



# Photovoltaic at customer premises

Subtask 5, Report n:o 4

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in co-operation with the country experts

International Energy Agency Demand-  
Side Management Programme

**Task XVII: Integration of Demand  
Side Management, Distributed  
Generation, Renewable Energy  
Sources and Energy Storages**

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## **EXECUTIVE SUMMARY - Photovoltaic at customer premises**

### **TASK XVII: INTEGRATION OF DEMAND SIDE MANAGEMENT, DISTRIBUTED GENERATION, RENEWABLE ENERGY SOURCES AND ENERGY STORAGES**

**Task extension: The effects of the penetration of emerging DER technologies to different stakeholders and to the whole electricity system**

**Background** Energy policies are promoting distributed energy resources such as energy efficiency, distributed generation (DG), energy storage devices, and renewable energy resources (RES), increasing the number of DG installations and especially variable output (only partly controllable) sources like wind power, solar, small hydro and combined heat and power.

Intermittent generation like wind can cause problems in grids, in physical balances and in adequacy of power.

Thus, there are two goals for integrating distributed energy resources locally and globally: network management point of view and energy market objectives.

Solutions to decrease the problems caused by the variable output of intermittent resources are to add energy storages into the system, create more flexibility on the supply side to mitigate supply intermittency and load variation, and to increase flexibility in electricity consumption. Combining the different characteristics of these resources is essential in increasing the value of distributed energy resources in the bulk power system and in the energy market.

This Task is focusing on the aspects of this integration.

**Objectives** The main objective of this Task is to study how to achieve a better integration of flexible demand (Demand Response, Demand Side Management) with Distributed Generation, energy storages and Smart Grids. This would lead to an increase of the value of Demand Response, Demand Side Management and Distributed Generation and a decrease of problems caused by intermittent distributed generation (mainly based on renewable energy sources) in the

physical electricity systems and at the electricity market.

## Approach

The first phase in the Task was to carry out a scope study collecting information from the existing IEA Agreements, participating countries with the help of country experts and from organized workshops and other sources (research programs, field experience etc), analyzing the information on the basis of the above mentioned objectives and synthesizing the information to define the more detailed needs for the further work. The main output of the first step was a state-of-the art report.

The second phase (Task extension) is dealing with the effects of the penetration of emerging DER technologies to different stakeholders and to the whole electricity system.

The main subtasks of the second phase are (in addition to Subtasks 1 – 4 of the phase one):

**Subtask 5:** Assessment of technologies and their penetration in participating countries

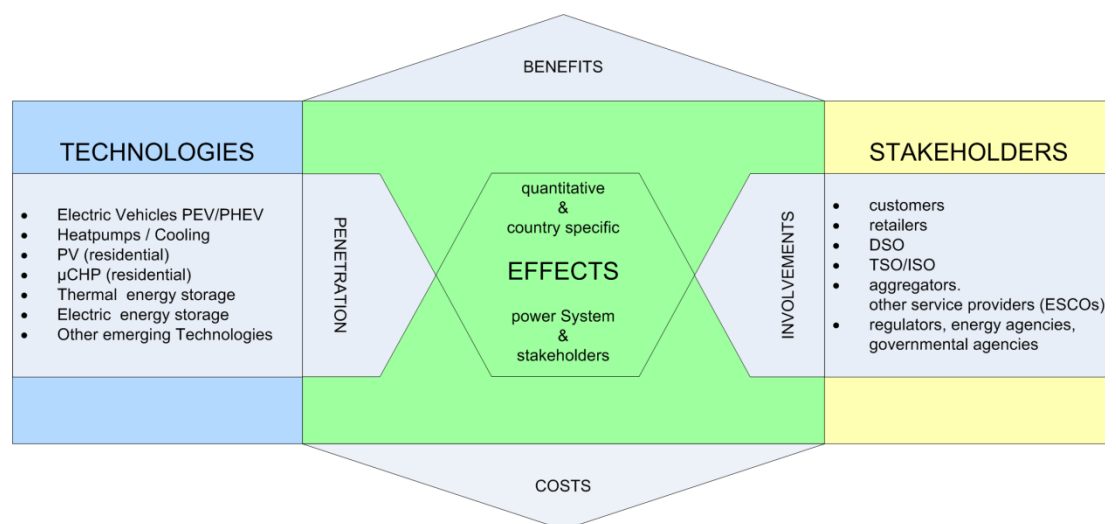
**Subtask 6:** Pilots and case studies

**Subtask 7:** Stakeholders involved in the penetration and effects on the stakeholders

**Subtask 8:** Assessment of the quantitative effects on the power systems and stakeholders

**Subtask 9:** Conclusions and recommendations

The figure below describes the concept of this extension.



## Results

The report describes the present PV technologies and the future development trends in technologies. It also discusses on the penetration of PV in European countries and especially in participating countries. Also the price development of PV modules and systems is discussed.

The following table shows the recent cumulative development of the grid-connected PV penetration in participating countries (in MWp):

	2009	2010	2011
Austria	49	99	187
France	306	1025	2831
Netherlands	62.5	91.9	130
Spain	3418	3787	4260

In Finland the grid-connected PV penetration is nil.

The rapid increase of PV capacity in most of the countries is related to the two main factors:

- PV technology and manufacturing capacity have been increased rapidly which has resulted in the decrease of PV prices. In 2011 prices decreased even up to more than 50 % in some countries.
- Energy policies with incentives and feed-in tariffs have supported the PV development

In 2010 the support policies in participating countries included

- In Austria the revised Green Electricity Act (GEA) forms the framework for national PV implementation in Austria. The nationwide feed-in tariff system for electricity introduced under the GEA is financed by all consumers of electricity via supplements on the electricity price and an obligatory purchase price for Green Electricity that is paid by electricity dealers. Besides the federal feed-in tariff scheme, an initiative launched in 2008 – the national Fund for Climate and Energy – provided rebates for newly installed private PV systems up to 5 kW installed capacity. In 2010 17,8 million EUR were granted under this funding scheme, leading to an installed capacity of over 11 MW. Each Austrian province is also running regional PV rebate programmes, aimed at overcoming the limitations of federal incentives. In most cases the support is subject to limited budgets and is linked to further requirements. Generally, the regional support is only granted where the installation is not supported by the federal feed-in tariff scheme. In 2010 the regional funding initiatives amounted to about 39,6 million EUR and helped to install a total PV capacity of about 22,6 MW.
- In France public initiatives structured and supported the expansion of the PV market during 2010: these included the feed-in tariff with a highly specific orientation towards building integration, the income tax credit of 25 % of the amount of the investment in PV system goods (this was 50 % until 29 September 2010) up to a cap of 8 000 EUR per taxpayer (16 000

EUR for a couple), the ADEME-FACE contracts for off-grid systems and various regional and local government support measures. In order to control the development of the market the French government set up in 2011 a new method of evolution of the purchase obligation prices. Since March 10th, 2011, the prices of the purchase obligation are reviewed every trimester (July 1st, 2011, October 1st, 2011, January 1st, 2012, etc). These prices depend on the number of installations demanded.

- In the Netherlands the market increase in 2010 compared to previous years is partly due to the release of a backlog of grants following the start of the new subsidy scheme (SDE) in 2008. Grants from previous years still remain in the pipeline. The subsidy scheme has now been revised and systems below 15 kW are no longer supported.
- In Spain Royal Decree 1565/2010 has amended the economic regime contained in Royal Decree 1578/2008 for photovoltaic installations in operation, putting electricity into the grid and registered in the Administrative Registry of Producers after 30 September 2008. Feed-in tariffs have been amended as follows: 45 % reduction for ground-based PV installations, 25 % reduction for large rooftop installations (> 20 kW), and 5 % reduction for smaller roof-top systems. With regard to PV systems in operation, putting electricity into the grid and registered before 30 September 2008, their economic regime has also been amended by cancelling the feed-in tariff after 25 years of operation. Other amendments include a definition of a «substantial change» in installations whereby the plant may become ineligible to continue to receive the feed-in tariff set in the previous economic regime. The feed-in tariff paid to Spanish PV installations was also reduced through limiting the operational hours, via Royal Decree Law 14/2010. Operational hours are limited to 1250 hours per year for fixed systems, 1644 hours per year for single-axis tracking systems and 1707 hours per year for two-axis tracking systems. Surplus generation outside these hours is purchased at regular wholesale electricity market prices. The limitation applies for the next three years; however, to compensate, the total period for which the feed-in tariff can be obtained has been extended three years. In addition, a network toll has been introduced, applicable to all electricity generation plants, with PV plants being exempt for the first three years.

International Energy Agency Demand-Side Management Programme

**Task XVII: Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages**

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# 1 Introduction

Solar photovoltaics (PV), which generates electricity through the direct conversion of sunlight, is one of the three technologies available to use sunlight as an active source. Concentrating solar power systems (CSP) use concentrated solar radiation as a high temperature energy source to produce electrical power and drive chemical reactions. CSP is typically applied in relatively large scale plants under very clear skies and bright sun. The availability of thermal storage and fuel backup allows CSP plants to mitigate the effects of sunlight variability. Solar heating and cooling (SHC) uses the thermal energy directly from the sun to heat or cool domestic water or building spaces.

In this report only PV is discussed and mainly from the small scale applications point of view where installations are at customers' premises..

## 2 Description of available photovoltaic technologies

### 2.1 General

PV systems directly convert solar energy into electricity. The basic building block of a PV system is the PV cell, which is a semiconductor device that converts solar energy into direct-current (DC) electricity. PV cells are interconnected to form a PV module, typically up to 50-200 Watts (W).

The PV modules combined with a set of additional application-dependent system components (e.g. inverters, batteries, electrical components, and mounting systems), form a PV system. PV systems are highly modular, i.e. modules can be linked together to provide power ranging from a few watts to tens of megawatts (MW).

R&D and industrialisation have led to a portfolio of available PV technology options at different levels of maturity. Commercial PV modules may be divided into two broad categories: wafer based c-Si and thin films [1]. There are a range of emerging technologies, including concentrating photovoltaics (CPV) and organic solar cells, as well as novel concepts with significant potential for performance increase and cost reduction.

### 2.2 Basic technologies at the moment

#### 2.2.1 PV technologies: an overview

- **Crystalline silicon (c-Si)** modules represent 85-90% of the global annual market today. C-Si modules are subdivided in two main categories: i) single crystalline (sc-Si) and ii) multi-crystalline (mc-Si).
- **Thin films** currently account for 10% to 15% of global PV module sales. They are subdivided into three main families: i) amorphous (a-Si) and micromorph silicon (a-Si/ $\mu$ c-Si), ii) Cadmium-Telluride (CdTe), and iii) Copper-Indium-Diselenide (CIS) and Copper-Indium-Gallium-Diselenide (CIGS).
- **Emerging technologies** encompass advanced thin films and organic cells. The latter are about to enter the market via niche applications.
- **Concentrator technologies (CPV)** use an optical concentrator system which focuses solar radiation onto a small high-efficiency cell. CPV technology is currently being tested in pilot applications.
- **Novel PV** concepts aim at achieving ultra-high efficiency solar cells via advanced materials

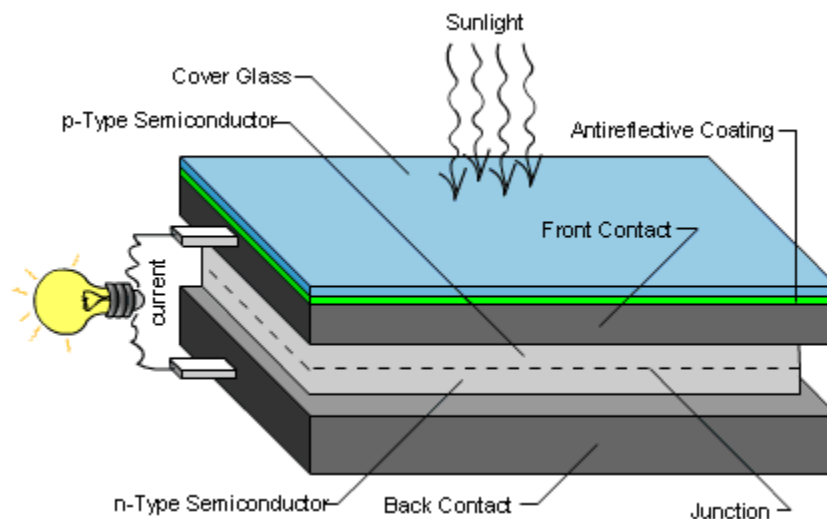


and new conversion concepts and processes. They are currently the subject of basic research.

