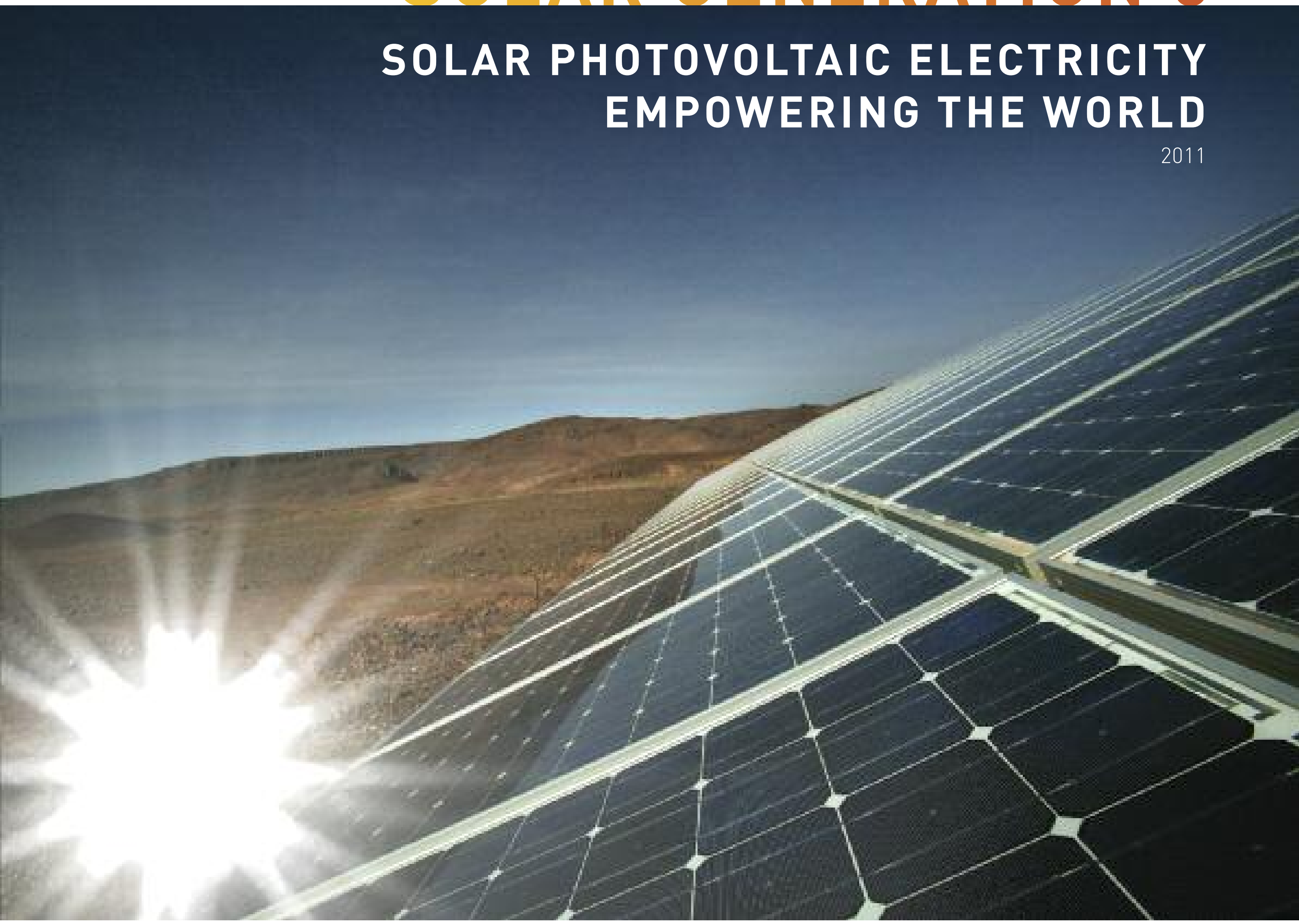
SOLAR GENERATION 6

SOLAR PHOTOVOLTAIC ELECTRICITY EMPOWERING THE WORLD

2011



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SOLAR GENERATION 6

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2011

FOREWORD

The European Photovoltaic Industry Association and Greenpeace International are pleased to present this 6th edition of the report “Solar Generation: Solar Photovoltaic Electricity Empowering the World”.

This report aims to provide a clear and understandable description of the current status of developing Photovoltaic power generation worldwide, and also of its untapped potentials and growth prospects in the coming years.

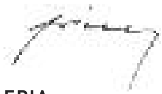
During 2010, the Photovoltaic (PV) market has shown unprecedented growth and wide-spread use of this environmentally friendly and distributed source of power generation. On a global basis, new PV installations of approximately 15,000 MW have been added during 2010, taking the entire PV capacity to almost 40,000 MW. This result is even above the optimistic forecast contained in the report, and it also translates into investments of over 50 bn€ in 2010, again ahead of the report’s forecast.

The most impressive result is however the number of installations and therefore of individuals, companies, and public entities participating in this development: nearly 2 million single PV installations produce photovoltaic power already today.

The cumulative electrical energy produced from global PV installations in 2010 equals more than half of the electricity demand in Greece, or the entire electricity demand in ten central African countries.*

* Angola, Benin, Botswana, Cameroon, Congo, Cote d’Ivoire, Eritrea, Ethiopia, Gabon and Ghana.

The strong growth in PV installations is currently driven in particular by European countries, accounting for some 70% of the global market, and accompanied by the promising key markets of North America, Japan, China and Australia. At the same time, the PV arena has importantly widened its number of participating countries and also increased their specific weight. Major new areas for development lie also in the Sunbelt region, with Africa, Middle East and South America just starting to create new growth opportunities, almost always dedicated to covering local demand.



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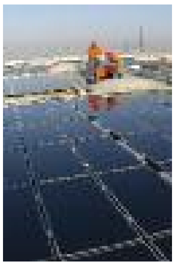

Installing thin film modules.

The major competitive advantages of PV technology lie in its versatility, i.e. the wide range of sizes and sites, resulting into proximity to electricity demand, in the value of its production profile concentrated during peak-load hours, and in its enormous potential for further cost reduction.

PV technology has reduced its unit costs to roughly one third of where it stood 5 years ago, thanks to continuous technological progress, production efficiency and to its wide implementation. The trend of decreasing unit cost will continue also in the future, just like in comparable industries such as semiconductors and TV screens. Adding the important feature of integrated PV solutions in particular in building architecture, the potential of further growth is simply enormous.

This edition of the Solar Generation report combines different growth scenarios for global PV development and electricity demand until 2050. It is built on the results of several reference market studies in order to accurately forecast PV growth in the coming decades. In addition, the economic and social benefits of PV, such as employment and CO_2 emissions reduction, are also worked out. With PV becoming a cost competitive solution for producing power, it will open up an increasing variety of new markets and contribute more and more significantly to cover our future energy needs.

PV technology has all the potential to satisfy a double digit percentage of the electricity supply needs in all major regions of the world. Going forward, a share of over 20% of the world electricity demand in 2050 appears feasible, and opens a bright, clean and sunny future to all of us.

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EXECUTIVE SUMMARY

Status of solar power today

At the end of 2009 the world was running 23 GW of photovoltaic (PV) electricity, the equivalent of 15 coal-fired power plants. At the end of 2010, this number should reach more than 35 GW. We have known for decades that just a portion of the energy hitting the Earth's surface from the Sun every day could power all our cities several times over.

> "Solar can and must be a part of the solution to climate change, helping us shift away from fossil fuel dependence."

Solar can and must be a part of the solution to combat climate change, helping us shift towards a green economy. It is also a potentially prosperous industry sector in its own right. Some industry indicators show just how far photovoltaic energy has already come.

- The cost to produce solar power has dropped by around 22% each time world-wide production capacity has doubled reaching an average generation cost of 15c€/KWh in EU.
- Average efficiencies of solar modules have improved a couple percentage points per year. The most efficient crystalline silicon modules, go to 19.5% in 2010 with a target of 23% efficiency by 2020, which will lower prices further. That increase in efficiencies is seen in all PV technologies.
- Solar power booms in countries where the boundary conditions are right.
- Over 1,000 companies are involved in the manufacturing of the established crystalline silicon technology and already more than 30 produce Thin Film technologies.
- The energy pay time back the electricity it took to create them in one to three years. The most cutting-edge technologies have reduced this to six months depending on the geographies and solar irradiation, while the average life of modules is more than 25 years.

Imagining a future with a fair share of Sun

The European Photovoltaic Industry Association (EPIA) and Greenpeace commissioned updated modelling into how much solar power the world could reasonably see in the world by 2030. The model shows that with a Paradigm Shift scenario towards solar power, where real technical and commercial capacity is backed-up by strong political will, photovoltaics could provide:

- 688 GW by 2020 and 1,845 GW by 2030.
- Up to 12% of electricity demand in European countries by 2020 and in many Sunbelt countries (including China and India) by 2030. Around 9% of the world's electricity needs in 2030.

Under an Accelerated scenario, which follows the expansion pattern of the industry to date and includes moderate political support, photovoltaics could provide:

- 345 GW by 2020 and 1,081 GW by 2030
- Around 4% of the world's electricity needs in 2020.

What are the benefits?

The benefits of a Paradigm Shift towards solar electricity as described in this model include:

- Provide clean and sustainable electricity to the world.
- Regional development, by creation of local jobs. New employment levels in the sector – as many as 1.62 million jobs as early as 2015, rising to 3.62 million in 2020 and 4.64 million in 2030.
- Clean electricity that contributes to international targets to cut emissions and mitigate climate change.
- Avoiding up to 4,047 million tonnes of CO_2 equivalent every year by 2050. The cumulative total of avoided CO_2 emissions from 2020 to 2050 would be 65 billion tonnes.

How can we get there?

A Paradigm Shift for solar is possible. While the PV sector is committed to improve efficiency of products and reduce costs, these aspects are not the major issues either. In fact, solar power is due to reach grid parity in a number of countries, some as early as 2015. Lessons from real examples show there are some key approaches to getting it right in solar power support schemes. These include:

Using Feed-in Tariffs (FiT) that guarantee investment for 15 to 20 years. FiT schemes have been proven to be the most efficient support mechanisms with a long, proven ability to develop the market world-wide.

Assessing PV investment profitability on a regular basis and adapting FiT levels accordingly. A fair level of FiT can help the market take-off and avoid over heated markets.

Assessing profitability through IRR calculations. All aspects of a support scheme including FiT, tax rebates and investment subsidies must be considered when calculating the internal rate of return (IRR) of a PV investment.

Controlling the market with the upgraded "corridor" concept. The corridor is a market control mechanism that allows to adjust FiT levels to accelerate or slow the PV market in a country. The FiT level can be increased or decreased regularly in relation to how much PV is in the market against predefined thresholds at regular intervals (for example, annually).

Refining FiT policies for additional benefits. The way a scheme is designed can encourage specific aspects of PV power. For example, systems that are integrated into buildings and substitute building components.

