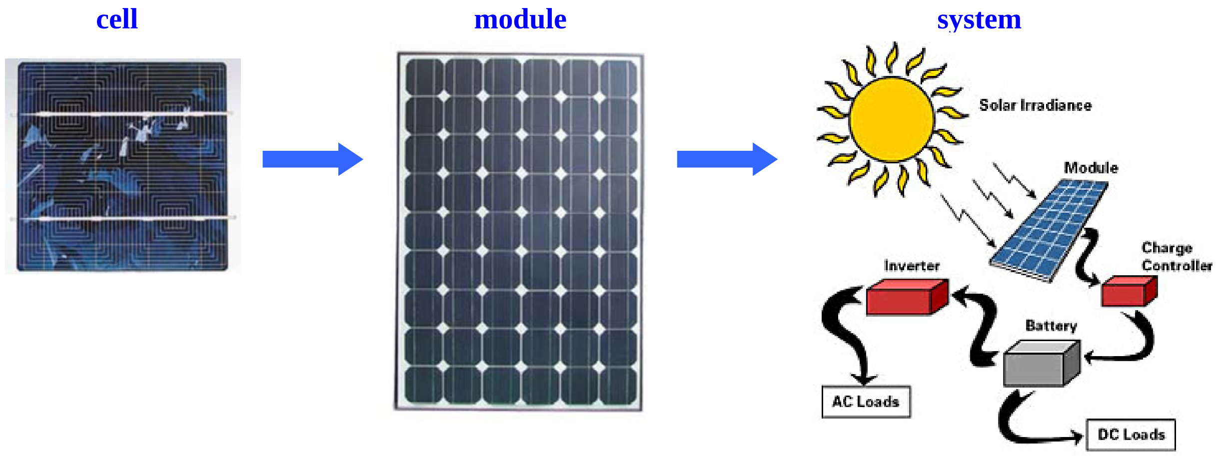

Figure 1. Basic steps from PV cell to PV system

PV systems are made up of a variety of components, which aside from the modules, may include conductors, fuses, batteries, inverters, etc. Components will vary, however, depending on the application. PV systems are modular by nature, meaning that systems can be expanded and components easily repaired or replaced if needed. PV systems are cost effective for many remote power applications, as well as for small stand-alone power applications in proximity to the existing electricity grid.

2.2 Principle of operation

A cell is created when a positively charged (p-type) layer of silicon is placed against a negatively charged (n-type) to create a diode for the flow of electrons. When silicon is exposed to light, electrical charges are generated. Referring to Figure 2, light entering the cell through the gaps between the top contacts metal gives up its energy by temporarily releasing electrons from the covalent bonds holding the semiconductor together; at least this is what happens for those photons with sufficient energy [12]. The p-n junction within the cell ensures that the now mobile charge carriers of the same polarity all move off in the same direction. These electrical charges are conducted away as DC power by placing metal contacts on the top and bottom of a PV cell. If an electrical load is connected between the top and rear contacts to the cell, electrons will complete the circuit through this load, constituting an electrical current in it. Energy in the incoming sunlight is thereby converted into electrical energy.

The cell operates as a “quantum device”, exchanging photons for electrons. Ideally, each photon of sufficient energy striking the cell causes one electron to flow through the load. In practice, this ideal is seldom reached. Some of the incoming photons are rejected from the cell or get absorbed by the metal contacts (where they give up their energy as heat). Some of the electrons excited by the photons relax back to their bound state before reaching the cell contacts and thereby the load.

The electrical power consumed by the load is the product of the electrical current supplied by the cell and the voltage across it. Each cell can supply current at a voltage between 0.5V-1V, depending on the particular semiconductor used for the cell. Since the electrical output of a single cell is quite small to generate sufficient amount of electricity multiple cells are connected together to form a module or a panel [13].

The PV module is the primary component of PV system and any number of PV modules can be connected to generate the desired amount of electricity. The modular structure of a PV system is considered an advantage since at any instant a new module can be incorporated to the system to satisfy the new electricity requirement. Different PV modules vary in structure; however, they generally include the following elements: (a) glass cover in which the transparent glass cover is placed over the PV cell for protection reasons, (b) anti-reflective sheet which is used to enhance the effect of the glass cover while the anti-reflective coating is used to block reflection, (c) cell and (d) frame and panel backing which are used to hold all the pieces together and protect the PV cell from damage [22].

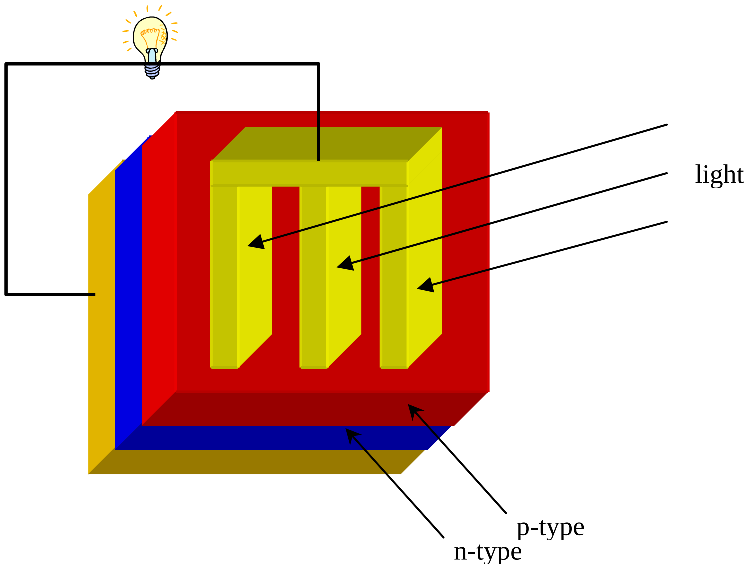

Figure 2. PV solar cell operating principle

2.3 PV technologies

The choice of the semiconductor defines the PV technology. There are two main PV technologies, such as, crystalline silicon solar cells and thin film solar cells as described in the following sections.

2.3.1 Crystalline silicon solar cells

The technology used to make most of the crystalline silicon solar cells, fabricated so far, borrows heavily from the microelectronics industry and is known as silicon wafer technology. The silicon source material is extracted from quartz, although sand would also be a suitable material. The silicon is then refined to very high purity and melted. From the melt, a large cylindrical single crystal is drawn. The crystal, or "ingot", is then sliced into circular wafers, less than 0.5mm thick, like slicing bread from a loaf. Sometimes this cylindrical ingot is "squared-off" before slicing so the wafers have a "quasi-square" shape that allows processed cells to be stacked more closely side-by-side. Most of this technology is identical to that used in the much larger microelectronics industry, benefiting from the corresponding economies of scale. Since good cells can be made from material of lower quality than that used in microelectronics, additional economies are obtained by using off-specification silicon and off-specification silicon wafers from this industry.

The first step in processing a wafer into a cell is to etch the wafer surface with chemicals to remove damage from the slicing step. The surface of crystalline wafers is then etched again using a chemical that etches at different rates in different directions through the silicon crystal. This leaves features on the surface, with the silicon structure that remains determined by crystal directions that etch very slowly. The p-n junction is then formed. The impurity required to give p-type properties (usually boron) is introduced during crystal growth, so it is already in the wafer. The n-type impurity (usually phosphorus) is now allowed to seep into the wafer surface by heating the wafer in the presence of a phosphorus source.

Crystalline silicon solar cells hold 93% of the market. Despite the fact that it is a relatively poor light absorbing semiconducting material, over the years it has been the primary raw material used in most solar PV cells due to its ability to yield stable and efficient cells, with efficiencies between 11-16% in terms of converting sunlight energy to electrical energy [23].

There are two types of crystalline silicon solar cells that are used in the industry, such as, (a) monocrystalline silicon cells (single-Si) and (b) multicrystalline silicon cells (multi-Si or poly-Si).

The monocrystalline silicon cell is made using cells saw-cut from a single cylindrical crystal of silicon. The main advantage of the monocrystalline silicon cells is the high efficiency which is around 15%. The multicrystalline silicon cell is made by sawing a cast block of silicon first into bars and then into wafers. Multicrystalline cells are cheaper to manufacture than monocrystalline ones due to the simpler manufacturing process. However they are slightly less efficient than the monocrystalline with average efficiency of approximately 12%.