Detailed information on technologies can also be found in the IEA PVPS Implementing Agreement website [www.iea-pvps.org](http://www.iea-pvps.org)

## 2.2.2 Recent technologies shortly

Photovoltaic cells generate a voltage when radiant energy falls on the boundary between dissimilar substances. Photovoltaic cells or solar cells are semiconductor devices that have a large-area photo cell diode that is capable of generating electric energy from sunlight. This conversion is called the photovoltaic effect. Photovoltaic cells are made from a semi-conducting material, generally silicon crystal. When sunlight hits the photovoltaic panel, the light is absorbed by the silicon crystal. This absorption loosens the electrons from their atoms, causing the electrons to flow through the silicon crystal and generate electricity.



**Figure 1. Basic structure of PV**

A monocrystalline cell is the most efficient (15-18% efficiency), but also the most costly photovoltaic cell. To make them, silicon is purified, melted, and crystallized into ingots. The ingots are sliced into thin wafers to make individual cells. The cells have a uniform colour, usually blue or black. The cell is attached to a base called a "backplane." This is usually a layer of metal used to physically reinforce the cell and to provide an electrical contact at the bottom. Since the top of the cell must be open to sunlight, a thin grid of metal is applied to the top instead of a continuous layer. The grid must be thin enough to admit adequate amounts of sunlight, but wide enough to carry adequate amounts of electrical energy.

A polycrystalline cell is more common and less expensive, but also less efficient (12-14% efficiency). The surface of polycrystalline cells has a random pattern of crystal borders instead of the solid colour of single crystal cells.

String ribbon photovoltaic is a variation on the polycrystalline production process, using the same molten silicon but slowly drawing a thin strip of crystalline silicon out of the molten form. These strips of photovoltaic material are then assembled in a panel with the same metal conductor strips attaching each strip to the electrical current.

This technology saves on costs over standard polycrystalline panels as it eliminates the sawing

process for producing wafers. Some string ribbon technologies also have higher efficiency levels than other polycrystalline technologies.

An amorphous cell (thin film) is relatively inexpensive, but produces much less power (5-6% efficiency). Amorphous silicon units are made by depositing very thin layers of vaporized silicon in a vacuum onto a support of glass, plastic, or metal. Amorphous silicon cells are produced in a variety of colours. Because the layers of silicon allow some light to pass through, multiple layers can be deposited. The added layers increase the amount of electricity the photovoltaic cell can produce. Each layer can be "tuned" to accept a particular band of light wavelength.

For almost all applications, the one-half volt produced by a single cell is inadequate. Therefore, cells are connected together in series to increase the voltage. Several of these series strings of cells may be connected together in parallel to increase the current as well. These interconnected cells and their electrical connections are then sandwiched between a top layer of glass or clear plastic and a lower level of plastic or plastic and metal. An outer frame is attached to increase mechanical strength, and to provide a way to mount the unit. This package is called a "module" or "panel". Typically, a module is the basic building block of photovoltaic systems. Groups of modules can be interconnected in series and/or parallel to form an "array." By adding "balance of system" (BOS) components such as storage batteries, charge controllers, and power conditioning devices, a complete photovoltaic system is achieved.

Each PV module convert the sun's light to DC electricity, this can be directly used or converted to AC electricity via inverters and then used or injected into the electrical grid.

### **2.3 Future technical perspectives**

R&D is aiming to reduce production costs and increase efficiency.

New types of photovoltaic cells are under development, among them, the multi-junction cells (efficiency >35%): multijunction devices receive their name from their use of multiple layers of cells, each layer acting as a junction where certain amounts of solar energy are absorbed. Each layer in a multijunction device is made from a different material with its own receptivity to certain types of solar energy. In a typical device, the top photovoltaic layer responds to solar waves that travel in short wavelengths and carry the highest energy, absorbing this energy and creating an electrical charge. As other solar waves pass through this layer, they are absorbed and translated into electricity by the lower layers. Typical materials used in this device include gallium arsenide and amorphous silicon. Though some two-junction devices have successfully been built, these devices are still largely in the research and development stage, with most research focused on three- and four-junction devices.

Another new approach is the use of a concentrator technology where the solar energy over a large area is concentrated onto a small area of solar cells. Concentration of sunlight using a fresnel lens or reflective surface can increase energy density several hundred times. This allows the use of more exotic solar cell technology that has greater efficiency. The cells used in concentrator modules are more expensive, but fewer cells are required, resulting in an overall cost per watt that is competitive with flat plate technologies. Concentrator efficiency levels above 30% have been demonstrated in the laboratory and 20% or better efficiency units are becoming commercially available. Concentrator technologies work best in regions where sunlight is not scattered by haze or air-pollution.

Concentrator systems reduce the amount of space needed for a photovoltaic installation but their main disadvantage is that they depend solely on direct light to produce electricity, while stand-alone photovoltaic panels can use both direct and diffuse light. Many regions do not receive enough direct light throughout the year for these systems to be practical. Another disadvantage is the complexity

of their construction, which makes these systems more difficult to build and install than photovoltaic panels on their own.

## 2.4 Current performance and price of different PV module technologies

The figure below shows the performance and price estimates for different technologies.

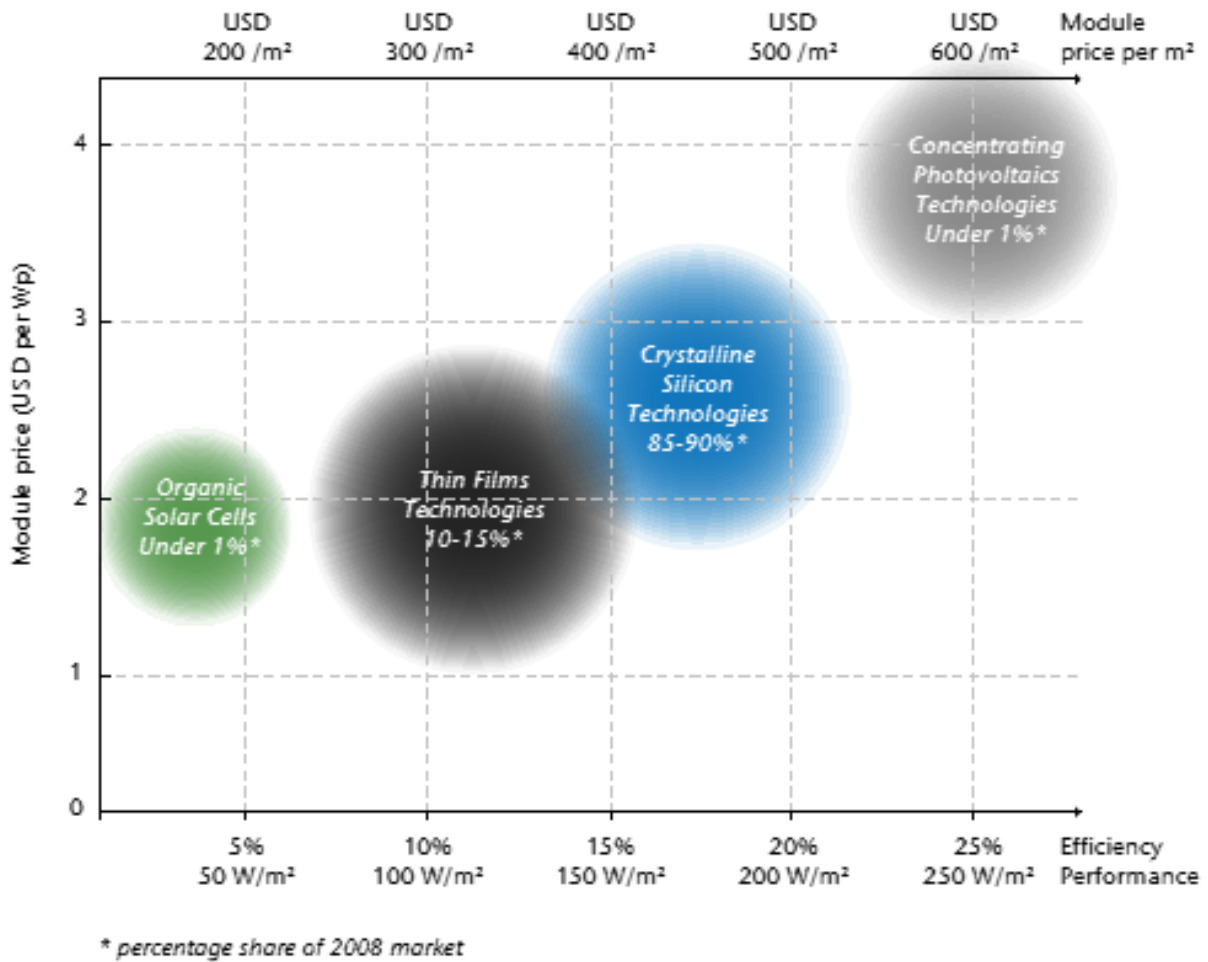


Figure 2. Current performance and prices of PV module technologies (all values refer to 2008) [1]