Drawing a national roadmap to grid parity. Financial incentives can be progressively phased-out as installed PV system costs are decreased and conventional electricity prices are increasing.

“The solar PV market has outpaced ‘Solar Generation’ predictions by nine years.”

Learning from the pioneers

Some nations have taken a lead with support schemes that encourage market creation and industry growth.

Germany: The first country to introduce a FiT, has shown the rest of the world how countries can achieve environmental and industrial development at the same time.

Japan: More than 2.6 GW of solar power were installed in 2009, almost 99% of which were grid-connected thanks to incentives administered by the Ministry of Economy, Trade and Industry.

Italy: Uses a FiT with higher rates for building integrated systems (guaranteed for 20 years) accompanied with net metering to encourage solar power.

USA: Allows a tax credit of 30% for commercial and residential PV systems that can be used by utilities. Several States offer very attractive schemes and incentives.

China: The world’s largest PV manufacturer with unlocked its PV market potential. The country is discussing FiT to meet a goal of 20 GW of solar power installed by 2020, 5 GW of this by 2015 which is of course negligible considering its huge potential.

Reference for the future

This publication is the sixth edition of the reference global solar scenarios that have been established by the European Photovoltaic Industry Association and Greenpeace jointly for almost ten years. They provide well documented scenarios establishing the PV deployment potential World-wide by 2050.

The first edition of Solar Generation was published in 2001. Since then, each year, the actual global PV market has grown faster that the industry and Greenpeace had predicted (see table 1).

TABLE 1
ANNUAL PV INSTALLED CAPACITY
MW

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Market Result MW	334	439	594	1,052	1,320	1,467	2,392	6,090	7,203	
SG I 2001	331	408	518	659	838	1,060	1,340	1,700	2,150	2,810
SG II 2004					985	1,283	1,675	2,190	2,877	3,634
SG III 2006						1,883	2,540	3,420	4,630	5,550
SG IV 2007							2,179	3,129	4,339	5,650
SG V 2008								4,175	5,160	6,950
SG VI 2011										13,625

SOLAR BASICS 1

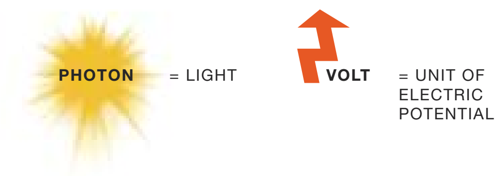
1 SOLAR BASICS

1.1. What does photovoltaic mean?

Photovoltaic systems contain cells that convert sunlight into electricity. Inside each cell there are layers of a semi-conducting material. Light falling on the cell creates an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power each cell generates.

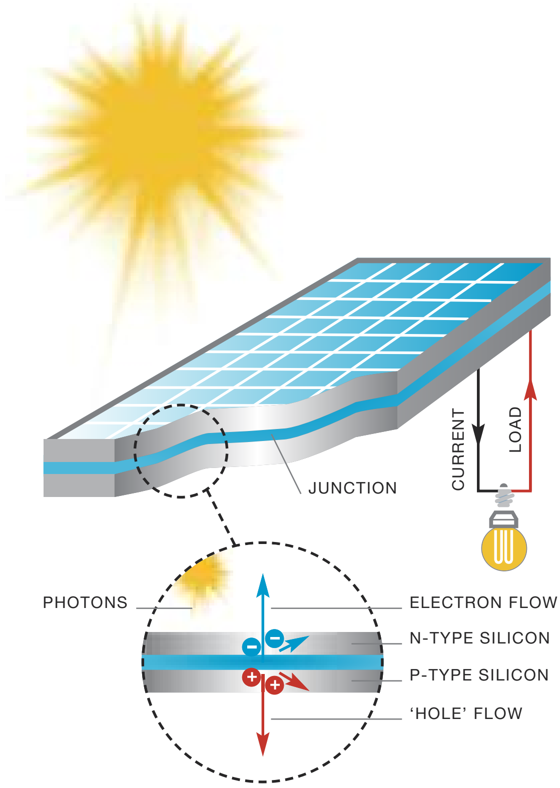
"PV technology exploits a virtually limitless source of free power from the sun."

FIGURE 1
THE MEANING OF THE WORD "PHOTOVOLTAIC"



source: EPIA.

FIGURE 2
EXAMPLE OF THE PHOTOVOLTAIC EFFECT



source: EPIA.

A photovoltaic system does not need bright sunlight in order to operate. It can also generate electricity on cloudy and rainy days from reflected sunlight.

1.2. Benefits of PV technology

PV technology exploits the most abundant source of free power from the Sun and has the potential to meet almost all of mankind's energy needs. Unlike other sources of energy, PV has a negligible environmental footprint, can be deployed almost anywhere and utilises existing technologies and manufacturing processes, making it cheap and efficient to implement.

a. Environmental footprint of PV

The energy it takes to make a solar power system is usually recouped by the energy costs saved over one to three years. Some new generation technologies can even recover the cost of the energy used to produce them within six months, depending on their location. PV systems have a typical life of at least 25 years, ensuring that each panel generates many times more energy than it costs to produce.

b. Improving grid efficiency

PV systems can be placed at the centre of an energy generation network or used in a decentralised way. Small PV generators can be spread throughout the network, connecting directly into the grid. In areas that are too remote or expensive to connect to the grid, PV systems can be connected to batteries.

c. Making cities greener

With a total ground floor area over 22,000 km2, 40% of all building roofs and 15% of all facades in EU 27 are suited for PV applications. This means that over 1,500 GWp of PV could technically be installed in Europe which would generate annually about 1,400TWh, representing 40% of the total electricity demand by 2020. PV can seamlessly integrate into the densest urban environments. City buildings running lights, air-conditioning and equipment are responsible for large amounts of greenhouse gas emissions, if the power supply is not renewable. Solar power will have to become an integral and fundamental part of tomorrow's positive energy buildings.

d. No limits

There are no substantial limits to the massive deployment of PV. Material and industrial capability are plentiful and the industry has demonstrated an ability to increase production very quickly to meet growing demands. This has been demonstrated in countries such as Germany and Japan which have implemented proactive PV policies.

Greenpeace has supported solar power as a clean way to produce power for 20 years. This is mainly because it avoids the harmful impact on the environment caused by carbon dioxide. Carbon dioxide is emitted during the burning of oil, coal and gas to generate electricity. The European Photovoltaic Industry Association has been actively working for the past 25 years to promote a self-sustaining PV industry.

1.3. Types of PV systems

PV systems can provide clean power for small or large applications. They are already installed and generating energy around the world on individual homes, housing developments, offices and public buildings.

Today, fully functioning solar PV installations operate in both built environments and remote areas where it is difficult to connect to the grid or where there is no energy infrastructure. PV installations that operate in isolated locations are known as stand-alone systems. In built areas, PV systems can be mounted on top of roofs (known as Building Adapted PV systems – or BAPV) or can be integrated into the roof or building facade (known as Building Integrated PV systems – or BIPV).

Modern PV systems are not restricted to square and flat panel arrays. They can be curved, flexible and shaped to the building's design. Innovative architects and engineers are constantly finding new ways to integrate PV into their designs, creating buildings that are dynamic, beautiful and provide free, clean energy throughout their life.

"There are no substantial limits to the deployment of PV."

Why solar ticks all the boxes:

- ☑ Free energy direct from the Sun
- ☑ No noise, harmful emissions or gases are produced
- ☑ Safety and reliability are proven
- ☑ Each module lasts around at least 25 years
- ☑ Systems can be recycled at the end of their life and the materials re-used
- ☑ PV is easy to install and has very low maintenance requirements
- ☑ Power can be generated in remote areas that are not connected to the grid
- ☑ Solar panels can be incorporated into the architecture of a building
- ☑ The energy used to create a PV system can be recouped quickly (between six months and three years) and that timeframe is constantly decreasing as technology improves
- ☑ Solar power can create thousands of jobs
- ☑ Solar contribute to the security of energy supply in every country.

a. Grid connected systems

When a PV system is connected to the local electricity network, any excess power that is generated can be fed back into the electricity grid. Under a FiT regime, the owner of the PV system is paid according the law for the power generated by the local electricity provider. This type of PV system is referred to as being 'on-grid'.

Residential and commercial systems

Most solar PV systems are installed on homes and businesses in developed areas. By connecting to the local electricity network, owners can sell their excess power, feeding clean energy back into the grid. When solar energy is not available, electricity can be drawn from the grid.

Solar systems generate direct current (DC) while most household appliances utilise alternating current (AC). An inverter is installed in the system to convert DC to AC.

Industrial and utility-scale power plants

Large industrial PV systems can produce enormous quantities of electricity at a single point respectful of the environment. These types of electricity generation plants can produce from many hundreds of kilowatts (kW) to several megawatts (MW).

The solar panels for industrial systems are usually mounted on frames on the ground. However, they can also be installed on large industrial buildings such as warehouses, airport terminals or railway stations. The system can make double-use of an urban space and put electricity into the grid where energy-intensive consumers are located.

grid-connected BIPV system on the roof and façade of a commercial building.

Large ground-mounted system in Germany.

TABLE 2
TYPICAL TYPE AND SIZE OF APPLICATIONS PER MARKET SEGMENT

Type of application	**Market segment**			
	Residential < 10 kWp*	Commercial 10kWp - 100kWp	Industrial 100kWp - 1MWp	Utility scale >1MWp
Ground-mounted			✓	✓
Roof-top	✓	✓	✓	
Integrated to facade/roof	✓	✓		

* Wp : Watt-peak, a measure of the nominal power of a photovoltaic solar energy device.

b. Stand-alone, off-grid and hybrid systems

Off-grid PV systems have no connection to an electricity grid. An off-grid system is usually equipped with batteries, so power can still be used at night or after several days of low Irradiation. An inverter is needed to convert the DC power generated into AC power for use in appliances.

Most standalone PV systems fall into one of three main groups:

- Off-grid industrial applications
- Off-grid systems for the electrification of rural areas
- Consumer goods.

Off-grid industrial applications

Off-grid industrial systems are used in remote areas to power repeater stations for mobile telephones (enabling communications), traffic signals, marine navigational aids, remote lighting, highway signs and water treatment plants among others. Both full PV and hybrid systems are used. Hybrid systems are powered by the Sun when it is available and by other fuel sources during the night and extended cloudy periods.

Off-grid industrial systems provide a cost-effective way to bring power to areas that are very remote from existing grids. The high cost of installing cabling makes off-grid solar power an economical choice.

Off-grid industrial application.

Off-grid systems for rural electrification

Typical off-grid installations bring electricity to remote areas or developing countries. They can be small home systems which cover a household's basic electricity needs, or larger solar mini-grids which provide enough power for several homes, a community or small business use.

Rural electrification system in an African village.

"Off-grid systems provide a cost-effective way to bring power to remote areas."

Consumer goods

PV cells are now found in many everyday electrical appliances such as watches, calculators, toys, and battery chargers (as for instance embedded in clothes and bags). Services such as water sprinklers, road signs, lighting and telephone boxes also often rely on individual PV systems.

Public lights in Berlin.