In general crystalline silicon solar cells have a relatively high production cost and subsequently high selling price. Moreover, its dependence on purified silicon as the key raw material creates additional

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difficulty since there is global shortage of the material. The relative high costs result from the complex and numerous production steps involved in wafer and cell manufacturing and the large amount of highly purified silicon feedstock required.

2.3.2 Thin-film solar cells

Due to the high production cost of the crystalline silicon wafers, the PV industry has been seeking for alternative ways of manufacturing PV solar cells using cheaper materials such as the thin-film solar cells.

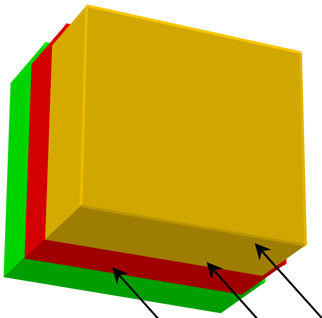

Figure 3. Thin-film technology approach

In the thin-film technology approach, thin layers of semiconductor material are deposited onto a supporting substrate, or superstrate, such as a large sheet of glass as indicated in Figure 3. Typically, less than a micron (μm) thickness of semiconductor material is required, 100-1000 times less than the thickness of silicon wafer. Reduced material use with associated reduced costs is a key advantage. Another advantage is that the unit of production, instead of being a relatively small silicon wafer, becomes much larger, for example, as large as a conveniently handled sheet of glass might be. This reduces manufacturing costs.

Silicon is one of the few semiconductors inexpensive enough to be used to make solar cells from self-supporting wafers. However, in thin-film form, due to the reduced material requirements, virtually any semiconductor can be used. Since semiconductors can be formed not only by elemental atoms, such as silicon, but also from compounds and alloys involving multiple elements, there is essentially an infinite number of semiconductors from which to choose. At present, solar cells made from different thin-film technologies are either available commercially, or close to being so, such as, cadmium telluride (CdTe), copper indium diselenide (CIS), amorphous silicon (a-Si) and thin-film silicon (thin film-Si) [20].

Amorphous silicon is in commercial production while the other three technologies are slowly reaching the market. Over the coming decade, one of the above technologies is expected to establish its superiority and attract investment in major manufacturing facilities that will sustain the downward pressure on cell prices. As each of these thin-film technologies has its own strengths and weaknesses, the likely outcome is not clear at present [21].

Table 1. Comparison of various most common PV technologies [24]

Technology	Typical efficiency*	Maximum efficiency* obtained (laboratory)	Cost
single-Si	12-16%	24.0%	Expensive
poly-Si	11-14%	18.6%	Less expensive
a-Si	6-7%	12.7%	Reduced cost

* solar energy to electrical energy conversion efficiency

Thin-film panels have several important drawbacks. What they gain in cost savings and flexibility they lose in efficiency resulting in the lowest efficiency of any current PV technology at approximately 6-7%. The main interest in these technologies rises from the fact that they can be manufactured by relatively

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inexpensive industrial processes, in comparison to crystalline silicon technologies yet they offer typically higher module efficiency than amorphous silicon.

2.4 Overall comparison

An overall comparison of the efficiency and the cost of the various most common PV solar cell technologies are tabulated in Table 1. In general as the efficiency of PV solar cells increases their cost increases too.

3. PV systems

The primary articles of commerce in the PV market are the PV modules which are integrated into systems designed for specific applications. The components added to the module constitute the “balance of system” or BOS. Balance of system components can be classified into four categories (see also Figure 1): (a) batteries which store electricity to provide energy on demand at night or on overcast days, (b) controllers which can manage the energy storage to the battery and deliver power to the load, (c) inverters which are required to convert the DC power produced by the PV module into alternate current (AC) power and (d) structure which is required to mount or install the PV modules and other components [11].

Not all systems will require all these components. For example in systems where no AC load is present an inverter is not required. For grid connected systems, the utility grid acts as the storage medium and batteries are not required. Some systems also require other components which are not strictly related to PVs. Some stand alone systems, for example, include a fossil fuel generator that provides electricity when the batteries become depleted; and water pumping systems require a DC or AC pump [2].

3.1 PV modules

To make modules, PV solar cell manufacturers assemble the cells into modules or sell them to module manufacturers for assembly. Because the first important applications of PV involved battery charging, most modules in the market are designed to deliver DC power at slightly over 12V. A typical crystalline silicon PV solar module consists of a series circuit of 36 cells, encapsulated in a glass and plastic package for protection from the environment. This package is framed and provided with an electrical connection enclosure, or junction box [19].

PV modules are rated on the basis of the power delivered under Standard Testing Conditions (STC) of 1kW/m^2 of sunlight and a PV cell temperature of 25°C. Their output measured under STC is expressed in terms of “peak Watt” or Wp nominal capacity. For example an annual industry shipments of 165MWp indicates that PV manufacturers made modules with the ability to generate 165MWp of electric power (nameplate capacity) under STC of 1kW/m^2 of sunlight and 25°C cell temperature. Typical conversion (solar energy to electrical energy) efficiencies for various PV technologies are tabulated in Table 1.

3.2 Batteries

If an off-grid PV system must provide energy on demand rather than only when the sun is shining, a battery is required as an energy storage device. The most common battery types are lead-calcium and lead-antimony. Nickel-cadmium batteries can also be used, in particular when the battery is subject to a wide range of temperatures. Because of the variable nature of solar radiation, batteries must be able to go through many cycles of charge and discharge without damage. The amount of battery capacity that can be discharged without damaging the battery depends on the battery type. Lead-calcium batteries are suitable only in “shallow cycle” applications where less than 20% discharge occurs each cycle. Nickel-cadmium batteries and some lead-antimony batteries can be used in “deep cycle” applications where the depth of discharge can exceed 80%.

Batteries are characterized by their voltage, which for most applications is a multiple of 12V, and their capacity, expressed in Ampere-hours (Ah). For example a 50Ah, 48V battery will store 50Ah × 48V = 2,400Wh of electricity under nominal conditions. Note that optimizing battery size is critical in obtaining good battery life, suitable system performance, and optimal system life-cycle costs. Unnecessary battery replacement is costly, particularly for remote applications.

3.3 Power conditioning

Several electronic devices are used to control and modify the electrical power produced by the PV array. These include (a) battery charge controllers, which regulate the charge and discharge cycles of the battery, (b) maximum power point trackers (MPPT), which maintain the operating voltage of the array to a value that maximizes array output, (c) inverters, in order to convert the DC output of the array or the battery into AC (AC is required by many appliances and motors, it is also the type of power used by utility grids and therefore grid connected systems always require the use of an inverter) and (d) rectifiers (battery chargers) in order to convert the AC current produced by a generator into the DC current needed to charge the batteries [10].

3.4 Generators

For off-grid applications it is also possible to have both a PV system and a fossil fuel generator running in parallel. The use of a generator eliminates the need to oversize the PV array and the battery bank in order to provide power during periods with little sunshine. The PV array and the generator supplement each other, the PV array reduces the fuel use and maintenance cost of the generator and the generator replaces the part of the PV system that would need to be oversized to ensure an uninterrupted supply of power.

Generators can use a variety of fossil fuels, such as gasoline, diesel oil, propane or natural gas. The requirement for a generator, and the fraction of the load met respectively by the PV system and the generator, will depend on many factors, including the capital cost of the PV array, operating costs of the generator, system reliability, and environmental considerations (e.g., noise of the generator, emission of fumes, etc.).

3.5 PV power systems

The PV power systems are classified into categories according to their operational requirements, their component configurations and how the system is connected to other power sources and loads. The two principal PV systems described in the following sections are the grid connected (or on-grid) systems and the stand alone systems (or off-grid) systems.

3.5.1 Grid connected systems

In grid connected applications the PV system feeds electrical energy directly into the electric utility grid (this includes central grids and isolated grids). Two application types can be distinguished, distributed generation and central power plant generation. An example of a distributed grid connected application is building integrated PV for individual residences or commercial buildings. The system size for residences is typically in the 2kWp to 4kWp range. For commercial buildings, the system size can range up to 100kWp or more. Batteries are not necessary when the system is grid connected [9].

In grid-connected systems, the PV system is designed to operate in parallel with the electric utility grid. The primary component of a grid connected system is the inverter which is used to convert the DC electrical supply to AC electrical supply. In some cases a bi-directional interface can be made between the PV system AC output circuit and the utility network. This will allow the PV system to either supply on-site electrical loads or feed back to the grid electricity excess of the load demand.