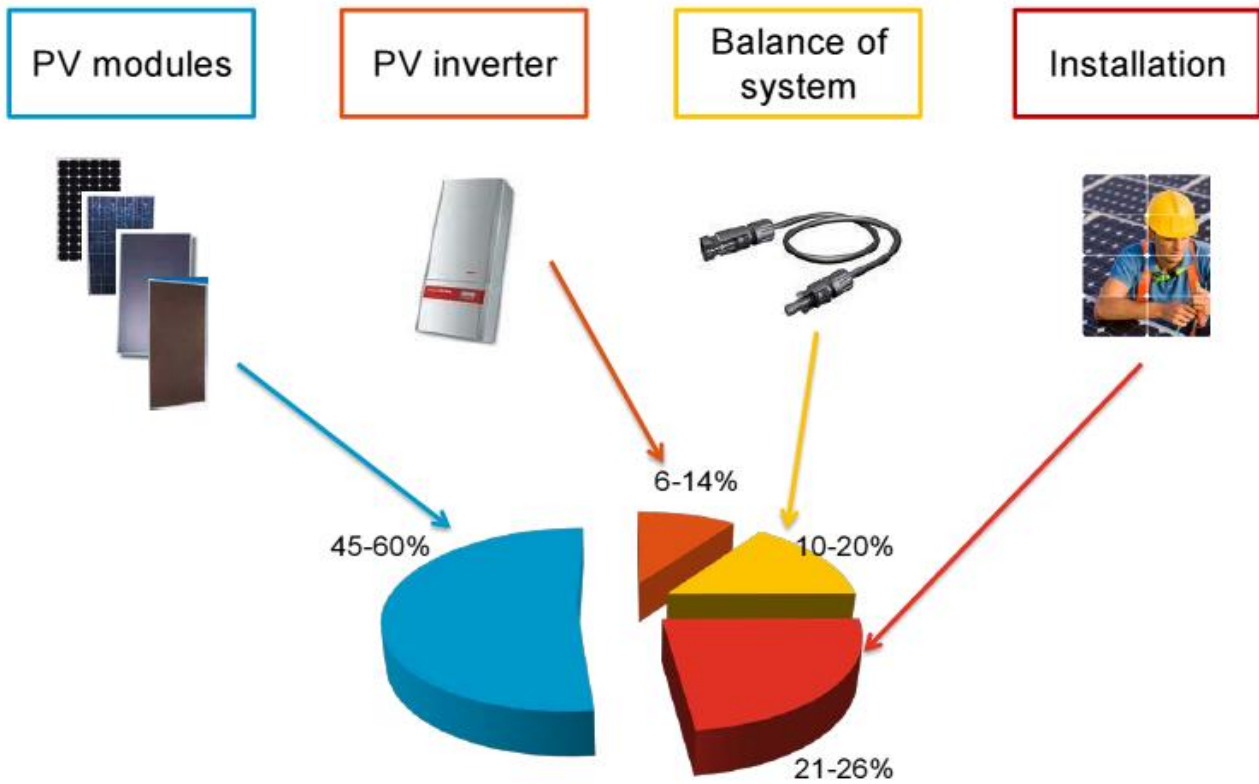
Conversion efficiency, defined as the ratio between the produced electrical DC-power and the amount of incident solar energy per second, is one of the main performance indicators of PV cells and modules. The table below shows the typical efficiencies of different PV technology commercial modules (in 2008).

Table 1. Current efficiencies of different PV technology commercial modules [1]

Wafer-based c-Si		Thin films		
sc-Si	mc-Si	a-Si; a-Si/ $\mu$ c-Si	CdTe	CIS/CIGS
14-20%	13-15%	6-9%	9-11%	10-12%

## 2.5 PV system prices

PV modules represent roughly about 50 % of the total system prices as can be seen in the Figure 3.



*2010 situation (industry averages)*

**Figure 3. Shares of different components of the PV system prices [5]**

PV system prices are decreasing as can be seen from the estimate of the Figure 4

- The price of PV modules and systems has been going down for more than 30 years.
- This will continue thanks to further technological improvements and economies of scale.
- A 36-51% decrease could be achieved on average by 2020.

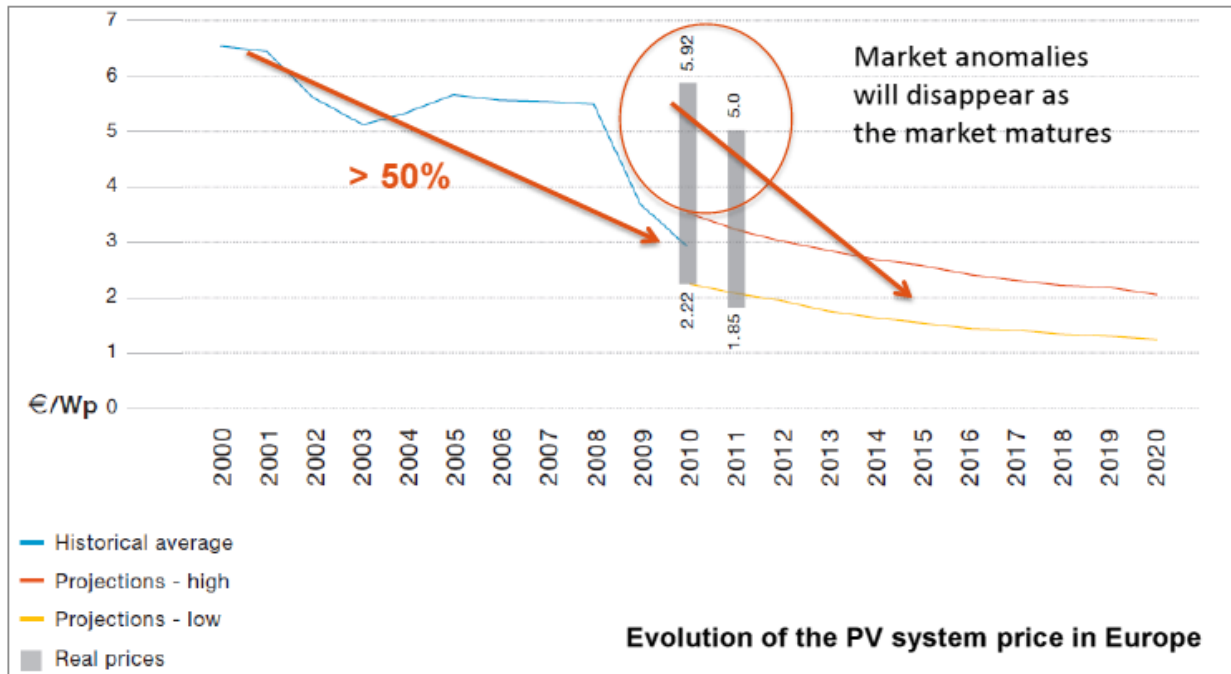


Figure 4. PV system price evolution [5]

In 2011 the prices of PV systems still decreased considerable as can be seen from the recent information of some countries:

- In the Netherlands [7] typical module and system prices decreased in 2011. Single module prices from all types can be bought at estimated between 1,11 and 4,70 €/Wp, (including 19% tax). The price erosion at the end of 2011 resulted even in single module prices around 0,85 €/Wp (including 19% tax). The majority of the systems are installed with mono or poly crystalline modules in the low price range. Complete installed system prices range from 2.80 €/Wp for small 600 Wp systems and 1.90 €/Wp for larger 50 kWp systems. Prices are including 19% tax. It is seen that the price erosion at the end of the year has dropped prices from 10 up to 30%
- In France [8] the turnkey price of building integrated rooftop systems was around 3,9 EUR/W by end of 2011 compared with 5,9 EUR/W 12 months ago (source SER), a 35 % decrease. Large roof of commercial/industrial buildings between 250 kW and 500 kW were 53 % less expensive at 2,6 EUR/W and turnkey prices of ground-mounted centralised systems were around 2,0 EUR/W (56 % decrease during the year). Reduction is principally due to price reduction of modules and, to a lesser extent, other components such as inverters. During 2011, the drop in the price of photovoltaic modules and systems induced a significant increase in the internal profitability rate of the projects and led to a rapid expansion in medium- and high-power systems.
- In Germany [9] turnkey prices of typical PV applications (VAT excluded (19 %), net, prices rounded, prices at end of 2011, usually grid connected):

1 – 2 kWp: 2.540 €/kWp  
 2 – 5 kWp: 2.260 €/kWp  
 5 - 10 kWp: 2.040 €/kWp  
 > 10 kWp: 1.790 €/kWp

The Table 2 below shows as an example one recent PV offer from the Netherlands (<http://www.wijwillenzon.nl/pakketten.html>)

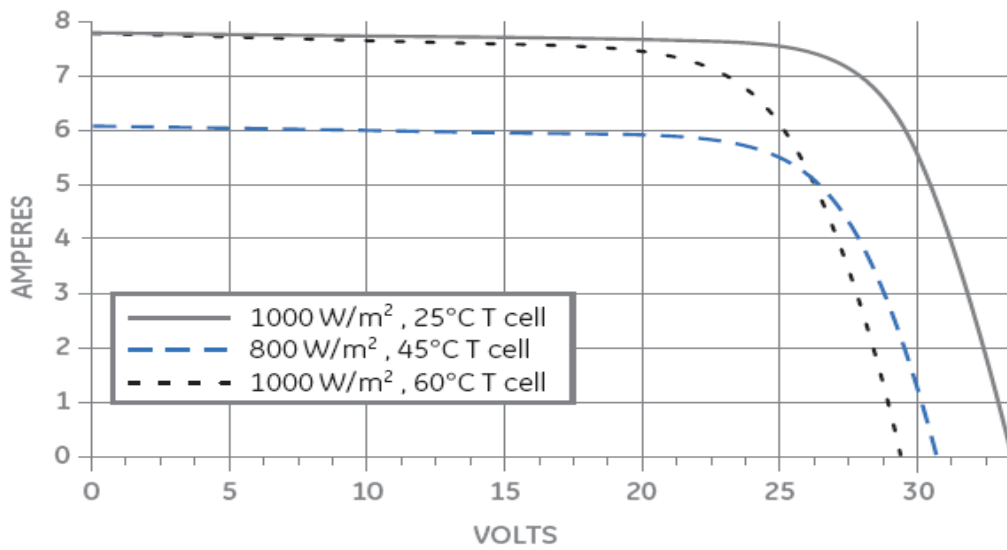
**Table 2. Example of the PV packet prices (€) in the Netherlands (prices valid from 16/04/2012, all packets includes mounting material, cables, inverter and transportation). (BWT = 19 % VAT)**

	<b>Prijs ex BTW</b>	<b>Prijs incl BTW</b>	<b>Prijs bij auto. incasso ex BTW</b>	<b>Prijs bij auto. incasso incl BTW</b>
Pakket A: 1410 Wp - plat dak 6 x 235 Wp panelen	2.081,17	2.476,59	2.011,17	2.393,29
Pakket A: 1410 Wp - schuin dak 6 x 235 Wp panelen	1.961,04	2.333,64	1.891,04	2.250,34
Pakket B: 2760 Wp - plat dak 12 x 230 Wp panelen	3.780,13	4.498,35	3.645,13	4.337,70
Pakket B: 2760 wp - schuin dak 12 x 230 Wp panelen	3.544,97	4.218,52	3.409,97	4.057,87
Pakket C: 3120 wp - plat dak 16 x 195 Wp panelen	4.176,62	4.970,18	4.041,62	4.809,53
Pakket C: 3120 wp - schuin dak 16 x 195 Wp panelen	3.910,79	4.653,84	3.775,79	4.493,19
Pakket D: 585 wp - plat dak 3 x 195 Wp panelen	874,98	1.041,22	844,98	1.005,52
Pakket D: 585 - schuin dak 3 x 195 Wp panelen	825,14	981,91	795,14	946,21

### 3 Current control modes [2]

The current and power output of photovoltaic modules are approximately proportional to sunlight intensity. At a given intensity, a module's output current and operating voltage are determined by the characteristics of the load. If that load is a battery, the battery's internal resistance will dictate the module's operating voltage.

An I-V curve as illustrated below is simply all of a module's possible operating points, (voltage/current combinations) at a given cell temperature and light intensity. Increases in cell temperature increase current slightly, but drastically decrease voltage.