1.4. The Solar potential

There is more than enough solar irradiation available to satisfy the world's energy demands. On average, each square metre of land on Earth is exposed to enough sunlight to generate 1,700 kWh of energy every year using currently available technology. The total solar energy that reaches the Earth's surface could meet existing global energy needs 10,000 times over.

A large amount of statistical data on solar energy availability is collected globally. For example, the US National Solar Radiation database has 30 years of solar irradiation and meteorological data from 237 sites in the USA. The European Joint Research Centre (JRC) also collects and publishes European solar irradiation data from 566 sites[1].

"The total solar energy that reaches the Earth's surface could meet existing global energy needs 10,000 times over."

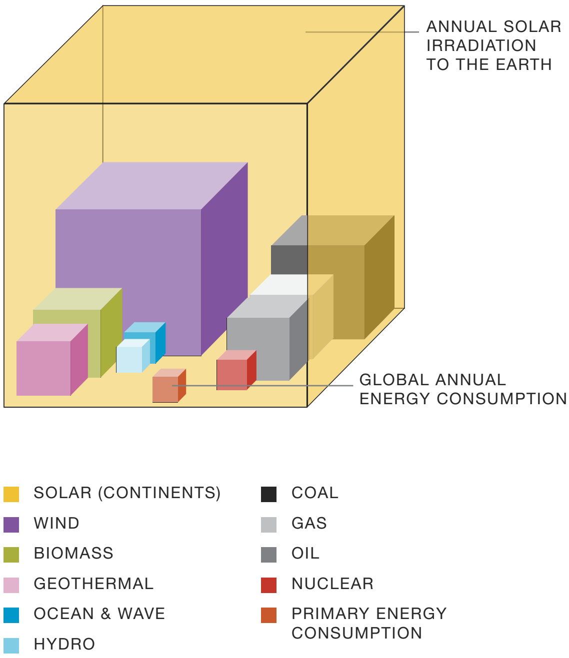
Where there is more Sun, more power can be generated. The sub-tropical areas of the world offer some of the best locations for solar power generation. The average energy received in Europe is about 1,200 kWh/m2 per year. This compares with 1,800 to 2,300 kWh/m2 per year in the Middle East.

While only a certain part of solar irradiation can be used to generate electricity, this 'efficiency loss' does not actually waste a finite resource, as it does when burning fossil fuels for power. Efficiency losses do, however, impact on the cost of the PV systems. This is explained further in Part 3 of this report.

EPIA has calculated that Europe's entire electricity consumption could be met if just 0.34% of the European land mass was covered with photovoltaic modules (an area equivalent to the Netherlands). International Energy Agency (IEA) calculations show that if 4% of the world's very dry desert areas were used for PV installations, the world's total primary energy demand could be met.

There is already enormous untapped potential. Vast areas such as roofs, building surfaces, fallow land and desert could be used to support solar power generation. For example, 40% of the European Union's total electricity demand in 2020 could be met if all suitable roofs and facades were covered with solar panels[2].

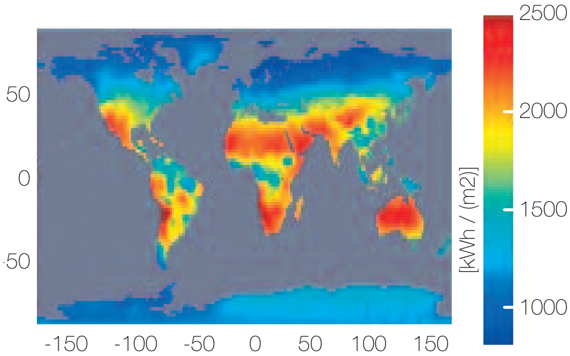
FIGURE 3
SOLAR IRRADIATION VERSUS ESTABLISHED GLOBAL ENERGY RESOURCES



FOSSIL FUELS ARE EXPRESSED WITH REGARD TO THEIR TOTAL RESERVES WHILE RENEWABLE ENERGIES TO THEIR YEARLY POTENTIAL.

source: DLR, IEA WEO, EPIA's own calculations.

FIGURE 4
SOLAR IRRADIATION AROUND THE WORLD



source: Gregor Czisch, ISET, Kassel, Germany.

1.5. Example: How PV can meet residential consumption

Electricity produced by a PV installation on a house over a year can generally cover the demands of a typical family. The graph in Figure 5 shows the daily electricity needs for a household of 2-3 people, compared to the electricity generated from a 20 m² PV installation in a sunny region (about 1200 kWh/kWp). Electricity demand is largely met and exceeded during spring and summer. In winter more electricity is used for lighting and heating, and there is a shorter daytime period. In this period the house can draw additional power from the grid.

The model assumes that the PV system uses modules with efficiency of 14%, and that it is installed on a roof at the optimum inclination angle. The Sunrise Project toolbox has been used for calculations.

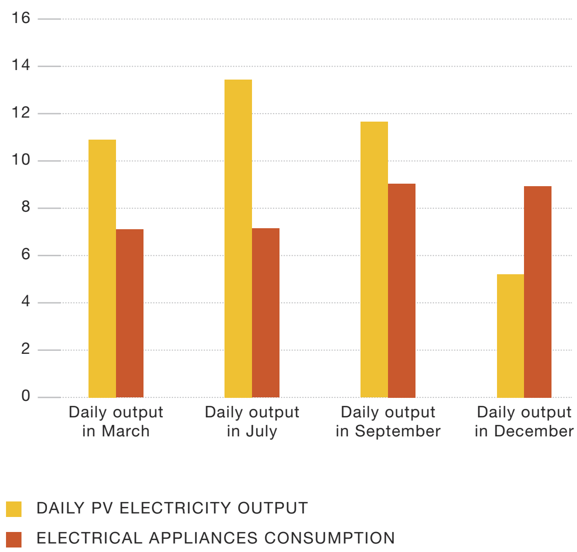
TABLE 3
POTENTIAL FOR SOLAR POWER IN THE EU-27 IN 2020

European population	497,659,814
Total ground floor area	22,621 km2
Building-integrated solar potential (roofs and facades)	12,193 km2 or 1,425 TWh/a
Expected electricity demand	3,525 TWh/a
Potential share of electricity demand covered by building-integrated PV	40%

source: Sunrise project/EPIA.

"Electricity demand is largely met and exceeded during spring and summer."

FIGURE 5
COMPARISON OF THE AVERAGE DAILY ELECTRICITY NEEDS OF A 2-3 PEOPLE HOUSEHOLD WITH THE ELECTRICITY OUTPUT OF A 20M² PV SYSTEM.
kWh/day



source: Sunrise project/EPIA.

Table 3 shows the electricity demand of typical households in nine different countries. The table also shows the area that would need to be covered in PV modules to cater to this demand. The numbers are averages, so large deviations are possible for individual households. These depend on factors such as the energy efficiency of the dwelling, the number of household appliance, and the level of insulation against heat loss and intrusion.

Depending on solar irradiation levels in each city and the electricity consumption pattern of a typical home, the required area for solar power ranges from 14 m² in Rome, to 45 m² in New York. The amount of roof space available for solar power generation varies by country. The average rooftop area needed per household in Tokyo or Seoul is significantly lower than that in Munich.

For solar energy to be truly effective, it must be implemented together with responsible energy consumption and energy efficiency. Measures such as improved insulation and double glazing will significantly improve energy consumption. Better energy efficiency makes it possible to meet electricity demand with sustainable solar power, using significantly lower coverage areas than those shown in Table 4.

"Solar energy must be implemented together with responsible energy consumption and energy efficiency."

TABLE 4
AVERAGE HOUSEHOLD CONSUMPTION AND PV COVERAGE AREA NEEDED TO MEET DEMAND IN NINE COUNTRIES

City, Country	Annual Consumption (kWh)	Area of PV modules needed (m²)
Copenhagen, Denmark	4,400	33
Kuala Lumpur, Malaysia	3,700	15
London, UK (2008)	3,300	24
Munich, Germany (2008)	4,000	25
New York, USA	11,000	45
Rome, Italy	2,700	14
Seoul, South-Korea	3,600	16
Sydney, Australia	8,000	30
Tokyo, Japan	3,500	20

source: EPIA, IEA PVPS.

SOLAR TECHNOLOGY AND INDUSTRY 2

2 SOLAR TECHNOLOGY AND INDUSTRY

2.1. PV systems

The key parts of a solar energy generation system are:

- Photovoltaic modules to collect sunlight
- An inverter to transform direct current (DC) to alternate current (AC)
- A set of batteries for stand-alone PV systems
- Support structures to orient the PV modules toward the Sun.

The system components, excluding the PV modules, are referred to as the balance of system (BOS) components.

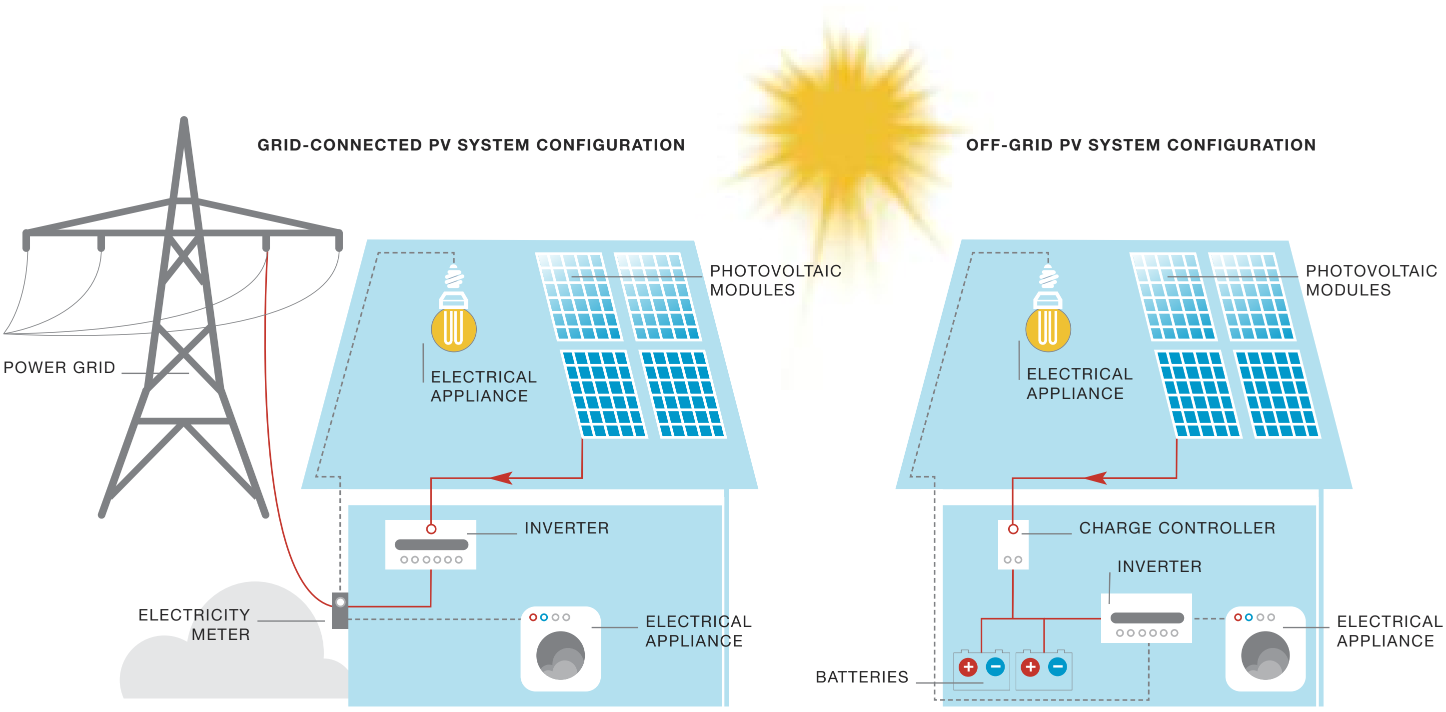
FIGURE 6
DIFFERENT CONFIGURATIONS OF SOLAR POWER SYSTEMS

a. PV cells and modules

The solar cell is the basic unit of a PV system. PV cells are generally made either from:

- crystalline silicon, sliced from ingots or castings,
- from grown ribbons or
- from alternative semiconductor materials deposited in thin layers on a low-cost backing (Thin Film).