The benefits of grid connected PV power generation are generally evaluated based on its potential to reduce costs for energy production and generator capacity, as well as its environmental benefits. For distributed generation, the electric generators (PV or other) are located at or near the site of electrical consumption. This helps reduce both energy (kWh) and capacity (kW) losses in the utility distribution network. In addition, the utility can avoid or delay upgrades to the transmission and distribution network where the average daily output of the PV system corresponds with the utility’s peak demand period (e.g., afternoon peak demand during summer months due to air conditioning loads). PV manufacturers are also developing PV modules which can be incorporated into buildings as standard building components such as roofing tiles and curtain walls. This helps reduce the relative cost of the PV power system by the cost of the conventional building materials, and allows the utility and/or building owner to capture distributed generation benefits. The use of PV in the built environment is expanding with demonstration projects in industrialized countries [1].

Central PV power generation applications are not currently cost-competitive and strong subsidies are required. Several multimegawatt central PV generation systems have however been installed as demonstration projects, designed to help acquire experience in the management of central PV power plants.

Installations of central PV generation, like distributed grid connected PV, represent a long-term strategy by governments and utilities to support the development of PV as a clean energy.

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3.5.2 Stand alone systems

Currently, PV is most competitive in isolated sites, away from the electric grid and requiring relatively small amounts of power, typically less than 10kWp. In these off-grid applications, PV is frequently used in the charging of batteries, thus storing the electrical energy produced by the modules and providing the user with electrical energy on demand.

Stand alone systems are designed to work independent of the electric utility grid, and are designed and sized to supply certain DC and/or AC loads. These stand alone systems may be powered by a PV array only, or it may be powered by a PV-hybrid system which combines either wind and solar energy, or an engine-generator with solar energy. In many stand alone systems a battery is used for energy storage to provide electricity support during night time when there is no sunlight available [16].

The key competitive arena for PV in remote off-grid power applications is against electric grid extension; primary (disposable) batteries; or diesel, gasoline and thermoelectric generators. PV competes particularly well against grid extension for small loads, far from the utility grid. Compared to fossil fuel generators and primary batteries, the key advantage of PV is the reduction in operation, maintenance and replacement costs; these often result in lower life-cycle costs for PV systems.

3.6 Key benefits of PV systems

During the past 20 years there has been a significant growth of the solar PV electric technology and governments in Japan, USA and Europe who are the major players of the solar energy market, are all providing financial incentives in order to encourage their people to adopt the eco-friendly PV systems as an alternative source of energy. The use of PV systems provides a number of key benefits:

- Energy security: Solar energy provides reliable access to energy where it is used. It can also supplement energy needs during blackouts and disaster recovery for electricity, water pumping and hot water,
- Energy independence: Solar energy can be used to reduce our independence on fossil fuels imported from foreign countries,
- Eco-friendly: Solar energy is a non polluting source of energy. The significant adaptation to PV electricity could further reduce CO_2 emissions in the environment,
- Economic benefits: When installed properly in homes, businesses it can begin to save money immediately,
- Job creation: New jobs are created in manufacturing, distribution, and also many building related jobs for electricians, plumbers, roofers, designers and engineers.

PV is a relatively new technology, which offers a new vision for consumers and business as to how power can be provided alternatively. PV technology is already proving to be a force for social change in rural areas in less developed countries. The unique characteristic of PV is that it is a “radical” and “disruptive” type of technology as compared to conventional power generation technologies.

4. Market demand

There are various types of firms involved in the photovoltaic industry. Typical organizations include PV cell and/or module manufacturers, BOS manufacturers, product distributors and dealers and system integrators.

4.1 Overview of PV market

Figure 4 shows the main energy sources of the world energy supply. Renewable energy sources account for 1.98% of the global energy, while fossil fuels account for 86% of the energy supply. Despite the fact that solar energy is a sustainable and clean energy, the market of solar energy is still very small. The market value of PVs reached 9 billion € in 2006. The current potential of the PV market creates strong competition among the major manufacturers and moreover an attractive market for new players to enter. During the past years growth of the PV market was primarily in the grid connected sector [7].

The demand side of the PV market can be divided into four sectors, shown in Figure 5, such as, (a) consumer goods and services market sector, in which PV solar cells and modules are used in a wide range of consumer products and small electrical appliances, including watches, calculators and toys [3]. The PV solar cells and modules are also used to provide power to road signs, lighting and phone boxes. In 2006 this sector contributed roughly 2% to the global annual production. The consumer goods market

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will continue to grow as the demand for mobile electricity supply increases. On the other hand the introduction of low-cost organic PV solar cells could reduce its relative market share; (b) grid connected systems market sector, related to the PV applications which are permanently connected to the electricity grid. This sector is the propellant of the PV boom, with most development taking place in the countries members of the Organization for Economic Co-operation and Development (OECD). Now PV technology is considered by many countries as an important technology for the future. Many of these countries already established or are in the process of establishing support programs to encourage the adoption of this new technology following in this way the examples of the major players of the PV market Japan, USA and Germany. In 1994 only 20% of new PV capacity was grid connected whereas the figure has grown to 84% in 2006; (c) off-grid electrification market sector in which PV can provide electrical power to communities in the developing countries who have no access to mains electricity [10].