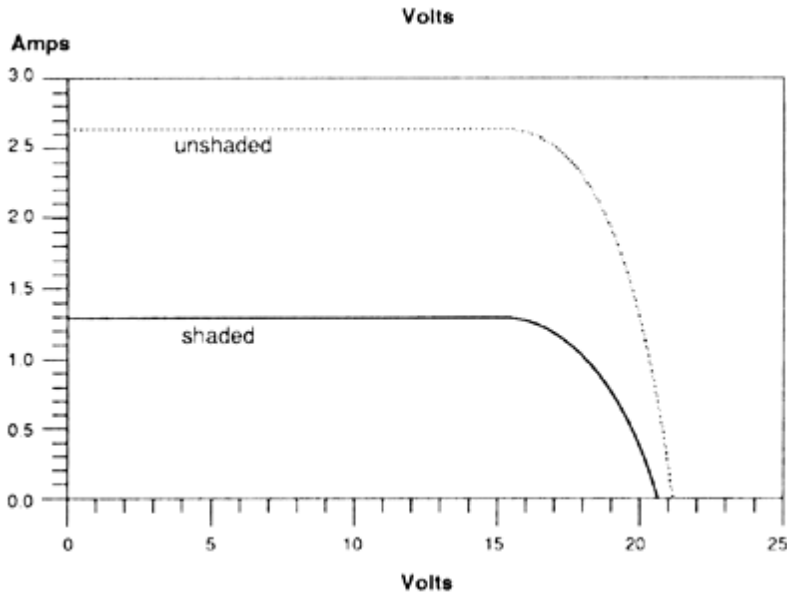


**Figure 5. Typical I-V curve (200 kW commercial module)**

Peak power	200	W
Max power voltage	26,3	V
Max power current	7,6	A
Open circuit voltage	32,9	V
Short circuit current	8,1	A
Short circuit temperature coeff.	5,6	mA/°C
Open circuit voltage coeff.	-0,12	V/°C
Max power temperature coeff.	-0,15	%/°C
Normal operating cell temperature	45	°C

**Table 1 Typical performance characteristic (200 kW commercial module)**

PV modules are very sensitive to shading, temperature and tilting. Because photovoltaic cells are electrical semiconductors, partial shading of the module will cause the shaded cells to heat up. They are now acting as inefficient conductors instead of electrical generators. Partial shading may ruin shaded cells. Partial module shading has a serious effect on module power output. For a typical module, completely shading only one cell can reduce the module output by as much as 80% (Figure 2). One or more damaged cells in a module can have the same effect as shading



**Figure 6. Shading effect**

Module temperature affects the output voltage inversely. For this reason, air should be allowed to circulate behind the back of each module so its temperature does not rise and reduce its output.

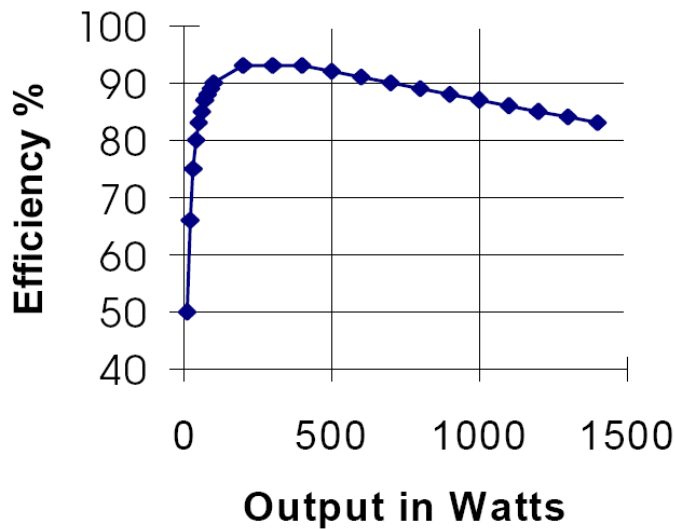
A basic component of PV systems is the inverter and it converts DC power from the batteries or in the case of grid-tie, directly from the PV array into high voltage AC power as needed. Inverters are very efficient (85 to 97%) and reliable (in the Figure 7 the efficiency of a commercial inverter).

Two types of stand-alone inverters predominate the market: modified sine and sine wave inverters. Modified sine wave units are less expensive per watt of power and do a good job of operating all except the most delicate appliances. Sine wave units produce power which is almost identical to the utility grid, will operate any appliance within their power range, and cost more per watt of output.

Utility-tie systems/sine wave inverters for utility interactive photovoltaic applications, provide direct conversion of solar electric energy to utility power with or without a battery storage system. These systems are designed to meet or exceed utility power company requirements and can be paralleled for any power level requirement.

For PV systems with batteries, a crucial component is the controller: The main function of a controller (or regulator) is to fully charge a battery without permitting overcharge while preventing reverse current flow when PV module is not producing electricity. Simple controllers contain a transistor that shunts the PV charging circuit, terminating the charge at a pre-set high voltage and, once a pre-set reconnect is reached, opens the shunt, allowing charging to resume. More sophisticated controllers utilize pulse width modulation (PWM) or maximum power point tracking (MPPT) to assure the battery is being fully charged.





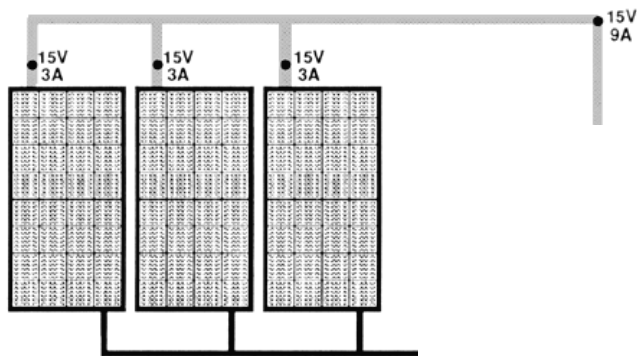
**Figure 7. Efficiency versus output power (DC-AC inverter)**

The circuitry in a controller reads the voltage of the batteries to determine the state of charge. Designs and circuits vary, but most controllers read voltage to control the amount of current flowing into the battery as the battery nears full charge. Features of a controller to consider include:

- Reverse current leakage protection - by disconnecting the array or using a blocking diode to prevent current loss into the solar modules at night.
- Low-voltage load disconnect (LVD) - to reduce damage to batteries by avoiding deep discharge.
- System monitoring - analog or digital meters, indicator lights and/or warning alarms.
- Overcurrent protection - with fuses and/or circuit breakers.
- System control - control of other components in the system; standby generator or auxiliary charging system, diverting array power once batteries are charged, transfer to secondary batteries.
- Load control - automatic control of secondary loads, or control of lights, water pumps or other loads with timers or switches.
- Temperature compensation - utilized whenever batteries are placed in a non-climate controlled space. The charging voltage is adjusted to the temperature.
- Pulse Width Modulation (PWM) - an efficient charging method that maintains a battery at its maximum state of charge and minimizes sulfation build-up by pulsing the battery voltage at a high frequency.
- Maximum Power Point Tracking (MPPT) - a new charging method designed to extract the most power possible out of a solar module by altering its operating voltage to maximize the power output.

In many applications the power available from one module is inadequate for the load. Individual modules can be connected in series, parallel, or both to increase either output voltage or current. This also increases the output power.

When modules are connected in parallel, the current increases; the Figure 8 below shows a simple example:

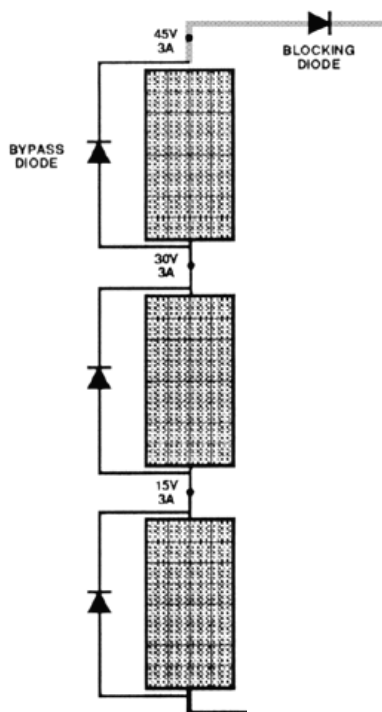


**Figure 8. Parallel configuration**

If the system includes a battery storage system, a reverse flow of current from the batteries through the photovoltaic array can occur at night. This flow will drain power from the batteries: a diode is used to stop this reverse current flow. Because diodes create a voltage drop, some systems use a controller which opens the circuit instead of using a blocking diode.

When modules are connected in series, the voltage increases. If one module in a series string fails, it provides so much resistance that other modules in the string may not be able to operate either. A bypass path around the disabled module will eliminate this problem (Figure 9). The bypass diode allows the current from the other modules to flow through.

Last type of diodes (Figure 10) are so called “isolation diodes” which are used to prevent the power from the rest of an array from flowing through a damaged series string of modules. They operate like a blocking diode.



**Figure 9. Bypass diode application**

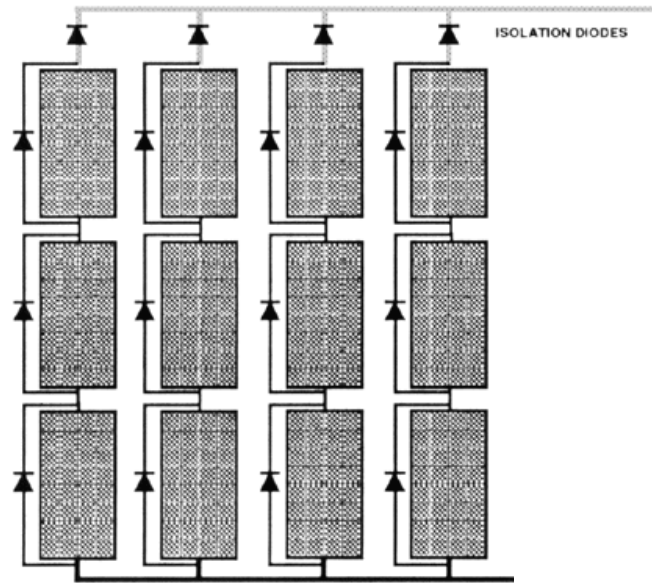


Figure 10. String arrangement

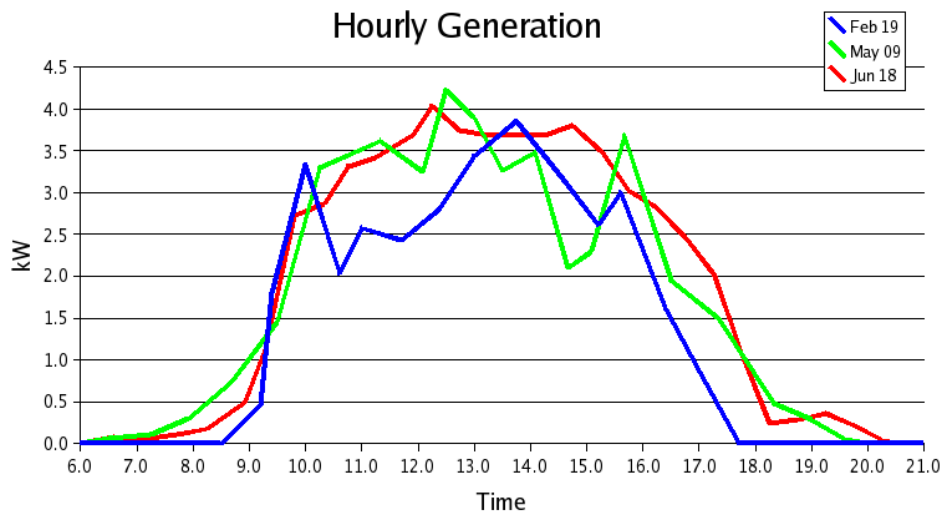
## 4 Curves of production and of pollutant emission [2]

Curves of energy production for PV system depend on the different technology and the insulation availability. PV systems are typically arranged in arrays of module in order to reach by a modular configuration the power installed required.