Cells are connected together to form larger units called modules. Thin sheets of EVA* or PVB** are used to bind cells together and to provide weather protection. The modules are normally enclosed between a transparent cover (usually glass) and a weatherproof backing sheet (typically made from a thin polymer). Modules can be framed for extra mechanical strength and durability. Thin Film modules are usually encapsulated between two sheets of glass, so a frame is not needed.



source: EPIA.

* Ethyl Vinyl Acetate.
** Polyvinyl Butyral.

Modules can be connected to each other in series (known as an array) to increase the total voltage produced by the system. The arrays are connected in parallel to increase the system current.

The power generated by PV modules varies from a few watts (typically 20 to 60 Wp) up to 300 to 350 Wp depending on module size and the technology used. Low wattage modules are typically used for stand-alone applications where power demand is generally low.

Standard crystalline silicon modules contain about 60 to 72 solar cells and have a nominal power ranging from 120 to 300 Wp depending on size and efficiency. Standard Thin Film modules have lower nominal power (60 to 120 Wp) and their size is generally smaller. Modules can be sized according to the site where they will be placed and installed quickly. They are robust, reliable and weatherproof. Module producers usually guarantee a power output of 80% of the Wp, even after 20 to 25 years of use. Module lifetime is typically considered of 25 years, although it can easily reach over 30 years.

b. Inverters

Inverters convert the DC power generated by a PV module to AC power. This makes the system compatible with the electricity distribution network and most common electrical appliances. An inverter is essential for grid-connected PV systems. Inverters are offered in a wide range of power classes ranging from a few hundred watts (normally for stand-alone systems), to several kW (the most frequently used range) and even up to 2,000 kW central inverters for large-scale systems.

c. Batteries and charge controllers

Stand-alone PV systems require a battery to store energy for future use. Lead acid batteries are typically used. New high-quality batteries, designed specifically for solar applications and with a life of up to 15 years, are now available. The actual lifetime of a battery depends on how it is managed.

Batteries are connected to the PV array via a charge controller. The charge controller protects the battery from overcharging or discharging. It can also provide information about the state of the system or enable metering and payment for the electricity used.

Antireflection coating based on nitride to optimize light penetration into solar cell.

PV modules integrated into flat roof.

2.2. Photovoltaic technologies

PV technologies are classified as first, second or third generation. First generation technology is the basic crystalline silicon (c-Si). Second generation includes Thin Film technologies, while third generation includes concentrator photovoltaics, organics, and other technologies that have not yet been commercialised at large scale.

a. Crystalline silicon technology

Crystalline silicon cells are made from thin slices (wafers) cut from a single crystal or a block of silicon.

The type of crystalline cell produced depends on how the wafers are made. The main types of crystalline cells are:

- Mono crystalline (mc-Si):
- Polycrystalline or multi crystalline (pc-Si)
- Ribbon and sheet-defined film growth (ribbon/sheet c-Si).

The single crystal method provides higher efficiency, and therefore higher power generation. Crystalline silicon is the most common and mature technology representing about 80% of the market today. Cells turn between 14 and 22% of the sunlight that reaches them into electricity. For c-Si modules, efficiency ranges between 12 and 19% (see Table 7).

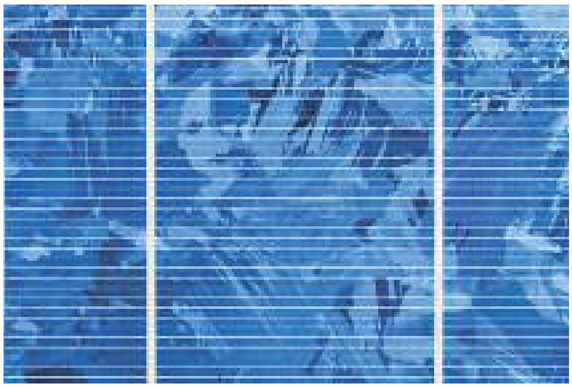
Individual solar cells range from 1 to 15 cm across (0.4 to 6 inches). However, the most common cells are 12.7 x 12.7 cm (5 x 5 inches) or 15 x 15 cm (6 x 6 inches) and produce 3 to 4.5 W – a very small amount of power. A standard c-Si module is made up of about 60 to 72 solar cells and has a nominal power ranging from 120 to 300 Wp depending on size and efficiency.

The typical module size is 1.4 to 1.7 m^2 although larger modules are also manufactured (up to 2.5 m^2). These are typically utilised for BIPV applications.

Manufacturing process

The manufacturing process of c-Si modules takes five steps (see Figure 8).

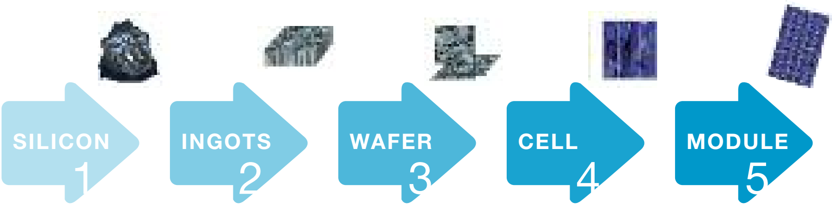
FIGURE 7
CRYSTALLINE SILICON CELLS



Polycrystalline silicon PV cell.

Monocrystalline solar cell.

FIGURE 8
CRYSTALLINE SILICON MANUFACTURING PROCESS



The steps, in detail are:

1. *Convert the metallurgical silicon into high purity polysilicon (known as solar grade silicon).*

   Silicon is the second most abundant element in the Earth's crust after oxygen. It is found in quartz or sand. Metallurgical silicon is 98 to 99% pure. The polysilicon required for solar cells can be up to 99.999999% pure. The most common process for converting raw silicon into solar grade silicon is the Siemens process.

2. *Form the ingots.*

   The polysilicon is melted in large quartz crucibles, and then cooled to form a long solid block called an ingot. The type of wafer that will be cut from the ingot depends on the process used to form the ingot. Monocrystalline wafers have a regular, perfectly-ordered crystal structure, while multicrystalline wafers have an unstructured group of crystals. The level of structure affects how electrons move over the surface of the cell.

3. *Slice the ingot or block into wafers.*

   A wire saw is used to slice the wafer from the ingot or block. The saw is about the same thickness as the wafer. This method of slicing produces significant wastage – up to 40% of the silicon (known as kerf loss). Using a laser cutter reduces kerf loss; however, this can only be done on ingots formed by string ribbon or sheet/edge-defined film growth.

4. *Transform the wafer into a solar cell.*

   The cell is the unit that produces the electricity. It is created using four main steps:

   a. *Surface treatment:* The wafer's top layer is removed to make it perfectly flat.

   b. *Creation of the potential difference (p-n) junction:* A potential difference between two points gives rise to an electromotive force that pushes electrons from one point to the other. A solar wafer needs to have a p-n between the surface and the bottom of the cell. This step takes place in a diffusion oven.

   c. *Deposition of an anti-reflective coating:* The coating enables the cell to absorb the maximum amount of light. It also gives cells their typical blue colour.

   d. *Metallisation:* Metal contacts (usually silver) are added to the cell so the electrons can be transported to the external circuit. A thin metal grid, known as a finger, is attached to the front surface of the cell. Wider metal strips, known as busbars, are connected to the front and back surfaces of the cell.

   The fingers collect the current generated by the cell, while the busbars connect the fingers and provide external connection points to other cells. The entire back surface of the cell is coated with aluminium to create a reflective inner surface.

5. *Connect and coat the cells to form a module.*

   The cells are effectively sandwiched between layers of coating material to protect them from the environment and breakage. Transparent glass is used for the front, while a weatherproof backing (typically a thin polymer) is applied to the back of the module. The cover is attached using thin sheets of EVA or PVB. Frames can be placed around the modules to increase their strength. For some specific applications, such as integration into a building, the back of the module is also made of glass to allow light through.

"Silicon is the second most abundant element in the earth's crust after oxygen."

Alternative cell manufacturing technologies

Advances and alternatives in cell manufacturing methods are producing cells with higher levels of efficiency. Some of the most promising emerging technologies include:

- *Buried contacts:*

  Instead of placing the fingers and busbars on the front of the cell, they are buried in a laser-cut groove inside the solar cell. The change makes the cell surface area larger, enabling it to absorb more sunlight.

- *Back contact cells:*

  The front contact of the cell is moved to the back. The cell's surface area is increased and shadowing losses are reduced. This technology currently provides the highest commercial cell-efficiency available on the market.

- *Pluto™:*

  Developed by Suntech, Pluto™ features a unique texturing process that improves sunlight absorption, even in low and indirect light.

- *HIT™ (Heterojunction with Intrinsic Thin Layer):*

  Developed by Sanyo Electrics, the HIT™ cell consists of a thin, single-crystal wafer sandwiched between ultra-thin amorphous silicon (a-Si) layers. Using both amorphous and single crystal silicon improves efficiency.

TABLE 5
COMMERCIALISED CELL EFFICIENCY RECORDS

Technology	Commercialised cell efficiency record
Mono (back contact)	22%
HIT™	19.8%
Mono (Pluto™)	19%
Nanoparticle ink	18.9%
Mono	18.5%

source: Greentech Media, July 2010.

b. Thin Films

Thin Film modules are constructed by depositing extremely thin layers of photosensitive material on to a low-cost backing such as glass, stainless steel or plastic. Once the deposited material is attached to the backing, it is laser-cut into multiple thin cells.

Thin Film modules are normally enclosed between two layers of glass and are frameless. If the photosensitive material has been deposited on a thin plastic film, the module is flexible. This creates opportunities to integrate solar power generation into the fabric of a building or end-consumer applications.