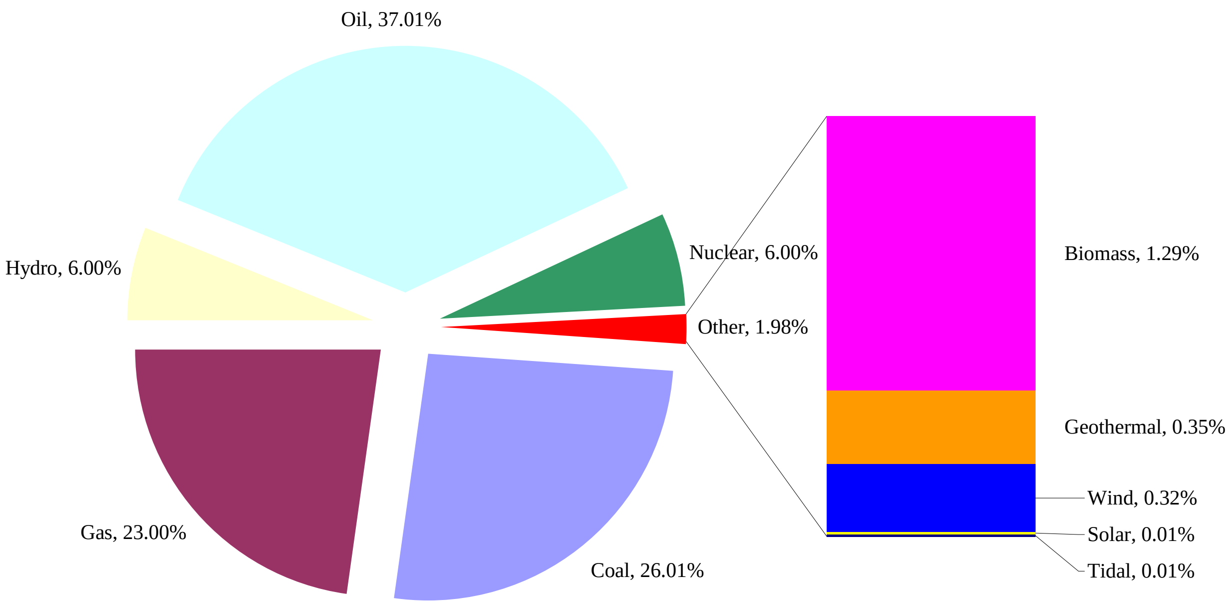

Figure 4. Share of world energy production in 2006

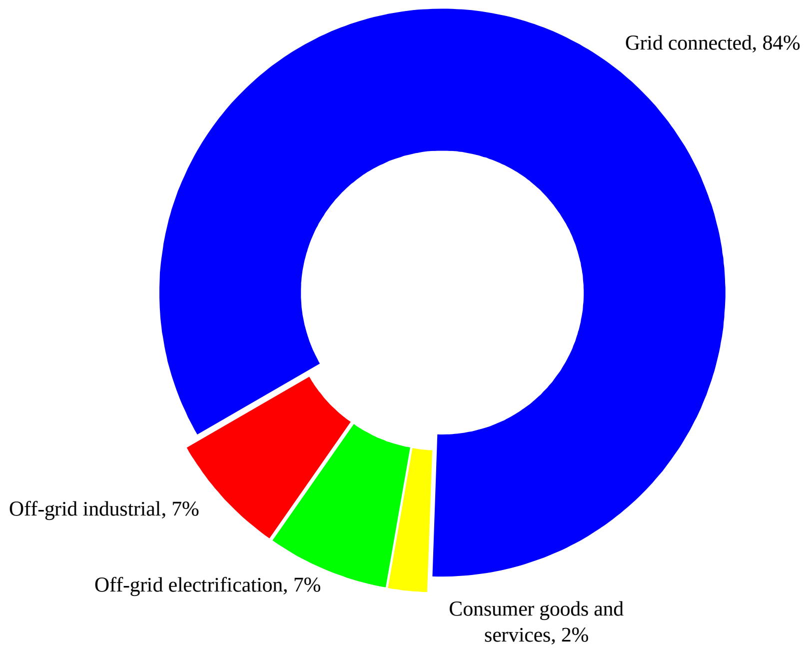

Figure 5. Share of global PV market in 2006

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About 1.7 billion people around the world currently live without basic energy services from which 80% of them live in rural areas. This significant market is a great opportunity for both the PV industry and the local population. Apart from the social advantages like providing clean drinking water in the developing world through PV solar powered water purification systems and pumps, the justification for using PV systems is the avoided fuel costs, usually expensive diesel, or by comparison the cost of extending the grid. Even though numerous rural development programmes have been initiated in the developing countries the impact has been relatively small. It is expected however that this market segment will capture a substantial share of the global PV market share in the coming decades [15]. In 2006 7% of global PV installations were dedicated to rural electrification; and (d) off-grid industrial market sector, is mainly related to the area of telecommunications. Modern telecommunications show an increased need for decentralization and low power consumption [16]. PV modules are used to power emergency telephones in remote areas such as in highways. In many cases PV solar electricity is the only practical source of energy to feed the telecoms appliances in remote areas. Other use of off-grid PV systems are for traffic signals, marine navigation aids, security phone, highway signs and wastewater treatment plants. Industrial PV systems offer high reliability and minimal maintenance. The demand for off-grid industrial PV systems is expected to continue to expand in response to the continued growth of the telecommunications industry. About 7% of the global PV installations were used for PV industrial off-grid applications in 2006.
The PV market remains one of the most dynamic sectors globally and over the past 10 years it has grown at an annual average rate of 35%. In 2006 in the face of silicon shortages more PV systems were installed as compared to previous years. Germany, USA and Japan are currently the dominant players of the global PV market while new promising markets emerging from Spain, Italy, France and Greece will stimulate further growth of the PV sector. Over the past decade the PV sector has become an important industry in many countries with positive effects to society such as increasing employment and industrial development.

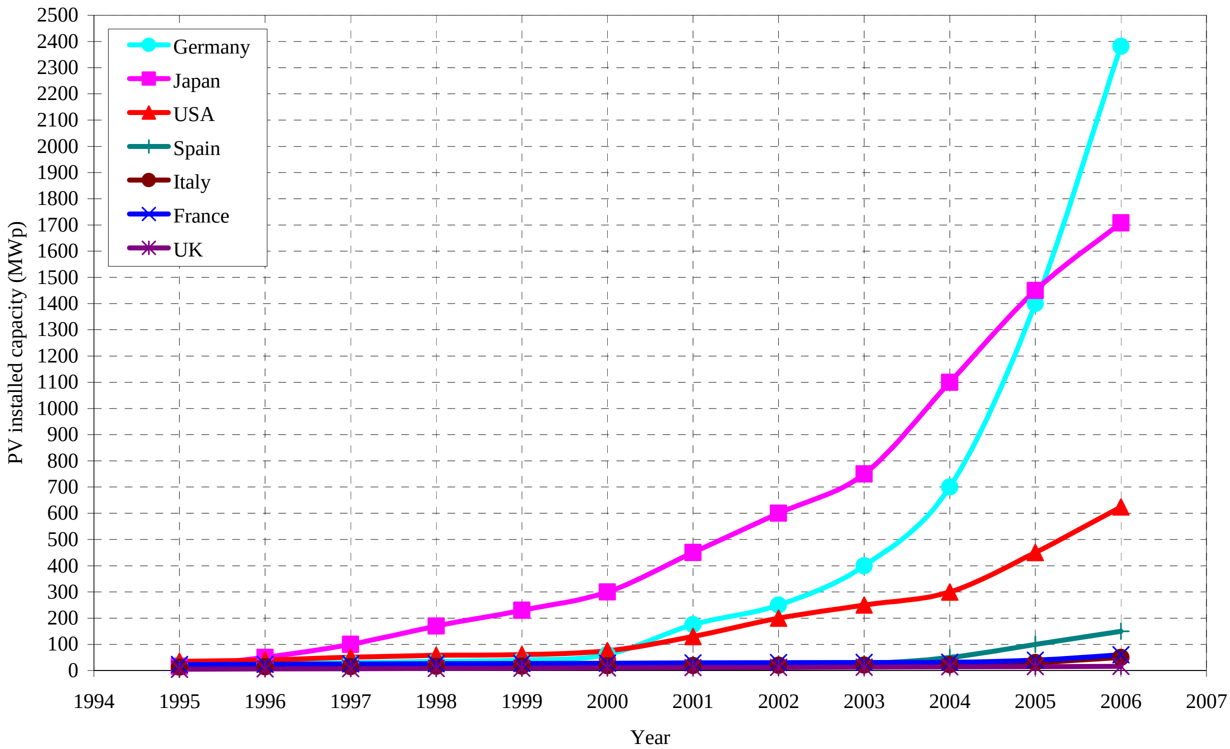

Figure 6. Share of various developed countries in the development of PV installed capacity

Nonetheless solar PV has two big challenges that need to be resolved: production costs need to go down before it becomes economically sustainable, while production capacity must continue to grow in order for PV to become a significant player in the global energy market.
Figure 6 illustrates the growth of PV capacity installed from 1995 to 2006 in the case of various developed countries. In 2006, Germany had the most cumulative installed capacity of 2382MW followed

by Japan with 1708MW and USA with 624MW. The reported installed capacity by the International Energy Agency (IEA), in the case of selected developed countries, such as, Germany, Japan, USA, UK, Spain, France, Italy, Switzerland, Australia, Austria, Netherlands, Canada, Denmark, EU, Finland, Israel, Korea, Mexico, Norway, Portugal and Sweden, is shown in Figure 7, represent a significant proportion of the worldwide PV capacity. In 2006 there was a cumulative global installed PV capacity of over 5000MW being double the cumulative installed capacity of 2004 which was 2500MW [18].

During 2006 an approximate 1525GW of PV power was installed. From Figure 6 and Figure 7 it can be concluded that by far the greatest proportion (around 80%) of PV power was installed in Germany and Japan alone. Germany clearly has the highest level of installed PV power capacity of 2382MW which holds 47% of the market as illustrated in Figure 8. A growing number of countries have followed the examples of Germany, Japan and the USA. France, UK, Italy, and notably Spain took off during 2006 as PV support programs begun to take effect. These programs will continue to provide a momentum for PV market growth in the years to come.