The yearly electricity which a PV system can generate is strictly related to the sun radiation of the specific site where the system is located. Different working conditions for example using 1 or 2 axis tracking system, influence the energy production profile of systems. Using tracking system is possible to collect more solar irradiation and consequently increase the energy production of 30% respect on the same fixed system.

The following graph shows as an example the power generated by a system in three different days in Southern Italy:

- A cloudless sunny day in February (blue).
- A mostly sunny day in May (green).
- A mostly sunny day in June (red).



The fuel (sunlight) is free and no noise or pollution is created from operating photovoltaic systems. Compared to fossil-generated electricity, each kilowatt of solar photovoltaic could prevent substantial emissions that endanger our environment and personal health. Typically in Italy, on an annual "per kilowatt" basis, PV offsets or saves up to 16 kilograms of nitrous oxides (NOx), 9 kilograms of sulphurous oxides (SOx), and 0.6 kilogram of other particles. In addition, one kilowatt of PV typically offsets between 600 and 2300 kilograms of carbon dioxide (CO2) per year. These savings, of course, vary with regional fossil fuel mix and solar insulation.

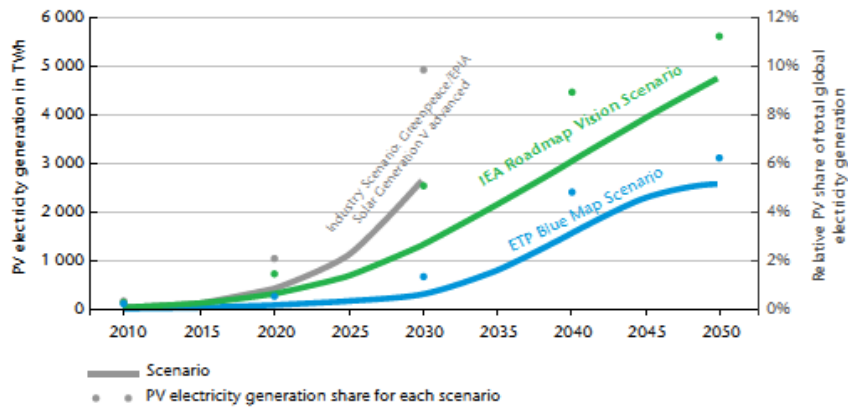
Photovoltaic opponents claim that this energy source is not as clean as assumed because Photovoltaic cell manufacturing is a polluting and energy consuming industry, and also energy or pollution involved in dismissing process should be taken into account. The energy used in a Photovoltaic module manufacturing is about 3-4 kWh/Wp. Thin film Photovoltaic cells contain heavy-metal compounds like gallium arsenide or cadmium telluride, which require special attention.

## 5 Future perspectives

### 5.1 Electricity generation and cumulative installed capacity

PV will need to play a significant role in the world's energy mix in 2050 to help achieve global climate change goals at the lowest cost. According to the BLUE Map scenario described in IEA's Energy Technology Perspectives 2008 (ETP) publication, by 2050, solar power is expected to provide 11% of annual global electricity production, with roughly half generated from PV (6%) and the remaining from concentrated solar power<sup>1</sup>. The IEA roadmap [1], however, forecasts a more rapid PV deployment than is estimated in the ETP 2008 study—i.e., PV is projected to reach 11% by 2050, almost the double the level estimated in the BLUE Map scenario (Figure 11).

<sup>1</sup> This roadmap outlines a set of quantitative measures and qualitative actions that represent one global pathway for solar PV deployment to 2050. It builds on the IEA Energy Technology Perspectives (ETP) BLUE Map scenario, which describes how energy technologies may be transformed by 2050 to achieve the global goal of reducing annual CO2 emissions to half that of 2005 levels. The ETP model is a bottom-up MARKAL model that uses cost optimisation to identify least-cost mixes of energy technologies and fuels to meet energy demand, given constraints such as the availability of natural resources. The ETP model is a global fifteen-region model that permits the analysis of fuel and technology choices throughout the energy system. The model's detailed representation of technology options includes about 1 000 individual technologies. The model has been developed over a number of years and has been used in many analyses of the global energy sector. In addition, the ETP model was supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors.



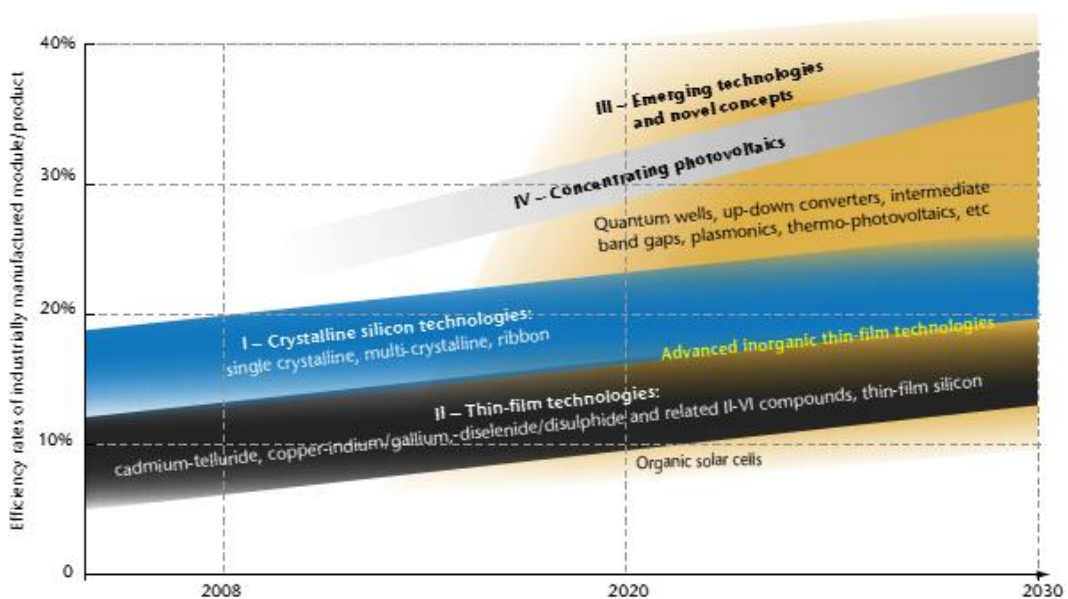
Note: The share of total electricity generation is calculated with the projected world electricity generation of the ETP BLUE Map scenario (42 300 TWh in 2050).

Sources: IEA Energy Technology Perspectives 2008, EPIA/Greenpeace Solar Generation V.

**Figure 11. Global PV power generation and relative share of total electricity generation**

## 5.2 Technology trends

It is expected that a broad variety of technologies will continue to characterise the PV technology portfolio, depending on the specific requirements and economics of the various applications. Figure 12 gives an overview of the different PV technologies and concepts under development.



Source: IEA PVPS.

**Figure 12. Photovoltaic technology status and prospects**

Table below summarises a set of general technology targets for flat-plate PV systems, expressed in terms of (maximum) conversion efficiency, energy-payback time, and operational lifetime. Typical commercial flat-plate module efficiencies are expected to increase from 16% in 2010 to 25% in 2030 with the potential of increasing up to 40% in 2050. Concurrently, the use of energy and

materials in the manufacturing process will become significantly more efficient, leading to considerably shortened PV system energy pay-back times.<sup>12</sup> The latter is expected to be reduced from maximum two years in 2010 to 0.75 year in 2030 and below 0.5 year in the long-term. Finally, the operational lifetime is expected to increase from 25 to 40 years.

Targets (rounded figures)	2008	2020	2030	2050
Typical flat-plate module efficiencies	Up to 16%	Up to 23%	Up to 25%	Up to 40%
Typical maximum system energy pay-back time (in years) in 1500 kWh/kWp regime	2 years	1 year	0.75 year	0.5 year
Operational lifetime	25 years	30 years	35 years	40 years

## 6 Spreading over the different countries [3]

The following tables show the current situation of PV in European countries

**Additional photovoltaic capacity installed in the European Union in 2009 and 2010\* (in MWp)**

	2009			2010		
	Réseau On-grid	Hors réseau Off-grid	Total	Réseau On-grid	Hors réseau Off-grid	Total
Germany	3 935,000	5,000	3940,000	7 406,000	5,000	7 411,000
Italy	698,700	0,100	698,800	2 321,000	0,100	2 321,100
Czech Rep.	408,626	0,020	408,646	1 489,780	0,000	1 489,780
France	215,200	6,000	221,200	719,000	0,146	719,146
Spain	15,765	1,245	17,010	369,000	1,000	370,000
Belgium	503,109	0,000	503,109	213,425	0,000	213,425
Greece	36,200	0,300	36,500	150,300	0,100	150,400
Slovakia	0,116	0,010	0,126	143,567	0,050	143,617
Austria	19,961	0,248	20,209	50,000	0,000	50,000
United Kingdom	6,922	0,155	7,077	45,000	0,255	45,255
Netherlands	10,578	0,091	10,669	29,393	0,000	29,393
Portugal	34,153	0,100	34,253	28,545	0,100	28,645
Slovenia	6,858	0,000	6,858	27,332	0,000	27,332
Bulgaria	4,285	0,008	4,293	11,540	0,000	11,540
Cyprus	1,109	0,033	1,142	2,869	0,049	2,918
Denmark	1,200	0,100	1,300	2,300	0,200	2,500
Finland	0,000	2,000	2,000	0,000	2,000	2,000
Romania	0,000	0,190	0,190	1,100	0,200	1,300
Sweden	0,516	0,338	0,854	1,000	0,300	1,300
Hungary	0,180	0,020	0,200	1,050	0,050	1,100
Luxembourg	1,795	0,000	1,795	0,916	0,000	0,916
Poland	0,121	0,248	0,369	0,150	0,220	0,370
Malta	1,289	0,000	1,289	0,143	0,000	0,143
Estonia	0,000	0,038	0,038	0,000	0,030	0,030
Lithuania	0,000	0,015	0,015	0,020	0,010	0,030
Ireland	0,000	0,210	0,210	0,000	0,000	0,000
Latvia	0,003	0,001	0,004	0,000	0,000	0,000
<b>Total EU 27</b>	<b>5 901,7</b>	<b>16,5</b>	<b>5 918,2</b>	<b>13 013,4</b>	<b>9,8</b>	<b>13 023,2</b>

\*Estimation. Estimate. Les décimales sont séparées par une virgule. Decimals are written with a comma. Source : EurObserver 2011.