Four types of Thin Film modules are commercially available:

1. *Amorphous silicon (a-Si)*

   The semiconductor layer is only about 1 μm thick. Amorphous silicon can absorb more sunlight than c-Si structures. However, a lower flow of electrons is generated which leads to efficiencies that are currently in the range of 4 to 8%. With this technology the absorption material can be deposited onto very large substrates (up to 5.7 m^2 on glass), reducing manufacturing costs. An increasing number of companies are developing light, flexible a-Si modules perfectly suitable for flat and curved industrial roofs.

2. *Multi-junction thin silicon film (a-Si/μc-Si)*

   This consists of an a-Si cell with additional layers of a-Si and micro-crystalline silicon (μc-Si) applied onto the substrate. The μc-Si layer absorbs more light from the red and near-infrared part of the light spectrum. This increases efficiency by up to 10%. The thickness of the μc-Si layer is in the order of 3 μm, making the cells thicker but also more stable. The current maximum substrate size for this technology is 1.4 m^2 which avoids instability.

3. *Cadmium telluride (CdTe)*

   CdTe Thin Films cost less to manufacture and have a module efficiency of up to 11%. This makes it the most economical Thin Film technology currently available.

   The two main raw materials are cadmium and tellurium. Cadmium is a by-product of zinc mining. Tellurium is a by-product of copper processing. It is produced in far lower quantities than cadmium. Availability in the long-term may depend on whether the copper industry can optimise extraction, refining and recycling yields.

4. *Copper, indium, gallium, (di)selenide/(di)sulphide (CIGS) and copper, indium, (di)selenide/(di)sulphide (CIS)*

   CIGS and CIS offer the highest efficiencies of all Thin Film technologies. Efficiencies of 20% have been achieved in the laboratory, close to the levels achieved with c-Si cells. The manufacturing process is more complex and less standardised than for other types of cells. This tends to increase manufacturing costs. Current module efficiencies are in the range of 7 to 12%.

   There are no long-term availability issues for selenium and gallium, Indium is available in limited quantities but they are no signs of an incoming shortage. While there is a lot of indium in tin and tungsten ores, extracting it could drive the prices higher. A number of industries compete for the indium resources: the liquid crystal display (LCD) industry currently accounts for 85% of demand. It is highly likely that indium prices will remain high in the coming years.

Typical module power ranges from 60 to 350 W depending on the substrate size and efficiency. There is no common industry agreement on optimal module size for Thin-Film technologies. As a result they vary from 0.6 to 1.0 m² for CIGS and CdTe, to 1.4 to 5.7 m² for silicon-based Thin Films. Very large modules are of great interest to the building sector as they offer efficiencies in terms of handling and price.

FIGURE 9
THIN FILM MODULE

Thin Film CdTe Module.

TABLE 6
SUMMARY OF RECORD EFFICIENCIES OF THIN FILM TECHNOLOGIES

Thin Film technology	Record commercial module efficiency	Record Lab efficiency
a-Si	7.1%	10.4%
a-Si/µ-Si	10%	13.2%
CdTe	11.2%	16.5%
CIGS/CIS	12.1%	20.3%

source: A. Green et al., 2010[3], Lux Research Inc[4], EPIA research

FIGURE 10
STEPS IN MAKING THIN FILM SOLAR CELLS

Thin Film manufacturing processes

Thin Films are manufactured in five common steps:

1. *A large sheet of substrate is produced.* Typically this is made of glass although other materials such as flexible steel, plastic or aluminium are also utilised.
2. *The substrate is coated with a transparent conducting layer (TCO).*
3. *Semiconductor material (absorber) is deposited onto the substrate or superstrate.* This layer can be deposited using many different techniques. Chemical and physical vapour depositions are the most common. For some technologies (usually CIGS, CIS and CdTe), a cadmium sulphide (CdS) layer is also applied to the substrate to increase light absorption.
4. *The metallic contact strips on the back are applied using laser scribing or traditional screen-printing techniques.* The back contact strips enable the modules to be connected.
5. *The entire module is enclosed in a glass-polymer casing.*

For flexible substrates, the manufacturing process uses the roll-to-roll (R2R) technique. R2R enables manufacturers to create solar cells on a roll of flexible plastic or metal foil. Using R2R has the potential to reduce production time, and both manufacturing and transport costs. R2R can be used at much lower temperatures in smaller, non-sterile production facilities.

c. Concentrator photovoltaics

Concentrator photovoltaics (CPV) utilise lenses to focus sunlight on to solar cells. The cells are made from very small amounts of highly efficient, but expensive, semi-conducting PV material. The aim is to collect as much sunlight as possible. CPV cells can be based on silicon or III-V compounds (generally gallium arsenide or GaA).

CPV systems use only direct irradiation.* They are most efficient in very sunny areas which have high amounts of direct irradiation.

The concentrating intensity ranges from a factor of 2 to 100 suns (low concentration) up to 1000 suns (high concentration). Commercial module efficiencies of 20 to 25% have been obtained for silicon based cells. Efficiencies of 25 to 30% have been achieved with GaAs, although cell efficiencies well above 40% have been achieved in the laboratory.

The modules have precise and accurate sets of lenses which need to be permanently oriented towards the Sun. This is achieved through the use of a double-axis tracking system. Low concentration PV can be also used with one single-axis tracking system and a less complex set of lenses.

FIGURE 11
CONCENTRATOR PV MODULES

Concentrator Photovoltaics installed on trackers to follow the sun.

* Sunlight consists of both direct and diffuse irradiation. Diffuse irradiation occurs because of the reflection and refraction of sunlight when it comes into contact with the Earth's atmosphere, clouds and the ground.

d. Third generation photovoltaics

After more than 20 years of research and development, third generation solar devices are beginning to emerge in the marketplace.

Many of the new technologies are very promising. One exciting development is organic PV cells. These include both fully organic PV (OPV) solar cells and the hybrid dye-sensitised solar cells (DSSC).

Suppliers of OPV produced 5 MW of solar cells in 2009. They are moving towards full commercialisation and have announced plans to increase production to more than 1 GW by 2012. Current cell efficiencies are about 6% for very small areas and below 4% for larger areas.

Manufacturers of DSSC produced about 30 MW of solar cells in 2009. By 2012, 200 MW are expected to be produced. In 2009, some low-power applications were already commercially available. Efficiencies achieved at the lab across a very small area are in the range of 8 to 12%. Commercial applications still have efficiency below 4%.

For both technologies, manufacturing costs is constantly decreasing and is expected to reach 0.50€/W by 2020. This is enabled by the use of the R2R manufacturing process and standard printing technologies. The major challenges for this sector are the low device efficiency and their instability in the long-term.

Third generation technologies that are beginning to reach the market are called "emerging" and can be classified as:

- Advanced inorganic Thin Films such as spherical CIS and Thin-Film polycrystalline silicon solar cells.
- Organic solar cells which include both fully organic and hybrid dye-sensitised solar cells.
- Thermo-photovoltaic (TPV) low band-gap cells which can be used in combined heat and power (CHP) systems.

Third generation PV products have a significant competitive advantage in consumer applications because of the substrate flexibility and ability to perform in dim or variable lighting conditions. Possible application areas include low-power consumer electronics (such as mobile phone rechargers, lighting applications and self-powered displays), outdoor recreational applications, and BIPV.

"Third generation solar devices are beginning to emerge in the market-place."

In addition to the emerging third generation PV technologies mentioned, a number of novel technologies are also under development:

- Active layers can be created by introducing quantum dots or nanotechnology particles. This technology is likely to be used in concentrator devices.
- Tailoring the solar spectrum to wavelengths with maximum collection efficiency or increasing the absorption level of the solar cell. These adjustments can be applied to all existing solar cell technologies.

Table 7 shows the efficiency ranges of currently available commercial technologies. The area that needs to be covered to generate 1 kWp is also shown.

TABLE 7
OVERVIEW OF COMMERCIAL PV TECHNOLOGIES

Commercial Module Efficiency

Technology	Thin Film					Crystalline Silicon		CPV
	(a-Si)	(CdTe)	CI(G)S	a-Si/μc-Si	Dye s. cells	Mono	Multi	III-V Multi-junction
Cell efficiency	4-8%	10-11%	7-12%	7-9%	2-4%	16-22%	14-18%	30-38%
Module efficiency						13-19%	11-15%	~25%
Area needed per KW (for modules)	~15m²	~10m²	~10m²	~12m²		~7m²	~8m²	

source: EPIA 2010. Photon international, March 2010, EPIA analysis. Efficiency based on Standard Test conditions.

e. Historical and future evolution

Crystalline silicon technologies have dominated the market for the last 30 years. Amorphous silicon (a-Si) has been the technology most used for consumer applications (e.g. calculators, solar watches) due to its lower manufacturing cost while c-Si technologies have been used mainly in both stand-alone and on-grid systems.

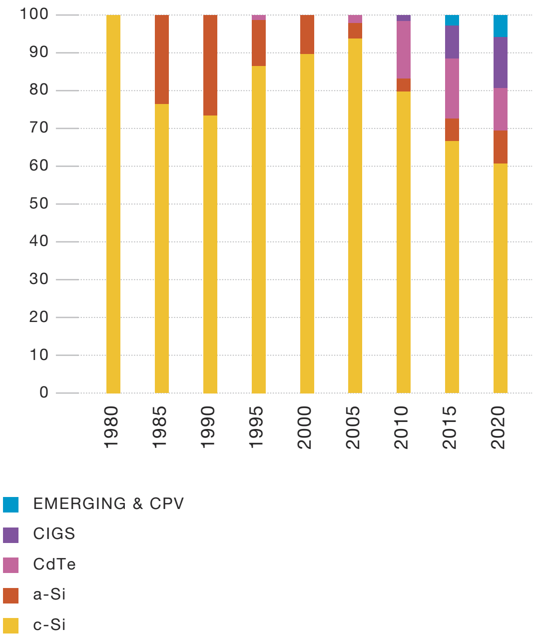
Within the c-Si technologies, mono- and multi-crystalline cells are produced in fairly equal proportion. However, multi-crystalline cells are gaining market share. Ribbon c-Si represents less than 5% of the market.

While a-Si has been the preferred clear Thin-Film technology used over the past three decades, its market share has decreased significantly compared to more advanced and competitive technologies. For example, CdTe has grown from a 2% market share in 2005 to 13% in 2010.

Technologies such as Concentrator PV (CPV), organics and dye-sensitised solar cells are beginning to enter the market. They are expected to achieve significant market share in the next few years, capturing around 5% of the market by 2020.

EPIA expects that by 2020 silicon wafer-based technologies will account for about 61% of sales, while Thin Films will account for around 33%. CPV and emerging technologies will account for the remaining 6%.

FIGURE 12
HISTORICAL EVOLUTION OF TECHNOLOGY MARKET SHARE AND FUTURE TRENDS
%



source: Historical data (until 2009) based on Navigant Consulting. Estimations based on EPIA analysis.