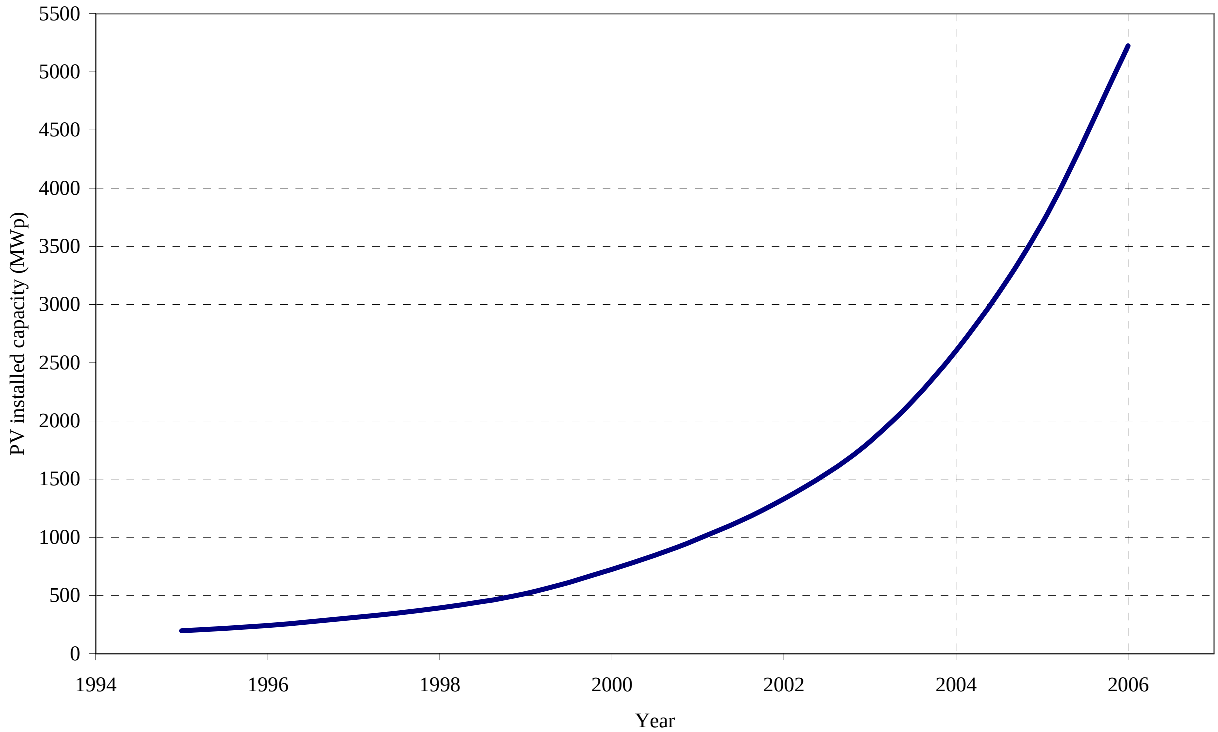

Figure 7. Historic development of PV installed capacity

In Europe, Luxemburg has the highest rate of PV installed capacity with 58Wp per inhabitant (58Wp/inhab) with Germany following with 9.6Wp/inhab whereas a representative figure for European Union member states is 0.5Wp/inhab.

4.2 Silicon market

Silicon is the principal material required for the production of solar cells based on crystalline technology. The availability of sufficient silicon is an essential precondition for a dynamic PV industry. Up until recent years the silicon industry produced electronic-grade silicon entirely for the semiconductor industry and more specifically for computer manufacturers [17]. Only a small fraction of it was supplied to the PV industry. Since 2005, demand for silicon has increased significantly in the PV industry, overtaking the capacity needs of the semiconductor industry. Consequently, this has affected the apportionment of silicon supply between the PV market and the semiconductor industry causing a rise of the price of silicon which further reduced the production efficiency of the PV production facilities.

During 2006 approximately half of the worldwide production of the electronic grade-silicon was used for the production of PV solar cells. Silicon used for the production of PV solar cells can be of lower quality than the one used for the production of electronic devices hence reducing production cost. This important fact has led several companies to develop processes for producing PV solar grade silicon. The development of these production lines however will take some time.

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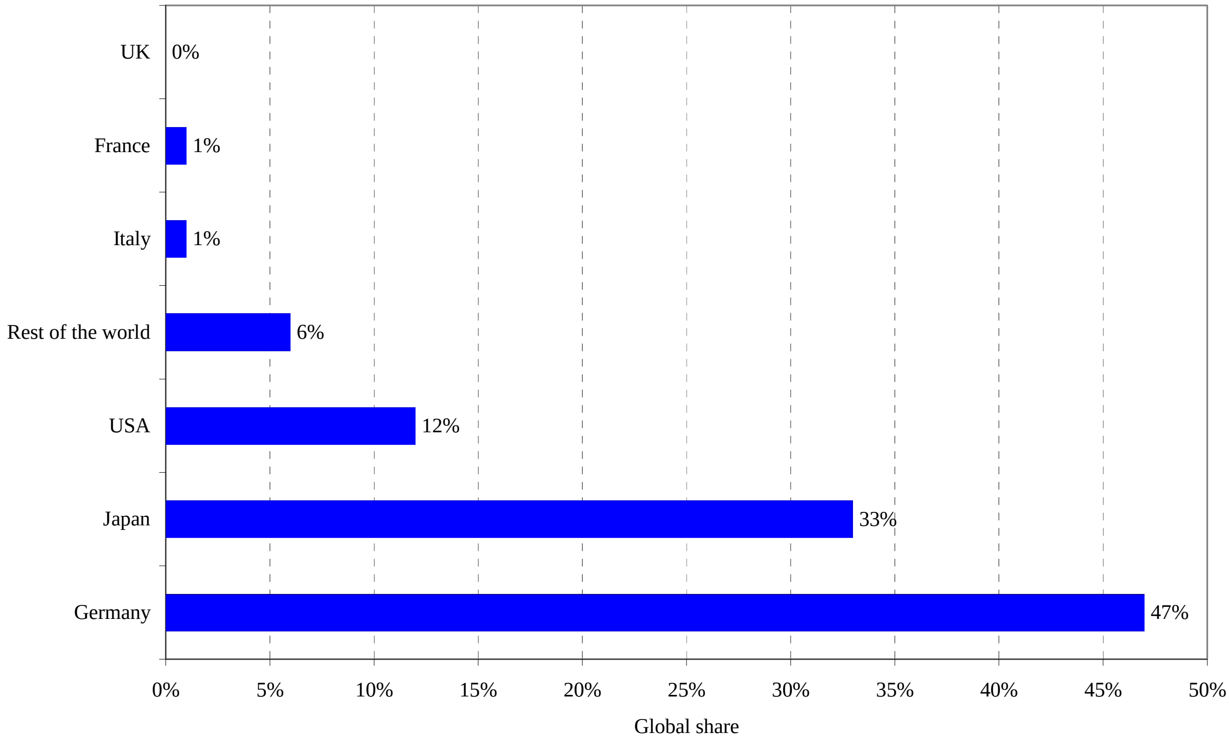

Figure 8. Share of world PV installed capacity in 2006

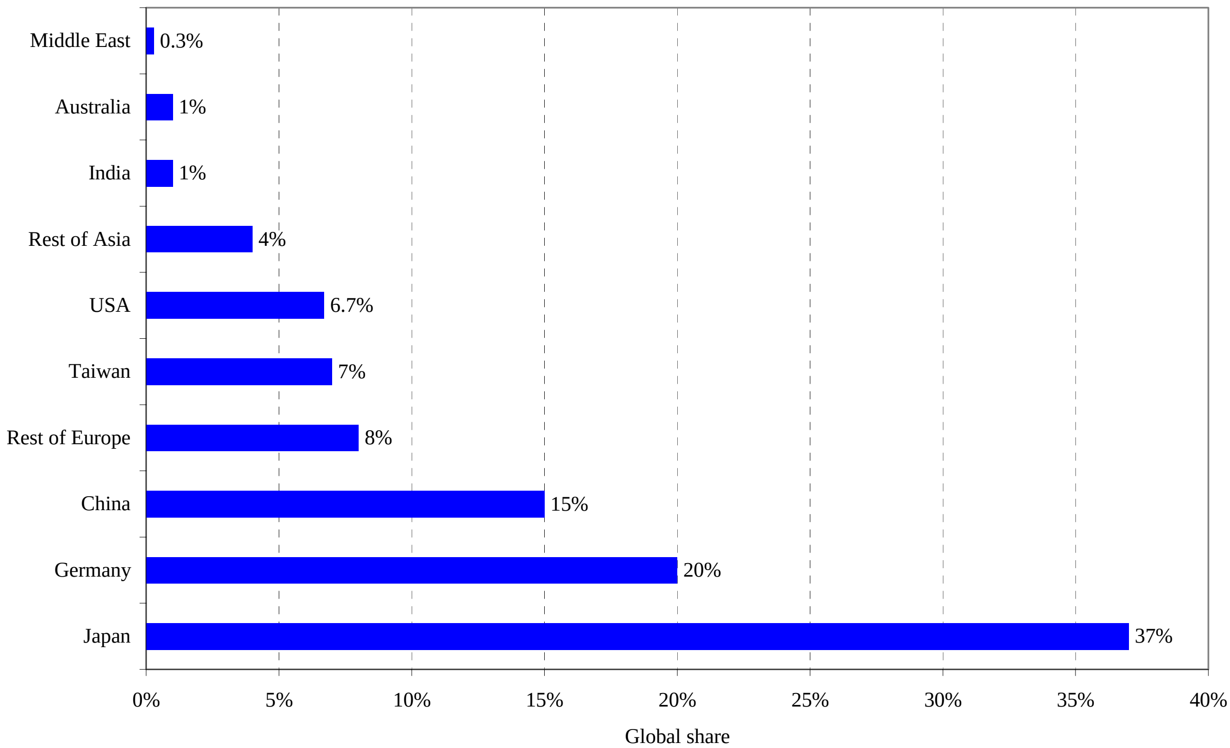

Figure 9. Global PV cell production in 2006

Until all new planned production lines operate the PV industry will continue to compete with the semiconductor industry for the limited availability of silicon. By 2009 the availability of solar grade silicon for the PV industry will lead to a much more relaxed situation in the silicon market causing the prices to return to normal. It is estimated that between the years 2009-2012 more than 4 billion € will be invested in up scaling silicon production capacities [7]. In 2009 the amount of investment in new plants

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to manufacture PV solar cells and modules is expected to exceed 1.2 billion €. This excludes wafer and silicon manufacturing capacities.