Cumulated photovoltaic capacity in the European Union countries at the end of 2009 and 2010\* (in MWp)

	2009			2010		
	Réseau On-grid	Hors réseau Off-grid	Total	Réseau On-grid	Hors réseau Off-grid	Total
Germany	9 914,000	45,000	9 959,000	17 320,000	50,000	17 370,000
Spain	3 418,000	20,081	3 438,081	3 787,000	21,081	3 808,081
Italy	1 144,000	13,400	1 157,400	3 465,000	13,500	3 478,500
Czech Rep.	462,920	0,400	463,320	1 952,700	0,400	1 953,100
France	306,000	29,200	335,200	1 025,000	29,346	1 054,346
Belgium	573,979	0,053	574,032	787,404	0,053	787,457
Greece	48,200	6,800	55,000	198,500	6,900	205,400
Slovakia	0,162	0,030	0,192	143,729	0,080	143,809
Portugal	99,194	3,000	102,194	127,739	3,100	130,839
Austria	48,991	3,605	52,596	98,991	3,605	102,596
Netherlands	62,507	5,000	67,507	91,900	5,000	96,900
United Kingdom	27,845	1,745	29,590	72,845	2,000	74,845
Slovenia	8,904	0,100	9,004	36,236	0,100	36,336
Luxembourg	26,357	0,000	26,357	27,273	0,000	27,273
Bulgaria	5,660	0,040	5,700	17,200	0,040	17,240
Sweden	3,595	5,169	8,764	4,595	5,469	10,064
Finland	0,170	7,479	7,649	0,170	9,479	9,649
Denmark	4,025	0,540	4,565	6,325	0,740	7,065
Cyprus	2,695	0,633	3,328	5,564	0,682	6,246
Romania	0,230	0,410	0,640	1,330	0,610	1,940
Poland	0,300	1,080	1,380	0,450	1,300	1,750
Hungary	0,450	0,200	0,650	1,500	0,250	1,750
Malta	1,527	0,000	1,527	1,670	0,000	1,670
Ireland	0,100	0,510	0,610	0,100	0,510	0,610
Lithuania	0,000	0,070	0,070	0,020	0,080	0,100
Estonia	0,000	0,050	0,050	0,000	0,080	0,080
Latvia	0,003	0,005	0,008	0,003	0,005	0,008
<b>Total EU 27</b>	<b>16 159,8</b>	<b>144,6</b>	<b>16 304,4</b>	<b>29 173,2</b>	<b>154,4</b>	<b>29 327,7</b>

\*Estimation. Estimate. Les décimales sont séparées par une virgule. Decimals are written with a comma. Source : EurObserv'ER 2011.



Electricity production from solar photovoltaic energy in the European Union in 2009 and 2010\* (in GWh)

	2009	2010
Germany	6 578,0	12 000,0
Spain	5 962,0	6302,0
Italy	677,0	1 600,0
Belgium	487,9	669,3
Czech Republic	88,8	615,6
France	215,0	600,0
Portugal	160,0	213,3
Greece	62,4	138,4
Slovakia	0,2	80,0
Netherlands	46,0	70,0
United Kingdom	26,5	41,8
Austria	21,0	26,0
Bulgaria	3,3	24,0
Luxembourg	20,3	21,0
Slovenia	4,2	15,0
Sweden	7,1	9,4
Finland	6,0	6,9
Denmark	3,7	5,7
Cyprus	2,9	5,6
Malta	1,1	2,6
Poland	1,2	1,8
Romania	0,8	1,7
Hungary	0,8	1,0
Ireland	0,4	0,4
Lithuania	0,0	0,1
Estonia	0,0	0,1
Latvia	0,0	0,0
<b>Total EU 27</b>	<b>14 376,6</b>	<b>22 451,6</b>

*\*Estimation. Estimate. Les décimales sont séparées par une virgule. Decimals are written with a comma. Source : EurObserv'ER 2011.*



The preliminary data from 2011 is given below [6].

PVPS Country	PV installed in 2011 (MW)	Cumulative installed capacity (MW)
Australia	837	1408
Austria	92	187
(Belgium)	958	1997
Canada	278	559
China	2200	3000
Denmark	10	17
France	1634	2831
Germany	7500	24820
Israel	120	190
Italy	9301	12803
Japan	1296	4914
Korea	157	812
Malaysia	1	14
Mexico	7	37
Netherlands	42	130
Norway	<1	9
Portugal	13	144
Spain	345	4260
Sweden	4	16
Switzerland	100	211
(Thailand)	50	100
Turkey	1	7
UK	899	976
USA	1867	3966
<b>Estimated totals</b>	<b>27713</b>	<b>63349</b>

xx Data sourced as part of the national survey report process

yy Data sourced from elsewhere

## 7 Present situation of photovoltaic in participating countries

### 7.1 Trends in participating countries [4]

#### 7.1.1 Austria (AUT)

The Austrian PV market more than doubled in 2010 compared to 2009. During 2010, grid-connected PV systems with a total PV power of 42.7 MW were installed, representing well over 99 % of the annual PV market. The cumulative installed PV capacity in Austria reached 95.5 MW at the end of 2010. Grid-connected applications increasingly dominate the market for PV, accounting for more than 96 % of the cumulative installed capacity by the end of 2010.

The revised Green Electricity Act (GEA) forms the framework for national PV implementation in Austria. The nationwide feed-in tariff system for electricity introduced under the GEA is financed by all consumers of electricity via supplements on the electricity price and an obligatory purchase price for Green Electricity that is paid by electricity dealers. The amount paid under the 2010 PV feed-in tariff increased to approximately 13,8 million EUR, an increase of 14 % over the previous year. Average feed-in tariffs were reduced by 7,5 % compared to 2009. The PV electricity produced

climbed from about 21 GWh to 26,3 GWh.

Besides the federal feed-in tariff scheme, an initiative launched in 2008 – the national Fund for Climate and Energy – provided rebates for newly installed private PV systems up to 5 kW installed capacity. In 2010 17,8 million EUR were granted under this funding scheme, leading to an installed capacity of over 11 MW.

Each Austrian province is also running regional PV rebate programmes, aimed at overcoming the limitations of federal incentives. In most cases the support is subject to limited budgets and is linked to further requirements. Generally, the regional support is only granted where the installation is not supported by the federal feed-in tariff scheme. In 2010 the regional funding initiatives amounted to about 39,6 million EUR and helped to install a total PV capacity of about 22,6 MW.

### **7.1.2 France (FRA)**

During 2010, 719 MW of PV were installed in France (mainland France, Corsica and the four French overseas departments Guadeloupe, Guyane, Martinique and Réunion), compared to the 155,5 MW installed during 2009. In mainland France, 91 % of the photovoltaic systems in service are less than 3 kW installed capacity. These systems represent 42 % of the total installed PV capacity.

The development of large ground-mounted PV installations initiated over the course of the two previous years continued in 2010. 78 ground-mounted systems of over 500 kW installed capacity were connected to the electricity grid in mainland France, with 16 of these plants being larger than 5 MW. Cumulative PV capacity in France at the end of 2010 was 1 054.3 MW. During 2010, PV capacity reached a little less than 1 % of total national electricity generation capacity, with about 23 % of new electricity generation capacity installed during the year being PV. The heavy demand for PV from private individuals and investors has not been met by the capacity of the national electricity grid operator (ERDF) to absorb all of the applications for connection to the grid. At the end of 2010, about 75 000 systems were awaiting connection throughout France (mainland and the overseas territories), with a potential for an additional 4 150 MW of installed capacity.

Public initiatives structured and supported the expansion of the PV market during 2010: these included the feed-in tariff with a highly specific orientation towards building integration, the income tax credit of 25 % of the amount of the investment in PV system goods (this was 50 % until 29 September 2010) up to a cap of 8 000 EUR per taxpayer (16 000 EUR for a couple), the ADEME-FACE contracts for off-grid systems and various regional and local government support measures.

The more detailed description of the present situation of PV in France is given in Appendix 1.

### **7.1.3 The Netherlands (NLD)**

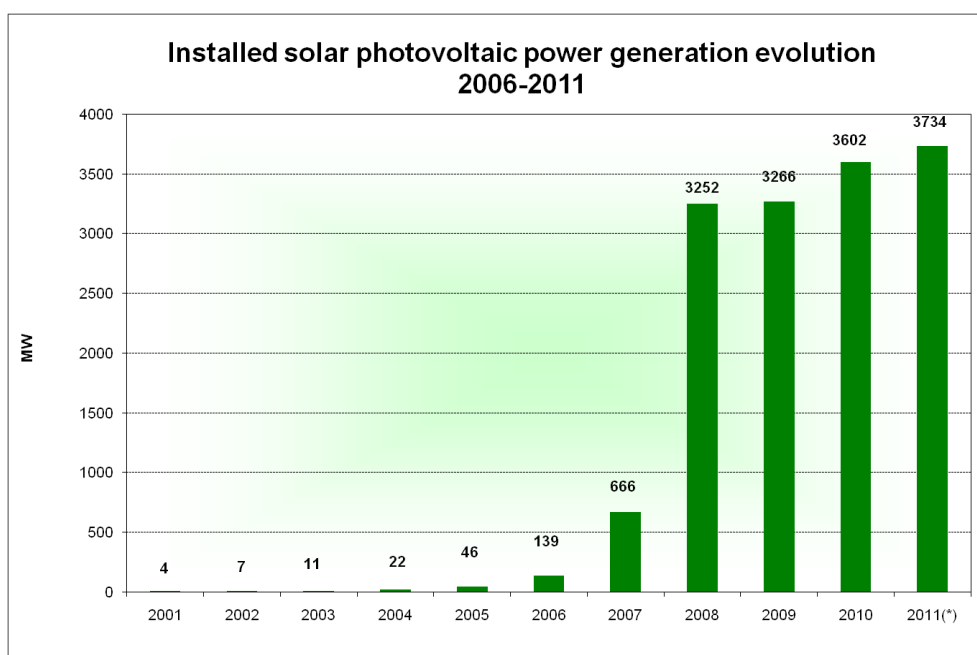
During 2010 about 21 MW of PV were installed in the Netherlands, bringing the cumulative installed capacity to 88 MW. This represents a doubling of the annual market compared to the previous year. PV electricity in the Netherlands represents about 0.05 % of the total electricity production. The market increase in 2010 compared to previous years is partly due to the release of a backlog of grants following the start of the new subsidy scheme (SDE) in 2008. Grants from previous years still remain in the pipeline. The subsidy scheme has now been revised and systems below 15 kW are no longer supported. However there is an increasing amount of small and medium scale PV systems being installed without subsidy, with the slightly decreasing price of solar

modules in 2010 playing an important role. Also significant have been the initiatives that bundle customer PV system demand and purchase batches of PV modules for more favourable prices.

Throughout the Netherlands there are increasing initiatives from the regional public authorities (cities and provinces) to install PV as part of efforts to reduce their carbon foot-print.

#### 7.1.4 Spain (ESP)

During 2010 annual installed PV power in Spain rebounded somewhat from the low amount of new PV power installed during 2009 to reach 392 MW, of which over 99 % were grid-connected. By end 2010, about 70 % of PV plants in Spain were larger than 1 MW. Two important Royal Decrees were published during 2010 that have and will continue to impact the Spanish PV market: Royal Decree 1565/2010 and the Royal Decree Law 14/2010.



Royal Decree 1565/2010 has amended the economic regime contained in Royal Decree 1578/2008 for photovoltaic installations in operation, putting electricity into the grid and registered in the Administrative Registry of Producers after 30 September 2008. Feed-in tariffs have been amended as follows: 45 % reduction for ground-based PV installations, 25 % reduction for large rooftop installations (> 20 kW), and 5 % reduction for smaller roof-top systems. With regard to PV systems in operation, putting electricity into the grid and registered before 30 September 2008, their economic regime has also been amended by cancelling the feed-in tariff after 25 years of operation. Other amendments include a definition of a «substantial change» in installations whereby the plant may become ineligible to continue to receive the feed-in tariff set in the previous economic regime.