2.3. The PV value chain

The PV value chain is typically divided into a number of upstream and downstream activities.

a. The upstream part of the value chain

Upstream activities include all steps from the manufacturing of equipment and materials to the production of modules, inverters and other balance of system (BOS) elements. Supply of certain materials and equipment is concentrated in the hands of a few very large players. For example:

- About 75 companies are active in polysilicon production. However, in 2009, more than 90% of the total supply was manufactured by seven major players from Europe, the USA and Japan. Nowadays many Chinese companies are ramping-up capacity and are expected to account for a larger share of the polysilicon market over the next few years[5].
- The market is more segmented and competitive in the area of wafer and cell manufacturing. More than 200 companies are active in this sector. Around 1,000 companies produced c-Si modules in 2010.
- Also with respect to inverter production, the top ten companies produce more than 80% of the inverters sold on the market, even though there are more than 300 companies active in this segment.
- In the case of Thin Film module manufacturing, about 160 companies are active. About 130 of these companies produce silicon-based Thin Films. Around 30 produce CIGS/CIS Thin Films, while a handful of companies are active in CdTe.
- There are currently more than 50 companies that offer turnkey c-Si production lines. Less than 30 manufacturers provide the PV industry with Thin Film production lines[6].

TABLE 8
NUMBER OF COMPANIES WORLD-WIDE IN THE THIN FILM VALUE CHAIN

	CdTe	a-Si	a-Si/µ-Si	CI(G)S
Number of companies (as of 2009)	4	131		30
Production in 2009	1,100 MW	< 300 MW	< 400 MW	< 200 MW

source: Energy Focus, Photon, JRC and EPIA.

TABLE 9
NUMBER OF COMPANIES WORLD-WIDE IN THE CRYSTALLINE SILICON VALUE CHAIN
2009

2009	SILICON	INGOTS	WAFERS	CELLS	MODULES
Number of companies:	75	208		239	988
Production capacity:	130,000 TONNES	15,000 MW		18,000 MW	19,000 MW
Effective production:	90,000 TONNES	10,000 MW		9,000 MW	7,000 MW

source: ENergy Focus, Photon, JRC and EPIA.

b. The downstream part of the value chain

The downstream part of the value chain includes:

- Wholesalers who function as intermediaries between the manufacturers and the installer or end customer.
- System developers who offer their services in building turnkey PV installations.
- Owners of PV installations that sell their power to the grid.

"The consolidation of the PV sector is likely to end the current fragmentation and facilitate the emergence of larger industry players."

Many small to medium enterprises (SMEs) are involved in these activities and most are locally organised. As such, this part of the value chain is very fragmented and difficult to track.

The engineering, procurement and construction (EPC) companies involved in the development of PV systems are experienced in obtaining finance, selecting the correct components and advising on a suitable location and system design. Most are familiar with local legal, administrative and grid connection requirements. They can guide the PV system owner through the different types of support mechanisms. EPC companies also physically install the PV system using either internal personnel or qualified subcontractors. As a result of the latest technological developments in BIPV and CPV, some developers have developed specific expertise and are now specialising in these areas.

PV systems have a typical lifespan of at least 25 years. At the end of its life, the system is decommissioned and the modules are recycled. In Europe, the PV CYCLE association established a voluntary take back scheme with established already a large number of collection points in different EU countries where PV modules are collected are sent to specialised PV recycling facilities for recycling. The recycled materials (such as glass, aluminium, semiconductor materials, ...) can then be re-used for the production of PV or other products. For more information about PV CYCLE, see Solar benefits and sustainability in part 6[7].

c. Consolidation trends in the solar industry

For many years, most companies have grown by specialising in a single activity within the value chain (especially in the case of c-Si technologies). These companies are known as "pure players". However, there has been an increasing tendency to integrate additional production steps into the same company. Known as "integrated players", these companies cover a number of activities ranging from silicon to module production. Companies that cover all steps in the process are known as "fully integrated players". Both approaches present benefits and drawbacks. On the one hand, the "pure players" may be more competitive in their core activity, but they can be highly dependent on standardisation efforts and their suppliers. The "integrated players" on the other hand have more security over their supply chain and are generally more flexible financially. However, their research and development expenditure cannot be affected to one specific part of the value chain.

While some of the top polysilicon producers are still pure players, many are also moving into the wafer production business. Most cell manufacturers secure sales through the production of modules. Today, many large c-Si PV companies are integrated players and some have, or intend to, become fully integrated. The Thin Film manufacturing sector is not segmented to the same extent as the entire manufacturing process is normally carried out at a single facility.

Integration does not only occur in the upstream part of the value chain. About 30% of module manufacturers are currently active in the development of complete PV systems.* Moreover, some system developers are also starting to own systems and sell electricity to grid operators. This is known as the utility concept and the business model is gaining support. This is especially true in the US, where an increasing number of module producers are entering the electricity generation market.

In recent years there have been a number of mergers and acquisitions amongst PV companies. A total of 61 such transactions were reported in the solar industry between July 2008 and March 2009[8]. This consolidation is likely to end the current fragmentation of the solar PV market and facilitate the emergence of larger industry players. Companies having large production capacities at their disposal will benefit from the consequent economies of scale. This will result into a further decrease of the manufacturing costs.

* This calculation is based on the membership of EPIA, which can be considered is a representative sample of all the players in the PV industry.

SOLAR COST AND COMPETITIVENESS: TOWARDS GRID PARITY 3

3. SOLAR COST AND COMPETITIVENESS: TOWARDS GRID PARITY

The cost of PV systems has been constantly decreasing over time. Grid parity (traditionally defined as the point in time where the generation cost of solar PV electricity equals the cost of conventional electricity sources) is already achieved for some specific applications in some parts of the world. Competitiveness is just around the corner.

This section outlines the factors that will affect the PV industry's ability to achieve competitiveness with conventional electricity producers and retail electricity prices.

"Over the past 30 years the PV industry has achieved impressive price decreases."

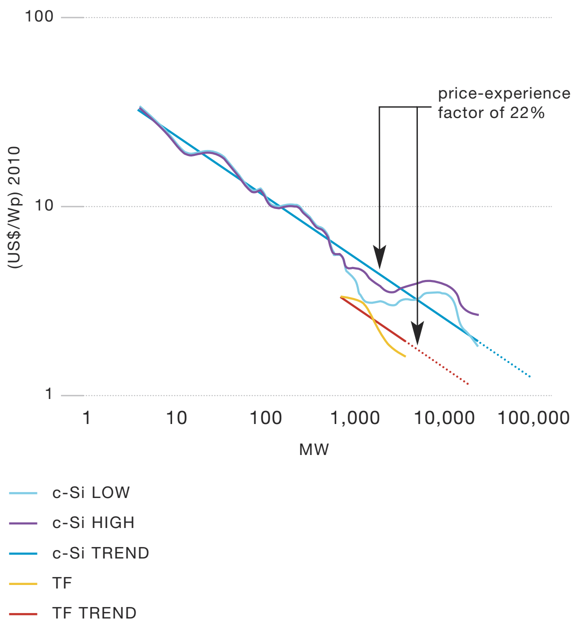
3.1. Price competitiveness of PV

a. PV module price

Over the past 30 years the PV industry has achieved impressive price decreases. The price of PV modules has reduced by 22% each time the cumulative installed capacity (in MW) has doubled (see Figure 13).

The decrease in manufacturing costs and retail prices of PV modules and systems (including electronics and safety devices, cabling, mounting structures, and installation) have come as the industry has gained from economies of scale and experience. This has been brought about by extensive innovation, research, development and ongoing political support for the development of the PV market.

FIGURE 13
PV MODULE PRICE EXPERIENCE CURVE
US$/Wp & MW



source: Navigant Consulting, EPIA.

Large ground-mounted PV system in Spain.

Large ground-mounted PV system in Spain.

b. PV system price

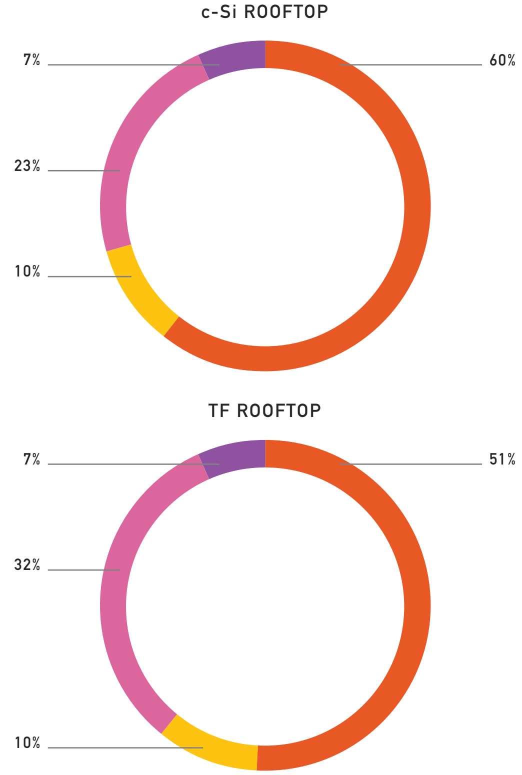
As explained above, the price of PV modules has decreased substantially over the past 30 years. The price of inverters has followed a similar price learning curve to that of PV modules. Prices for some balance of systems (BOS) elements have not decreased with the same pace. The price of the raw materials used in these elements (typically copper, steel and stainless steel) has been more volatile. Installation costs have decreased at different rates depending on the maturity of the market and type of application. For example, some mounting structures designed for specific types of installations (such as BIPV) can be installed in half the time it takes to install a more complex version. This of course lowers the total installation costs.

Reductions in prices for materials (such as mounting structures), cables, land use and installation account for much of the decrease in BOS costs. Another contributor to the decrease of BOS and installation-related costs is the increase in efficiency at module level. More efficient modules imply lower costs for balance of system equipment, installation-related costs and land use.

Figure 14 shows as an example the price structure of PV systems for small rooftop (3 kWp) installations in mature markets. In only 5 years time, the share of the PV modules in the total system price has fallen from about 60-75% to as low as 40-60%, depending on the technology. The inverter accounts for roughly 10% of the total system price. The cost of engineering and procurement makes up about 7% of the total system price. The remaining costs represent the other balance of system components and the cost of installation.

The forecasts for prices of large PV systems are summarised in Figure 15. In 2010, the range represents prices for large systems in Germany. The rate at which PV system prices will decrease depends on the installed PV capacity. By 2030 prices could drop to between €0.70/Wp to €0.93/Wp. By 2050, the price could be even as low as €0.56/Wp.

FIGURE 14
COSTS OF PV SYSTEM ELEMENTS
%

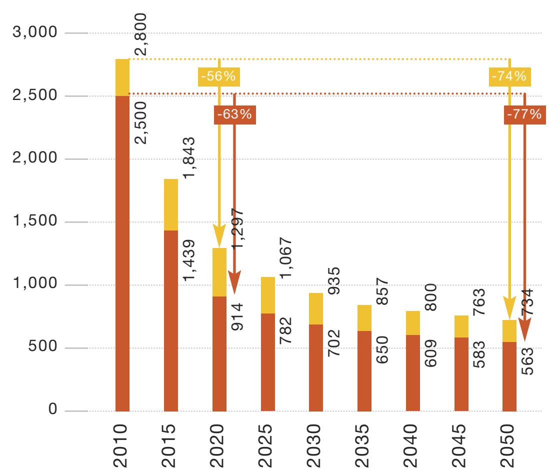


MODULE PRICE
INVERTER PRICE
BOS+INSTALLATION
ENGINEERING & PROCUREMENT

source: EPIA, EuPD, Navigant Consulting, Photon Consulting, SolarBuzz.
note: Values based on mature markets.