4.3 PV cell producers market

Up until now the manufacture of PV solar cells was concentrated mainly in three regions, Japan, USA and Europe. The countries having the biggest share of the PV cell production market is Japan with 37%, Germany with 20% and China with 15%. In terms of production facilities China had in 2006 the strongest growth of PV production facilities. This is shown in Figure 9.

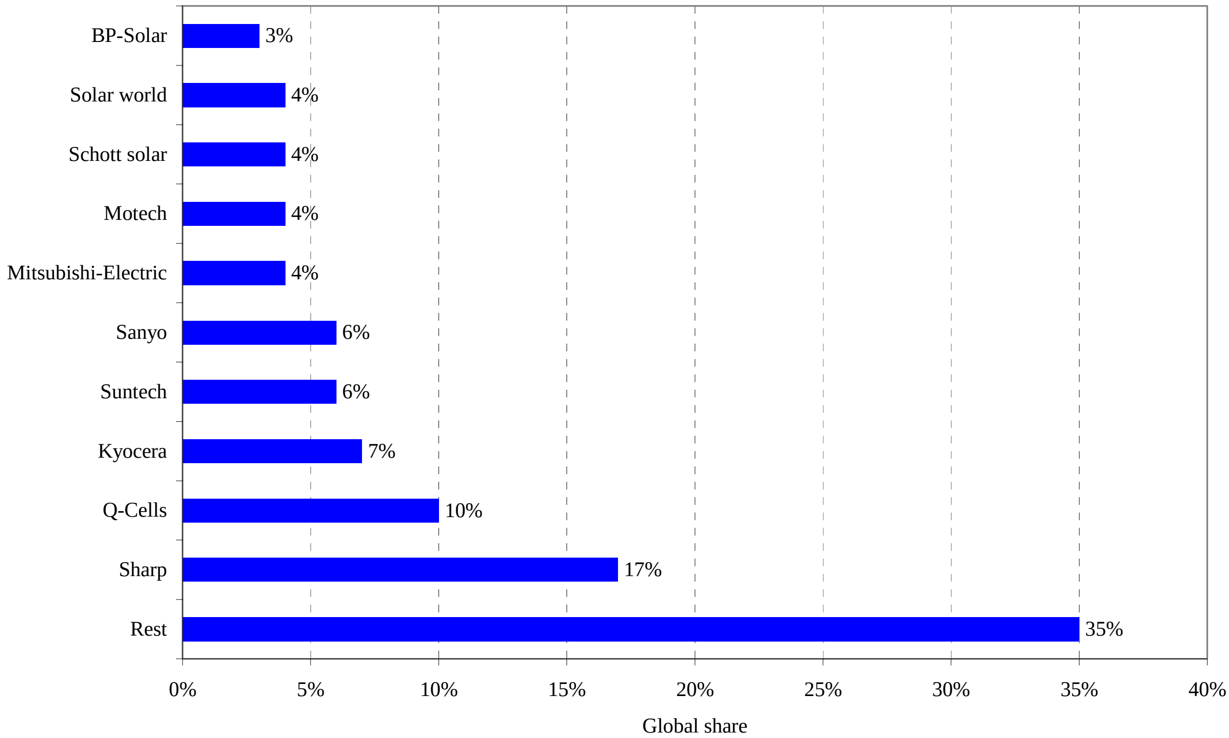

Figure 10. Top-10 PV cell producers in 2006

The leading PV cell production companies are depicted in Figure 10. More recently the leading company in cell production has been the Japanese company Sharp. However in 2007 it has been losing market share to the German company Q-cells and Solar World and the Chinese Suntech. These companies together have decreased the dominant position of Sharp from 23.6% in 2005 to 17.1% in 2006. The annual production of PV cells has increased from 32MWp in 2001 to approximately 500MWp in 2006.

4.4 PV market forecasts

By the year 2050 the world electricity production is expected to increase to about 60000TWh compared to 15500TWh during the year 2001 as illustrated in Figure 11. Further, as indicated in Figure 12, it is foreseen that the global electricity production using fossil fuels will be decrease by the year 2050 to 48.86%. Also, it is estimated that over the next forty years the share of the global solar electricity production will increase to 2.5%. Sharper increase of the solar power share in the global electricity production market is expected to occur after the year 2030. The use of natural gas for generating electricity will increase in the next fifteen years which then begins to decrease to a global market share of approximately 15%. From 2010 onwards the nuclear energy share increases rapidly with an average rate of 5.16%. The critical assumptions need to be taken in order to reach the above forecasted values are [8]: (a) the world population is expected to grow at a decreasing rate to 8.9 billions by 2050.