The feed-in tariff paid to Spanish PV installations was also reduced through limiting the operational hours, via Royal Decree Law 14/2010. Operational hours are limited to 1250 hours per year for fixed systems, 1644 hours per year for single-axis tracking systems and 1707 hours per year for two-axis tracking systems. Surplus generation outside these hours is purchased at regular wholesale electricity market prices. The limitation applies for the next three years; however, to compensate, the total period for which the feed-in tariff can be obtained has been extended three years. In addition, a network toll has been introduced, applicable to all electricity generation plants, with PV

plants being exempt for the first three years.

These changes followed months of uncertainty. Applying the legislation retrospectively to existing installations has been controversial, with fears that the changes will jeopardize the financial position of some installations. However, a new regulatory framework based in a “net balancing” scheme is expected to be approved during 2012 aiming at boosting the installation of PV in houses without increasing the deficit between the incomes and the expenses of the Spanish Electric System.

In June 2010, Spain adopted a national action plan for renewable energies 2011 – 2020 (PANER). According to the plan, by 2020 the share of renewable in final energy consumption should increase to 20 %. According to the PANER, 3,6 % of the Spanish electricity energy demand in 2020 should be met by PV electricity.

## 8 References

1. Technology Roadmap. Solar photovoltaic energy. IEA 2010, 50 p.
2. Internal report of the ADDRESS project
3. PHOTOVOLTAIC BAROMETER, A study carried out by EurObserv'ER. 2011, 22 p
4. Trends in photovoltaic applications. Survey report of selected IEA countries between 1992 and 2010. Report IEA-PVPS T1-20:2011, 48 p.
5. Solar photovoltaics competing in the energy sector. Gaëtan Masson, Senior Economist, Presentation in Hamburg, PVPS, September 2011
6. Tr 2011 prereview, IEA-PVPS Task 1, October 2012
7. National Survey Report of PV Power Applications in The Netherlands 2011. IEA-PVPS Task 1, April 2012
8. Photovoltaic Power Applications in France. National Survey Report 2011. IEA-PVPS Task 1. May 2012
9. National Survey Report of PV Power Applications in Germany 2011. IEA-PVPS Task 1, July 2012

## **Appendix 1      Present situation of PV in France**

### **A1 1.      Solar power – Photovoltaic panels**

#### **Challenges**

Although the photovoltaic technology is now well developed, it appears that the deployment of photovoltaic installations differs from one country to another. In Germany the installed capacity reached 23GW by the end of 2011 while it amounted to 12GW in Italy and 2GW in France. This heterogeneity is due to several factors. In Germany the government made a strong commitment to renewable energies deployment and pioneered feed-in tariffs for photovoltaic electricity 20 years ago (“Electricity feed Law” introduced on January 1<sup>st</sup> 1991) enabling a fast installed capacity growth. A 2006 ADEME report showed that, a simpler feed-in tariff system and administrative procedure compared to the French one was also a catalyst.

Installed capacity increase still depends on national regulations and incentive schemes. It is national energy policy decisions more than the technology maturity itself that have a direct impact on photovoltaic deployment and consequently photovoltaic technology improvements.

### **A1 2.      The current state of photovoltaic installations in France**

#### **Technological and commercial offer**

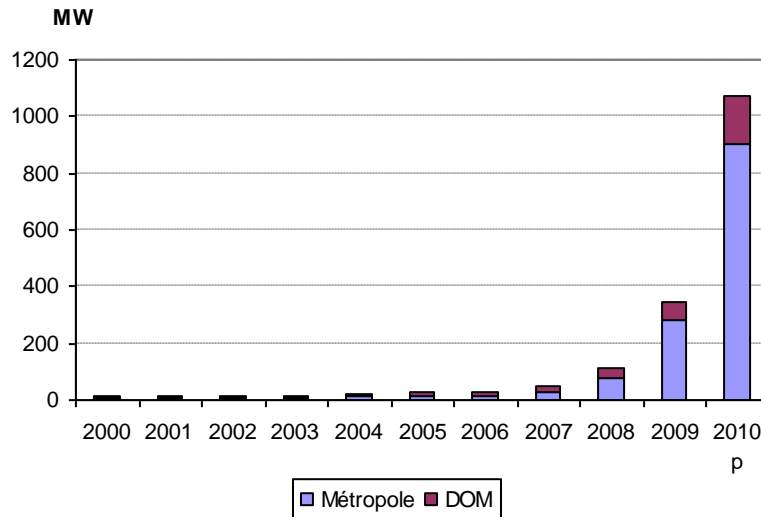
Each year the performances of the photovoltaic panels are increased and new technologies are tested. But the commercial offer today consists of two main technologies: the silicon technologies (monocrystalline, polycrystalline) and the thin-film technologies.

The silicon technology is the oldest of the two. It is a mature product which has an efficiency of 15 %, which should evaluate toward 25%. The thin-film technology is newer, has a lower efficiency, 10 to 15% in general, but is also cheaper.

#### **Current situation in France**

The 2006 ADEME publication on the photovoltaic market in France gives the global trend of the photovoltaic installed capacity. Until 1999, photovoltaic installations mainly concerned isolated systems (not connected to the grid). It is only in 1999 that the annual number of connected-to-grid installations started to increase (following an exponential curve). At the same time the annual number of isolated installations started to decrease.

This same report gave perspectives numbers for the year 2010, and in particular the annual installed capacity in France in the best case scenario: 58.8 MW. It is interesting to compare this number to the real ones. The French Statistical and Observation Service (SOeS) gives the following official numbers: in 2009, 236 MW were installed and in 2010, 724 MW were installed (see Figure below).



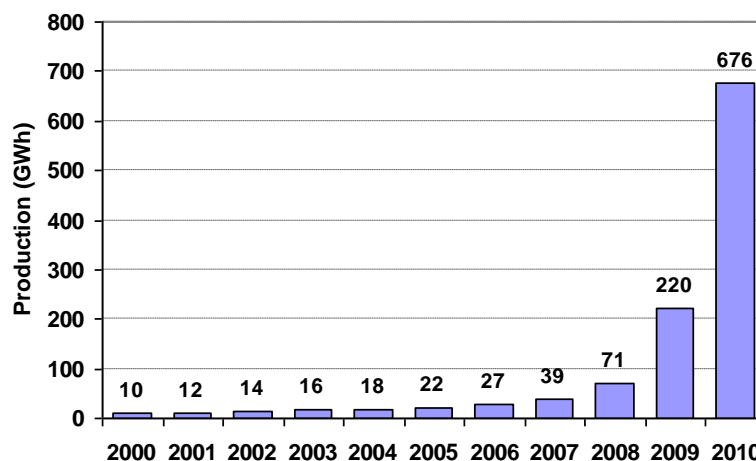
**Figure A 1. Photovoltaic power installed in France (cumulated)<sup>2</sup>**

At the end of 2010, there was a total of 1 072 MWh installed in France. It is important to notice that at the end of 2008, the 112 MW installed represented only 10% of the power installed at the end of 2010. The boom of photovoltaic panels is very recent.

This quick development of the photovoltaic market is due to the installation costs decrease as well as the different incentives granted by the government (purchase obligation and income-tax credit).

As a consequence the photovoltaic industry started off much faster than the Environment Grenelle expectations. The revision of the government's aids should comfort the photovoltaic development but also control its growth rhythm.

### Annual photovoltaic electricity production

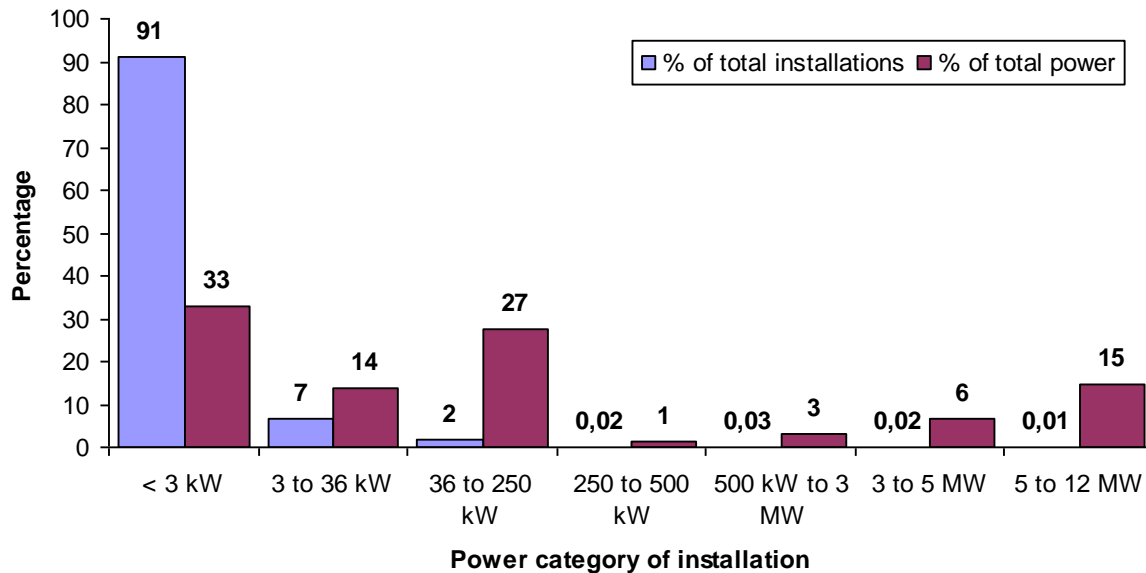


**Figure A 2. Annual photovoltaic electricity production (France + Overseas department)<sup>3</sup>**

<sup>2</sup> Figure from raw statistical data given by the Statistical and Observation Service (SOeS) – [http://www.statistiques.developpement-durable.gouv.fr/fileadmin/documents/Themes/Energies\\_et\\_climat/Les\\_differentes\\_energies/Energies\\_renouvelables/2010/photovoltaique%20France%202010.xls](http://www.statistiques.developpement-durable.gouv.fr/fileadmin/documents/Themes/Energies_et_climat/Les_differentes_energies/Energies_renouvelables/2010/photovoltaique%20France%202010.xls)

The annual photovoltaic electricity production evolution is linked to the annual number of installations (**Virhe. Viitteen lähde ei löytnyt.**). In 2010, 676 GWh were produced by photovoltaic installations (in France and in the overseas department). This represents about 0.12% of the annual total electricity production in France, 550 TWh in 2010.

### Distribution of the installations by power



**Figure A 3. Distribution of the total photovoltaic installations by the end of June 2010<sup>4</sup>**

The figure above shows the distribution (in %) of the total photovoltaic installations in France in terms of number of installations and power. The great majority of the installations, 91%, are low power (< to 3 kW) but produce only 33 % of the total power production.

### Connection-to-grid queue

Another interesting fact is the number of installations awaiting a grid connection.

The following table shows the number and power (in MWp) of connected-to-grid installations that are in the waiting line for being connected to the grid by ERDF.

<sup>3</sup> Raw statistical data given by the Statistical and Observation Service (SOeS) – [http://www.statistiques.developpement-durable.gouv.fr/fileadmin/documents/Themes/Energies\\_et\\_climat/Les\\_differentes\\_energies/Energies\\_renouvelables/2010/photovoltaique%20France%202010.xls](http://www.statistiques.developpement-durable.gouv.fr/fileadmin/documents/Themes/Energies_et_climat/Les_differentes_energies/Energies_renouvelables/2010/photovoltaique%20France%202010.xls)

<sup>4</sup> Etat des lieux du parc photovoltaïque Français – 2011 – Ser-Soler



Queue of connected-to-grid installations	31/12/2008	30/09/2009	30/06/2010	30/06/2011	30/09/2011	30/12/2011 (ERDF)
Number	22 375	34 340	73 174	36 612	30 055	29 591
Power (MWp)	526	1 659	2 953	1 826	1 680	1 531

**Figure A 4. Queue of connected-to-grid installations (data of Ser-Soler and ERDF for 12/2011)<sup>5</sup>**

These numbers show that there is a very strong interest of the public in photovoltaic power.