"By 2030 prices could drop to between €0.70/Wp to €0.93/Wp."

FIGURE 15
EVOLUTION OF PRICES OF LARGE PV SYSTEMS
€/KWp



ACCELERATED SCENARIO
PARADIGM SHIFT SCENARIO

source: Greenpeace/EPIA Solar generation VI 2010.

c. PV electricity generation cost

The indicator used to compare the cost of PV electricity with other sources of electricity generation is the cost per kilowatt hour (kWh). The Levelised Cost of Electricity (LCOE) is a measurement tool that is used to compare different power generation plants. It covers all investment and operational costs over the system lifetime, including the fuels consumed and replacement of equipment.

Using LCOE makes it possible to compare a PV installation with a power plant utilising a gas or nuclear fuel source. Each system has very different lifetimes and investment costs which are taken into account for the LCOE calculation. The LCOE takes this into account. Moreover, for PV systems, the LCOE considers the location of the system and the annual irradiation. For example, Scandinavia typically receives 1,000 kWh/m² of sunlight. In southern Europe the irradiation can go over 1,900 kWh/m², while in the Middle East and in sub-Saharan Africa sunlight irradiation can reach up to 2,200 kWh/m².

"Expected generation costs for large, ground-mounted PV systems in 2020 are in the range of €0.07 to €0.17/kWh across Europe.

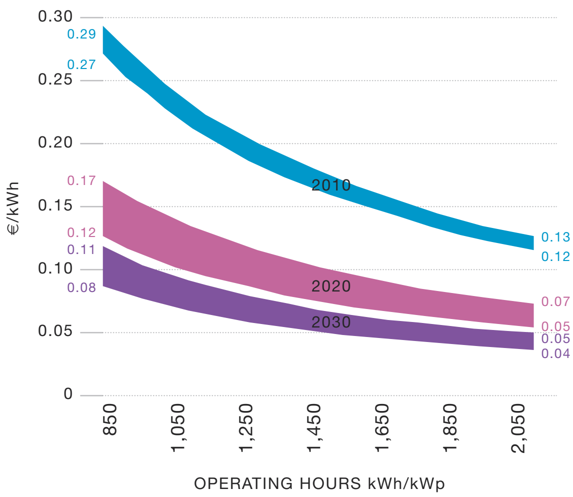
Figure 16 shows current PV electricity generation costs for large ground-mounted systems. The data is based on the most competitive turnkey system price and a typical system performance ratio (the amount of kWh that can be produced per kWp installed) of 85%.

For large ground-mounted systems, the generation costs in 2010 range from around €0.29/kWh in the north of Europe to €0.15/kWh in the south and as low as €0.12/kWh in the Middle East.

According to EPIA estimations those rates will fall significantly over the next decade. Expected generation costs for large, ground-mounted PV systems in 2020 are in the range of €0.07 to €0.17/kWh across Europe. In the sunniest Sunbelt countries the rate could be as low as €0.04/kWh by 2030.

EPIA forecasts that prices for residential PV systems and the associated LCOE will also decrease strongly over the next 20 years. However, they will remain more expensive than large ground-mounted systems.

FIGURE 16
LEVELISED COST OF ELECTRICITY (LCOE)
€/KWh



source: Greenpeace/EPIA Solar generation VI 2010.

d. Electricity price evolution

Costs for the electricity generated in existing gas and coal-fired power plants are constantly rising. This is a real driver for the full competitiveness of PV. Energy prices are increasing in many regions of the world due to the nature of the current energy mix. The use of finite resources for power generation (such as oil, gas, coal and uranium), in addition togrowing economic and environmental costs will lead to increased price for energy generated from fossil and nuclear fuels.

An unfair advantage

Conventional electricity prices do not reflect actual production costs. Many governments still subsidise the coal industry and promote the use of locally-produced coal through specific incentives. The European Union invests more in nuclear energy research (€540 million yearly in average over five years through the EURATOM treaty) than in research for all renewable energy sources, smart grids and energy efficiency measures combined (€335 million yearly in average over seven years through the Seventh framework program). Actually today in Europe, fossil fuels and nuclear power are still receiving four times the level of subsidies that all types of renewable energies do[9].*

Given the strong financial and political backing for conventional sources of electricity over several decades, it is reasonable to expect continuing financial support for renewable energy sources, such as wind and solar, until they are fully competitive.

PV power plant in Darro, Spain.

External costs of conventional electricity generation

The external costs to society incurred from burning fossil fuels or nuclear power generation are not currently included in most electricity prices. These costs are both local and, in the case of climate change, global. As there is uncertainty about the magnitude of these costs, they are difficult to quantify and include in the electricity prices.

The market price of CO_2 certificates remains quite low (around €14/tonne CO_2 end of 2010)[10] but is expected to rise in the coming decades.

On the other side, the real cost of CO_2 was calculated at €70/tonne CO_2 from 2010 to 2050[11].

Other studies consider even higher CO_2 costs, up to US$160/tonne CO_2[12].

Taking a conservative approach, the cost of carbon dioxide emissions from fossil fuels could be in the range of US$10 to US$20/tonne CO_2. PV reduces emissions of CO_2 by an average of 0.6 kg/kWh. The resulting average cost avoided for every kWh produced by solar energy will therefore be in the range of US$0.006 to US$0.012/kWh.

The *Stern Review on the Economics of Climate Change*, published by the UK government in 2006, concluded that any investment made now to reduce CO_2 emissions will be paid back in the future as the external costs of fossil fuel consumption will be avoided.

"Conventional electricity prices do not reflect actual production costs."

* Globally, the IEA has recently estimated fossil fuel subsidies at US$312bn, The European Energy Association: EEA Technical report 1/2004 (the most recent figures for the EU (EU15)) put fossil fuel subsidies at €21.7bn compared to €5.3bn for renewable energy.

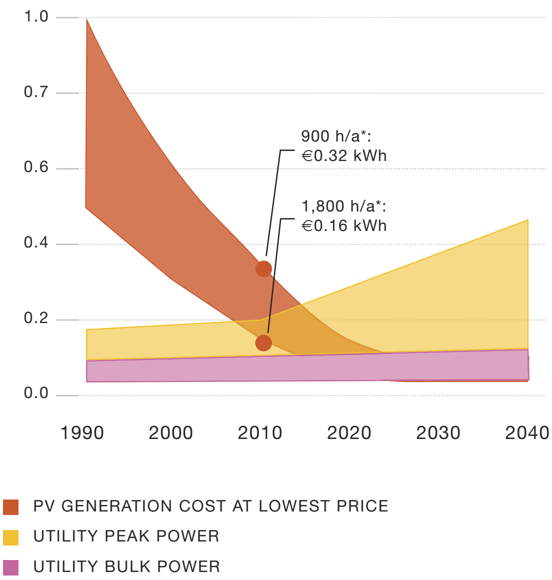
PV generation cost is decreasing, electricity prices are increasing

In many countries with high electricity prices and high Sun irradiation, the competitiveness of PV for residential systems could already be achieved with low PV system costs and the simplification of administrative procedures.

Figure 17 shows the historical development and future trends of retail electricity prices compared to the cost of PV electricity. The upper and lower parts of the PV curve represent northern Europe and southern of Europe respectively. The utility prices for electricity are split into peak power prices (usually during the day) and bulk power. In southern Europe, solar electricity is already or will become cost-competitive with peak power within the next few years. Areas with less irradiation, such as central Europe, will reach this point before 2020. The trend is similar for most regions world-wide. For example, in developing countries electricity prices are rising due to higher demand whereas PV electricity generation cost is already low and PV often more cost-competitive.

"In many countries with high electricity prices and high sun irradiation, the competitive-ness of PV for residential consumers could already be achieved with low PV system costs and the simplification of administrative procedures."

FIGURE 17
DEVELOPMENT OF UTILITY PRICES AND PV GENERATION COSTS
€/KWh



*h/a: Hours of sun per annum. 900 h/a corresponds to northern countries of Europe. 1,800 h/a corresponds to southern countries of Europe.

source: EPIA.

e. Market segments for PV

PV consumer applications do not benefit from any support mechanism and have been on the market for many years. They have already proven their competitiveness. Consumer applications provide improved convenience, and often replace environmentally non friendly batteries.

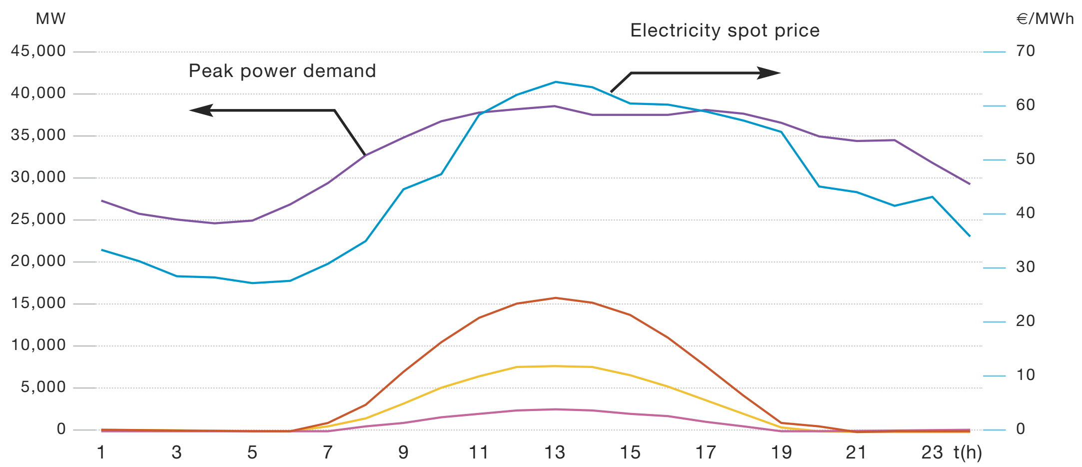
Off-grid applications are already cost-competitive compared to diesel generators, which have high fuel costs, or the extension of the electricity grid, which requires a considerable investment.

Grid-connected applications are not yet competitive everywhere. A distinction must be made between decentralised residential applications and the more centralised utility-scale ground-mounted systems.

Large utility-scale PV systems provide electricity at a price that cannot be directly compared with residential electricity prices but with the cost of conventional (centralised) sources of electricity. The electricity generated in a large PV system is not consumed directly, but sold on the electricity spot market where it competes directly with other sources of electricity. The evolution of prices on the spot market is linked to supply and demand factors. These prices are also closely related to the energy mix currently used for power generation.