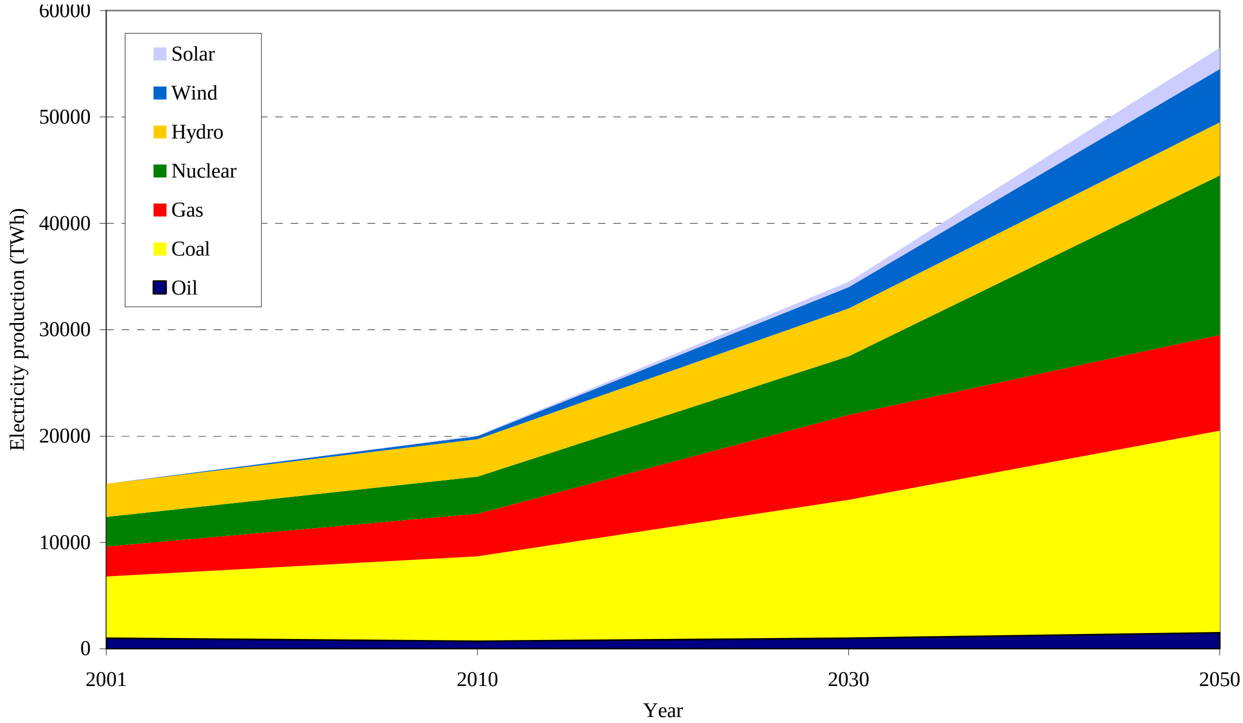

Figure 11. Forecasted world electricity production

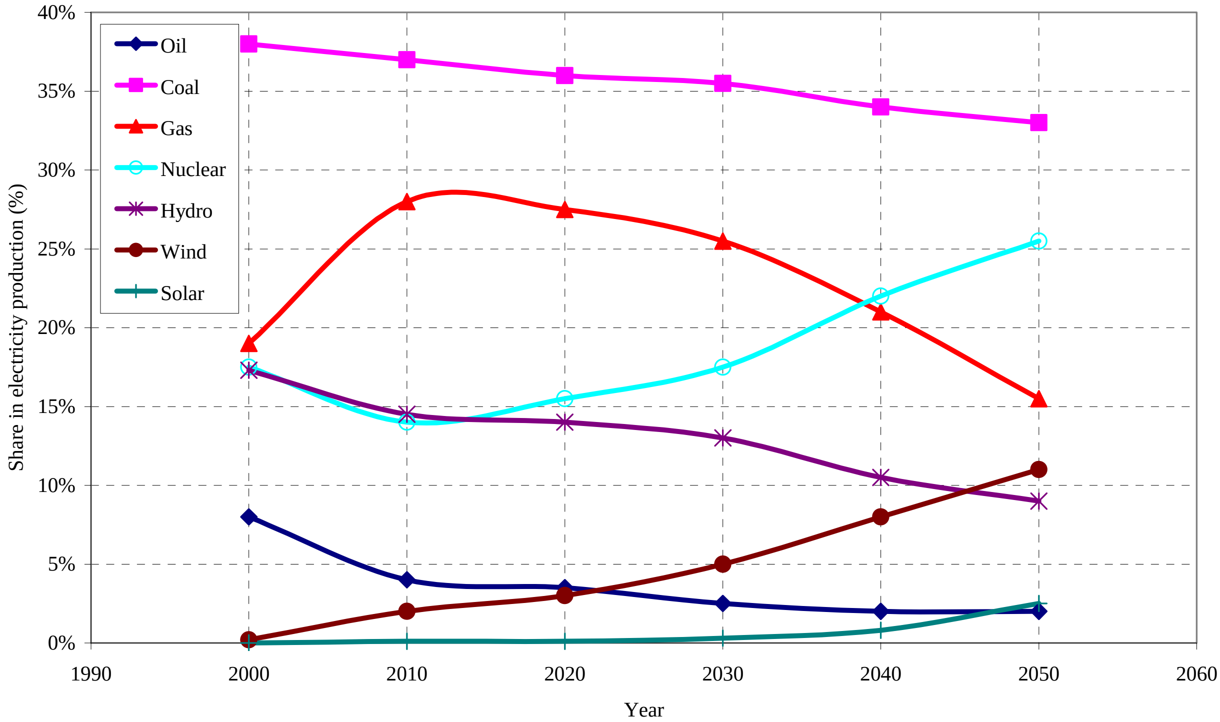

Figure 12. Share of global electricity production

After 2030 the population in several regions of the world decreases, including Europe and China; (b) the rate of economic growth in industrial regions settles to under 2% per year in the very long run. Growth in Asian emerging economies falls significantly after 2010, while it accelerates in Africa and the Middle East. The global economic growth is expected to slow from 3.5% per year during the period 1990-2010 to 2.9% during the period 2010-2030 and to 2.2% until 2050; (c) the accumulated production of oil to date is 900Gbl. It is assumed that there remain almost 1100Gbl of identified reserves and slightly more than 600Gbl of resources that have not yet been identified. Higher recovery rates through technological progress are expected to extend the ultimate recoverable resource base from 2700Gbl today to 3500Gbl

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in 2050; (d) technology development will be critical in the shaping the future energy system. A thorough examination of the technical possibilities for the next 50 years suggests new portfolios of energy technologies will challenge conventional ones based on fossil and renewable sources with electricity as a main carrier; (e) for governments around the world climatic changes and global warming play an important role in their energy decision policies. Different programs are adopted to stimulate and provide incentives for the research and development of new alternative sources of energy, aiming to lower greenhouse gas emissions; and (f) any energy outlook for the long-term has to deal with the possibility of "peak oil" and "peak gas" that some geologists expect soon. The consequent increase in prices may profoundly influence the development of competing energy technologies and reshape the future energy system.

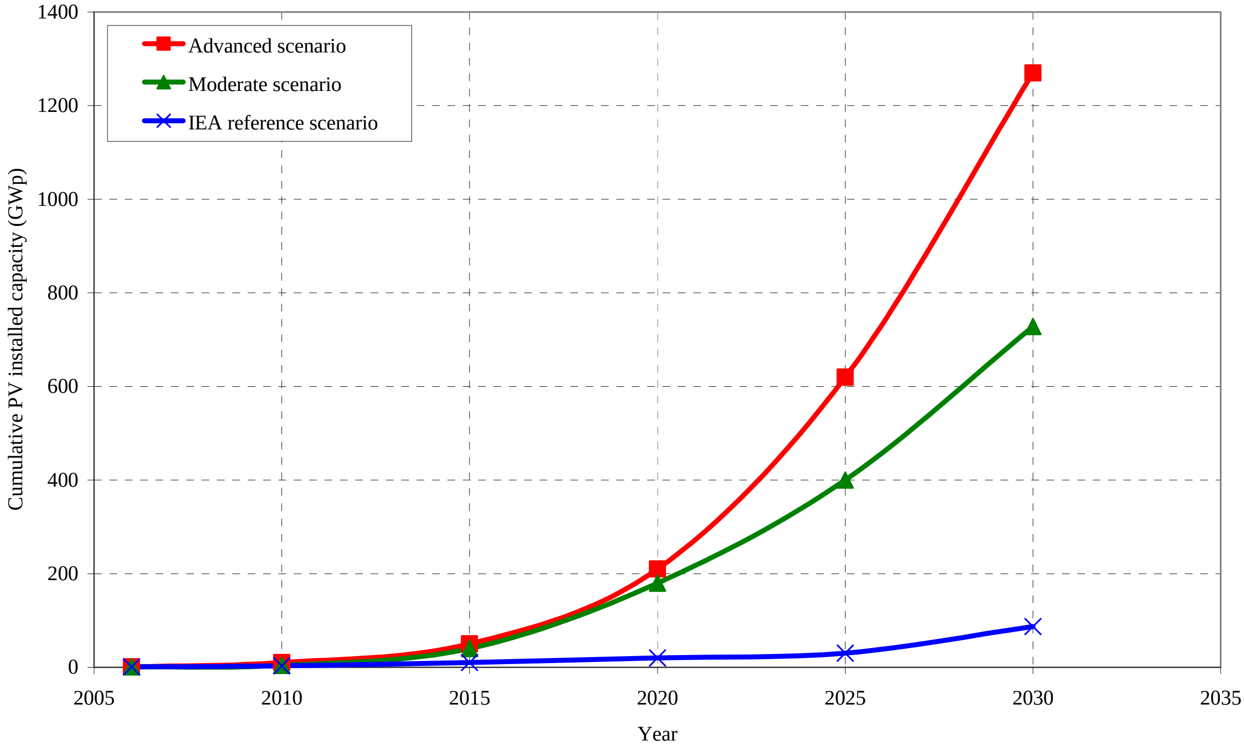

Figure 13. Global PV cumulative capacity up to year 2030

Figure 13 and Figure 14 illustrate the forecasted development of the global PV cumulative capacity up to 2030 and the forecasted global PV annual installed capacity up to 2030 under three different scenarios, such as, (a) advanced scenario, which is based on the assumption that ongoing and additional market mechanisms will lead to a dynamic expansion of worldwide PV installed capacity, (b) moderate scenario, which is based on the development of PV against the background of a lower level political commitment, meaning that with insufficient global political support, fast market development is difficult, implying no potential for economies of scale, thus, PV production costs and prices will fall at a slower rate and (c) IEA reference scenario [8], which is based on the projections of the PV capacity in the International Energy Agency.

Under the advanced scenario and as depicted by Figure 13, the global PV cumulative capacity could reach approximately 1270GWp by the year 2030 and the solar PV systems could be generating 1800TWh electricity around the world. The total number of people in Europe that will be supplied with PV grid-connected solar systems would reach 776 million. The estimate is based on the average household size of 2.5 people and average annual electricity consumption of 3800kWh. A number of 6.3 million people will be employed globally.