### **A1 3. Regulations and Government's actions**

Since the beginning of the first photovoltaic connected-to-grid installations (2003), the regulations have changed many times.

The main actions led by the government consisted in helping, financially, the investments in new PV installations, and setting up a purchase obligation of the produced electricity with favourable prices.

One of the specificity of the French government's actions is to support photovoltaic installations that are integrated to the building. The support comes from a higher purchase obligation price of the kWh.

#### **2006**

In 2006, there was an income-tax credit up to 50% of the installations investments.

The purchase obligation prices were of 30 c€/kWh in Metropolitan France and 40 c€/kWh in overseas department. If the installation was integrated to the building, the purchase price was of 55 c€/kWh<sup>6</sup>.

#### **2009**

In 2009, the purchase prices of the electricity were increased respectively to 33 c€/kWh, 44 c€/kWh and 60 c€/kWh<sup>7</sup>.

#### **2010**

However, in order to limit abusive installations profiting from the advantageous purchase obligation prices while solar panel prices had plummeted, the government announced by the end of 2009 that the prices would be reviewed beginning of 2010. In March 2010, a first revision changed the purchase obligation prices to 31.4 c€/kWh (Metropolitan France), 40 c€/kWh (overseas department) and 50 to 58 c€/kWh depending on the building type (building integrated installation).

In August 2010, these prices were reviewed once more, dropping to 27.6 c€/kWh, 35.2 c€/kWh and 44 to 58 c€/kWh.

Since the 29<sup>th</sup> of September 2010, the income-tax credit was lowered from 50 to 25% of the investments made for a new photovoltaic installation.

<sup>5</sup> Etat des lieux du parc photovoltaïque Français – Ser-Soler (2009, 2010 and 2011) and « Bilan ERDF des demandes de raccordement au 31/12/11 » on [www.photovoltaique.info](http://www.photovoltaique.info)

<sup>6</sup> Le marché photovoltaïque en France en 2006 - ADEME

<sup>7</sup> La lettre de la CRE – n°15 – May/June 2009

## 2011

Again in order to control the development of the market the French government set up in 2011 a new method of evolution of the purchase obligation prices. Since March 10<sup>th</sup>, 2011, the prices of the purchase obligation are reviewed every trimester (July 1<sup>st</sup>, 2011, October 1<sup>st</sup>, 2011, January 1<sup>st</sup>, 2012, etc). These prices depend on the number of installations demanded.

For a power below 100 kWp (typically for building integrated PV systems), the purchase obligation price of electricity depends on the type of the building, the installed peak power and the degree of building integration (either “building integration” or “simplified building integration”). For higher power installations an invitation to tender is organised.

The price matrix for 2011 is given below and gives the prices in conformity with the decree of the 4<sup>th</sup> of March 2011.

Types of installation		2011 Prices of the purchase obligation (c€/kWh)			
		Before 01/07	01/07 - 30/09	01/10 - 31/12	
Residential	building integrated	[0-9kW]	46	42,55	40,63
		[9-36kW]	40,6	37,23	35,55
	simplified building integration	[0-36kW]	30,35	27,46	24,85
		[36-100kW]	28,85	26,09	23,61
Education and Health	building integrated	[0-9kW]	40,6	36,74	33,25
		[9-36kW]	40,6	36,74	33,25
	simplified building integration	[0-36kW]	30,35	27,46	24,85
		[36-100kW]	28,85	26,09	23,61
Other buildings	building integrated	[0-9kW]	35,2	31,85	28,82
	simplified building integration	[0-36kW]	30,35	27,46	24,85
		[36-100kW]	28,85	26,09	23,61
Other types of installation		[0-12MW]	12	11,68	11,38

Figure A 5. Purchase obligation price grid for the different types of installations and for 2011<sup>8</sup>

The income-tax credit is again lowered in 2011, from up to 25% to up to 22% of the installation investments.

### A controlled financial support

As said previously, every trimester the purchase obligation prices will be reviewed depending on the number of projects submitted. The target trajectory is of 25 MW/trimester. If the real number of projects submitted is over this target, then the prices are modulated by a coefficient (<1) in order to slow the development. If the real number of projects submitted is under this target, then the prices are modulated by a coefficient (>1) in order to boost the development.

<sup>8</sup> MEDDTL (Ecology, Sustainable Development, Transport and Housing Department) website – Energies et Climat > Energies > Energies renouvelables > Energie solaire > Energie photovoltaïque : le nouveau dispositif

## **A1 4. Deployment perspectives**

In 2007 took place the Environment Grenelle in France. It permitted to think about various problematic on ecology and sustainable development.

In September 2009, the first law, “law Grenelle 1”, was published. Considering the European directive 2009/28/CE, which fixes the French renewable energy target to 23%, and considering the goals given by the *Program of investments in electricity production*<sup>9</sup>, the decree of the 15<sup>th</sup> December 2009 fixes the goal of photovoltaic power installed at horizon 2012 of 1 100 MW and at horizon 2020 of 5 400 MW.

With its 1 072 MW installed end 2010, France is really ahead of its goal. The priming stage of the photovoltaic industry is now well achieved. The next stage will be a development stage, where the emphasis will be put on the industrial processes and environmental performances of the photovoltaic industry in order to meet the respective Grenelle objectives.

## **A1 5. Conclusion**

As the 2010 numbers show, a total of 1 072 MWp in 2010 of which 724 MWp installed during 2010, the launching of the photovoltaic energy is a success compared to the Grenelle objectives (1 100 MWp in 2012). The development of photovoltaic installations must now be managed by the government in order to control the costs for the community since the support is mainly financial state help. This is why regulations have recently (2010 and 2011) been modified.

However this success is to be taken carefully as in 2010 the 1072 MWp installed produced 676 GWh which represents only 0.12% of the 2010 total electricity production.

The government’s actions to manage this rapid growth of the photovoltaic energy production are mainly laws and norms which define grid-connection aspect, purchase obligation prices and income-tax credit.

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<sup>9</sup> Programmation pluriannuelle des investissements de production électrique – 2009

## Appendix 2 Overview of the IEA Demand-Side Management Programme

### IEA Demand Side Management Programme

The Demand-Side Management (DSM) Programme is one of more than 40 co-operative energy technology programmes within the framework of the International Energy Agency (IEA). The Demand-Side Management (DSM) Programme, which was initiated in 1993, deals with a variety of strategies to reduce energy demand. The following 16 member countries and the European Commission have been working to identify and promote opportunities for DSM:

Austria	Netherlands
Belgium	Norway
Canada	New Zealand
Finland	Spain
France	Sweden
India	Switzerland
Italy	United Kingdom
Republic of Korea	United States

Sponsors: RAP

**Programme Vision during the period 2008 - 2012:** Demand side activities should be active elements and the first choice in all energy policy decisions designed to create more reliable and more sustainable energy systems

**Programme Mission:** Deliver to its stakeholders, materials that are readily applicable for them in crafting and implementing policies and measures. The Programme should also deliver technology and applications that either facilitate operations of energy systems or facilitate necessary market transformations

The Programme's work is organized into two clusters:

- The load shape cluster, and
- The load level cluster.

The 'load shape' cluster will include Tasks that seek to impact the shape of the load curve over very short (minutes-hours-day) to longer (days-week-season) time periods. Work within this cluster primarily increases the reliability of systems. The 'load level' will include Tasks that seek to shift the load curve to lower demand levels or shift between loads from one energy system to another. Work within this cluster primarily targets the reduction of emissions.

A total of 24 projects or "Tasks" have been initiated since the beginning of the DSM Programme. The overall program is monitored by an Executive Committee consisting of representatives from each contracting party to the Implementing Agreement. The leadership and management of the individual Tasks are the responsibility of Operating Agents. These Tasks and their respective Operating Agents are:

Task 1 International Database on Demand-Side Management & Evaluation Guidebook on the Impact of DSM and EE for Kyoto's GHG Targets - *Completed*  
Harry Vreuls, NOVEM, the Netherlands

Task 2 Communications Technologies for Demand-Side Management - *Completed*  
Richard Formby, EA Technology, United Kingdom

Task 3 Cooperative Procurement of Innovative Technologies for Demand-Side Management – *Completed*  
Dr. Hans Westling, Promandat AB, Sweden

Task 4 Development of Improved Methods for Integrating Demand-Side Management into Resource Planning - *Completed*  
Grayson Heffner, EPRI, United States

Task 5 Techniques for Implementation of Demand-Side Management Technology in the Marketplace - *Completed*  
Juan Comas, FECSA, Spain

Task 6 DSM and Energy Efficiency in Changing Electricity Business Environments – *Completed*  
David Crossley, Energy Futures, Australia Pty. Ltd., Australia

Task 7 International Collaboration on Market Transformation - *Completed*  
Verney Ryan, BRE, United Kingdom

Task 8 Demand-Side Bidding in a Competitive Electricity Market - *Completed*  
Linda Hull, EA Technology Ltd, United Kingdom

Task 9 The Role of Municipalities in a Liberalised System - *Completed*  
Martin Cahn, Energie Cites, France

Task 10 Performance Contracting - *Completed*  
Dr. Hans Westling, Promandat AB, Sweden

Task 11 Time of Use Pricing and Energy Use for Demand Management Delivery- *Completed*  
Richard Formby, EA Technology Ltd, United Kingdom

Task 12 Energy Standards  
To be determined

Task 13 Demand Response Resources - *Completed*  
Ross Malme, RETX, United States

Task 14 White Certificates – *Completed*  
Antonio Capozza, CESI, Italy

Task 15 Network-Driven DSM - *Completed*  
David Crossley, Energy Futures Australia Pty. Ltd, Australia

Task 16 Competitive Energy Services  
Jan W. Bleyl, Graz Energy Agency, Austria  
Seppo Silvonen/Pertti Koski, Motiva, Finland

Task 17 Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages  
Seppo Kärkkäinen, Elektraflex Oy, Finland

Task 18 Demand Side Management and Climate Change - *Completed*  
David Crossley, Energy Futures Australia Pty. Ltd, Australia

Task 19 Micro Demand Response and Energy Saving - *Completed*  
Barry Watson, EA Technology Ltd, United Kingdom

Task 20 Branding of Energy Efficiency  
Balawant Joshi, ABPS Infrastructure Private Limited, India

Task 21 Standardisation of Energy Savings Calculations  
Harry Vreuls, SenterNovem, Netherlands

Task 22 Energy Efficiency Portfolio Standards  
Balawant Joshi, ABPS Infrastructure Private Limited, India

Task 23 The Role of Customers in Delivering Effective Smart Grids  
Linda Hull. EA Technology Ltd, United Kingdom

Task 24 Closing the loop - Behaviour change in DSM, from theory to policies and practice  
Sea Rotmann, SEA, New Zealand and Ruth Mourik DuneWorks, Netherlands

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Also, visit the IEA DSM website: <http://www.ieadsm.org>