Under the moderate scenario the global PV cumulative capacity would reach 728GW by the year 2030 and the solar PV systems will be generating 1027TWh of electricity globally generating jobs for 2.5 million people.

Under the IEA reference scenario the global PV cumulative capacity would reach 87GW and the solar PV systems will be generating 142TWh of electricity around the world and 287000 people will be employed by 2030.

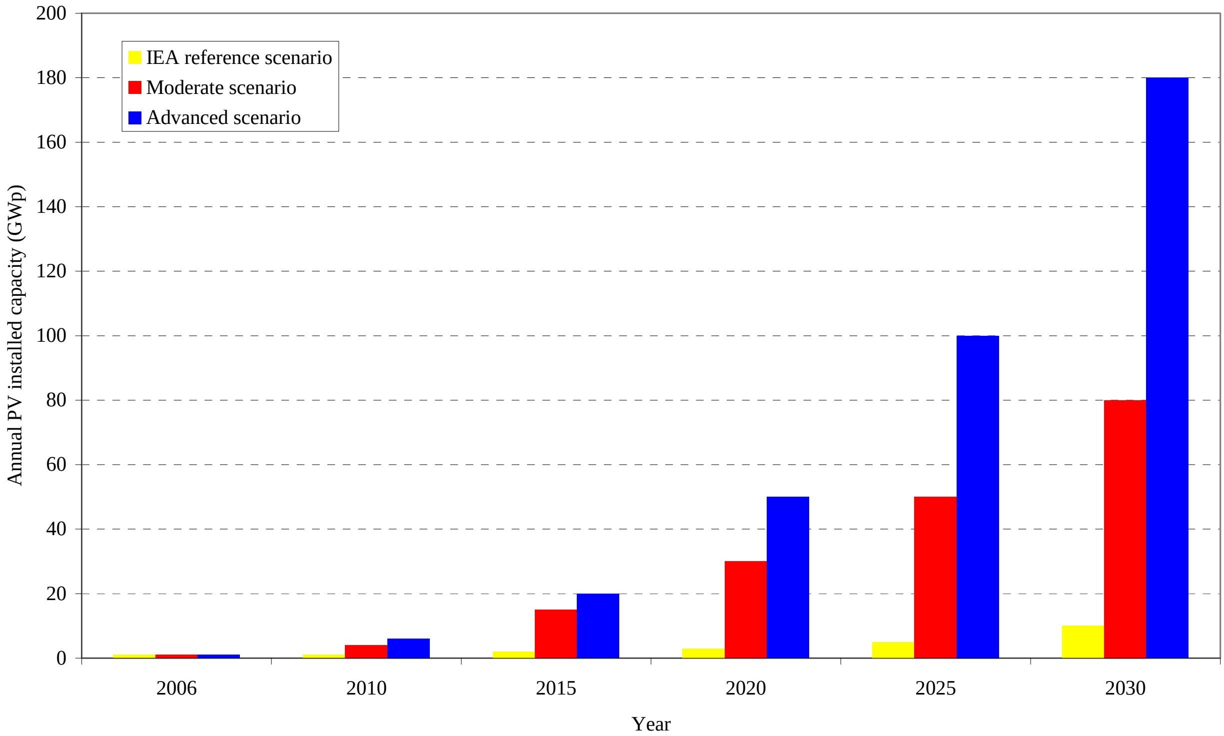

Figure 14. Global PV annual installed capacity up to year 2030

4.5 PV economics

During the last two decades, PV solar cells and modules have been significantly developed resulting to a reduction of the solar energy price. PV modules and other system components have undergone an impressive transformation, becoming cheaper, greener and better performing. This is evinced by the module price reductions, by the increase of power conversion efficiencies and energy yields, by enhanced system availabilities, by drastically shortened "energy payback times" (the period needed for a system to amortize the energy required for its manufacture), and by a variety of other indicators. The continued research for new technologies will aid in a further reduction of the PV modules price. According to optimists there is enormous potential for further PV cost reduction through technological innovation and economies of scale. The ultimate objective, however, is to come as close as possible to the cost of a "fossil" kWh which is a price that is constantly increasing.

Table 2. Expected development of PV technology over the coming decades

Item	1980	Today	2015-2020	2030	Long term potential
Typical turn-key system price (€/Wp, excl. VAT)	>30	5	2.5-2.0	1	0.5
Typical electricity generation costs southern Europe (€/kWh)	>2	0.30	0.15-0.12 (competitive with retail electricity)	0.06 (competitive with wholesale electricity)	0.03
Typical commercial module flat plate* efficiencies	up to 8%	up to 15%	up to 20%	up to 25%	up to 40%
Typical commercial concentrator** module efficiencies	~10%	up to 25%	up to 30%	up to 40%	up to 60%

* Flat plate refers to standard modules for use under natural sunlight.

** Concentrator refers to systems that concentrate sunlight (and, by necessity, track the sun across the sky).

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Nevertheless, PV technology has by no means demonstrated its full potential. Table 2 gives an indication of where PV was 25 years ago, where it stands today and what it could realistically achieve over the next 25-50 years. Current turn-key system prices may vary from 4000€/kWp to 8000€/kWp, depending on system type (roof-top add-on, building-integrated, ground-based, etc.), size, country, and other factors. The figure of 5000€/kWp, however, is considered representative. Similarly, prices in 2015 may range between 2000€/kWp and 4000€/kWp. All prices are expressed as constant 2007 values.
The conversion from turn-key system price to generation costs requires several assumptions. Table 2 assumes that (a) an average performance ratio of 75%, i.e., a system yield of 750kWh/kWp/yr at an insolation level of 1000kWh/m^2/yr. In southern Europe, where insolation is typically 1700 kWh/m^2/yr, a performance ratio of 75% translates into 1275kWh/kWp/yr, (b) 1% of the system's price will be spent each year on operation & maintenance, (c) the PV system's economic value depreciates to zero after 25 years and (d) the discount rate is 4% [24, 24].

5. Conclusions

In this work, an overview of the technology and market of PV systems was carried out. In particular the PV key benefits were presented and the various PV solar cell technologies were described and compared. Emphasis had been given to the current and future PV solar systems market demand including their current and future economics.
PV systems are modular by nature, meaning that systems can be expanded and components easily repaired or replaced if needed. PV systems are cost effective for many remote power applications, as well as for small stand-alone power applications in proximity to the existing electricity grid. Central PV power generation applications are not currently cost-competitive and strong subsidies are required. Several multimegawatt central PV generation systems have been installed as demonstration projects, designed to help acquire experience in the management of central PV power plants.
During the past 20 years there has been a significant growth of the solar PV electric technology and governments in Japan, USA and Europe who are the major players of the solar energy market, are all providing financial incentives in order to encourage their people to adopt the eco-friendly PV systems as an alternative source of energy. Today PV technology is considered by many countries as an important technology for the future. Many of these countries have already established or are in the process of establishing support programs to encourage the adoption of this new technology following in this way the examples of the major players of the PV market Japan, USA and Germany [14]. Installations of central PV generation, like distributed grid connected PV, represent a long-term strategy by governments and utilities to support the development of PV as a clean energy.
Large centralized solar PV power stations able to provide low-cost electricity on a large scale would become increasingly attractive approaching 2020. The PV market remains one of the most dynamic sectors globally and over the past 10 years it has grown at an annual average rate of 35%. During the past years growth of the PV market was primarily in the grid connected sector. In terms of production facilities China had in 2006 the strongest growth of PV production facilities.
EU leaders committed to transforming Europe into a highly energy-efficient, low-carbon economy by cutting EU emissions at least 20% of 1990 levels by 2020 [4]. These emissions targets are underpinned by three energy-related objectives, which are also to be met by 2020, such as, (a) a 20% reduction in energy consumption through improved energy efficiency, (b) an increase in RES share of the market to 20% and (c) as part of RES effort, a 10% share for sustainably produced biofuels in petrol and diesel in each EU country. It is estimated that in 2020 PV installations may contribute to the reduction of CO_2 emissions by the equivalent of 75 average sized coal-fired power plants or 45 million cars [4].
Solar PV technologies have two big challenges that need to be resolved. Production costs need to go down before it becomes economically sustainable, while production capacity must continue to grow in order for PV to become a significant player in the global energy market.

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