The competitiveness of large-scale PV systems will then be reached when the cumulative benefit of selling PV electricity on spot markets matches that of conventional electricity sources over the course of a full year. In sunny countries, PV can compete during the midday peak when gas powered plants or specific peak-generation devices are used. Figure 18 shows three scenarios for the deployment of PV electricity, the electricity demand and electricity spot price in Spain during the summer. It clearly shows that PV produces electricity during moments of peak demand when the spot prices are the highest.

FIGURE 18
PEAK LOAD DEMAND AND ELECTRICITY SPOT PRICE IN SPAIN ON 18 JULY 2007



- PV INSTALLED: 20,000 MWp
- PV INSTALLED: 10,000 MWp
- PV INSTALLED: 3,137 MWp (REAL CAPACITY INSTALLED IN SPAIN IN 2008)

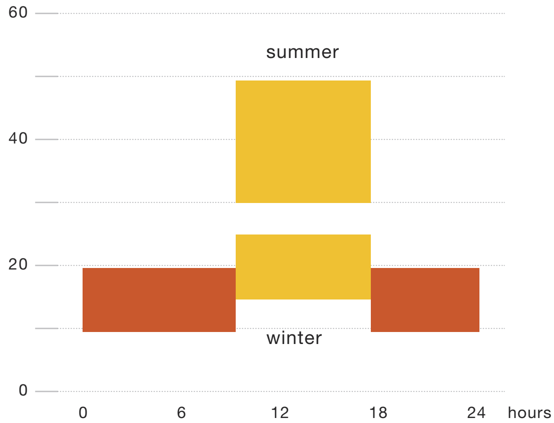
source: OMEL/UCTE. Sunrise project based on measured data.

For the residential segment, EUROSTAT estimates electricity prices in the EU-27 were in the range of €0.09 and €0.27/kWh (including taxes) during the second half of 2010. This is lower than the cost of generating PV electricity. However, in 2010 the average household electricity price in Europe was 5% higher than in the second half of 2007. As a comparison, between 2007 and 2009, the cost of PV electricity dropped by almost 40% to an average of €0.22/kWh.

Care must be taken when comparing the cost of PV electricity across larger regions as there might be huge differences between countries and even within the same country. In some countries, electricity prices are more responsive to demand peaks. In California, Japan and some EU countries, electricity prices increase substantially during the day. This is particularly true in the summer, as demand for electricity is the highest during this period. In other countries, the electricity prices are the highest during winter periods.

In California however where during the summer days the electricity price is substantially higher than during winter, PV is already competitive during these summer peaks. The summer is also the period when the electricity output of PV systems is at its highest. PV therefore serves the market at exactly the point when demand is the greatest. Figure 19 shows the significant variation between regular and peak prices for household electricity in the Californian market.

FIGURE 19
RANGE OF HOUSEHOLD ELECTRICITY PRICES IN CALIFORNIA
$ct/kWh



LOW CONSUMPTION PERIOD
PEAK CONSUMPTION PERIOD

source: Hyde, BSW-Solar, 2006.

Glass roof, a-si amorphous silicon thin film integrated in glass.

Workers installing PV modules.

3.2. Factors affecting PV system cost reduction

The solar industry is constantly innovating in order to improve products efficiency and make materials use more environmentally friendly. However, the cost of PV systems also needs to be reduced to make them competitive with conventional sources of electricity. EPIA believes this can be achieved through:

- Technological innovation
- Production optimisation
- Economies of scale
- Increased performance ratio of PV
- Extended lifetime of PV systems
- Development of standards and specifications.

a. Technological innovation

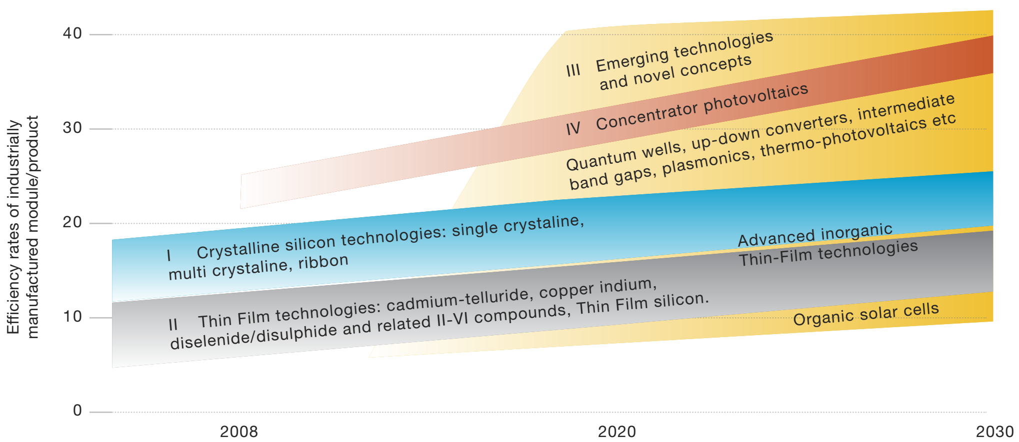
One of the main ways the industry can reduce manufacturing and electricity generation costs is through efficiency. When PV modules are more efficient, they use less material (such as active layers, aluminium frames, glass and other substrates). This requires less energy for manufacturing and also lowers the balance of system (BOS) costs. With higher-efficiency modules, less surface area is needed. This reduces the need for mounting structures, cables, and other components. All of these savings affect the final generation cost.

However, efficiency is not the only factor that needs to be studied. The PV sector has a primary goal to introduce more environmentally friendly materials to replace scarce resources such as silver, indium and tellurium, and materials such as lead and cadmium. Lead-free solar cells are already available in the market. However, a number of manufacturers claim that by 2012 the cells are expected to be lead-free without performance losses. Alternatives to silver will be on the market by 2013 to 2015[13].

Another key area of research aims to reduce material usage and energy requirements. The PV sector is working to reduce costs and energy payback times by using thinner wafers (see Table 9), more efficient wafers, and polysilicon substitutes (for example, upgraded metallurgical silicon). In the field of Thin Film technologies the top priorities are to increase the substrate areas and depositions speeds while keeping material uniformity.

"The cost of PV systems needs to be reduced to make them competitive with conventional sources of electricity."

FIGURE 20
PHOTOVOLTAIC TECHNOLOGY STATUS AND PROSPECTS
%



source: IEA PVPS.

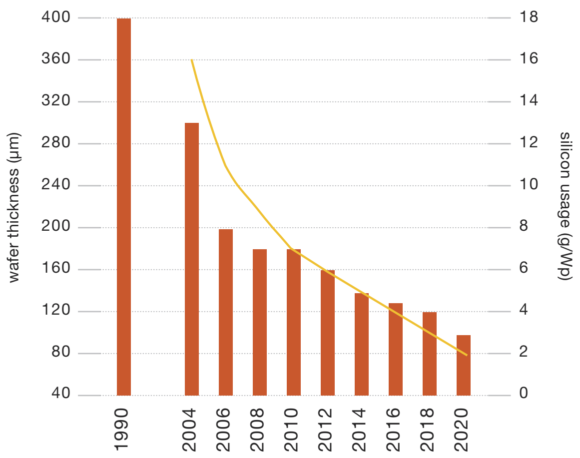
Wafer thickness and dimension

A good example of technology evolution is the wafer dimension. The method of producing the wafers needs to be modified so that thinner and larger wafers can be handled. This requires changes to the cell process and the technology used to build the module. For example, the contacts will probably need to be moved to the back of the cell. Larger solar cells require modifications to other system components such as the inverter.

Wafer thickness is expected to be reduced from 180 to 200 μm today, to less than 100 μm by 2020. Reducing wafer thickness and kerf losses also reduces silicon usage. Currently solar cell manufacturing techniques use about 7 g/W of silicon. This could drop to less than 3 g/W by 2020 (see Figure 21). Larger wafer sizes are expected from about 2015.

"Capacity increases, combined with technological innovation and manufacturing optimisation, have radically reduced the cost per unit."

FIGURE 21
c-Si SOLAR CELL DEVELOPMENT
wafer thickness in μm & silicon usage in g/Wp



source: EU PV Technology Platform Strategic Research Agenda, C-Si Roadmap ITPV, EPIA roadmap 2004.

b. Production optimisation

As companies scale-up production, they use more automation and larger line capacities. Improved production processes can also reduce wafer breakage and line downtime (periods of time when the production line is stopped for maintenance or optimisation). Production efficiency improvements enable the industry to reduce the costs of solar power modules.

c. Economies of scale

As with all manufacturing industries, producing more products lowers the cost per unit. Economies of scale can be achieved at the following supply and production stages:

- Bulk buying of raw materials
- Obtaining more favourable interest rates for financing
- Efficient marketing.

Ten years ago, cell and module production plants could remain viable by producing enough solar modules to generate just a few MW of power each year. Today's market leaders have plants with capacity above 1 GW, several hundred times than a decade ago. Capacity increases, combined with technological innovation and manufacturing optimisation, have radically reduced the cost per unit. The decrease is approximately 22% each time the production output is doubled (see Figures 13 and 22).

d. Increased performance ratio of PV systems

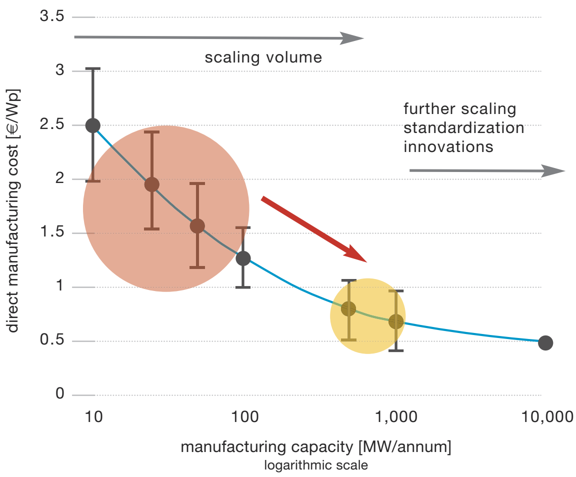
The cost per kWh is linked to PV system quality and reflected in its performance ratio (the amount of electricity generated by the module compared to the electricity measured on the AC side of the meter). The lower the losses between the modules and the point at which the system feeds into the grid, the higher the performance ratio. Typically, system performance ratios are between 80 and 85%. If losses can be reduced further, the cost per kWh can be lowered. Monitoring of systems enables manufacturers and installers to quickly detect faults and unexpected system behaviour (for example, due to unexpected shadows). This helps to maintain high performance ratios of PV systems.

e. Extended life of PV systems

Extending the lifetime of a PV system increases overall electrical output and improves the cost per kWh. Most producers give module performance warranties for 25 years, and this is now considered the minimum lifetime for a PV module.

The component that affects product lifetime the most is the encapsulating material. Intense research is being carried out in this field. However, the industry is cautious about introducing substitute materials because they need to be tested over the long-term. Today, PV modules are being produced with lifetimes of at least 25 years. The target is to reach lifetimes of 40 years by 2020 (see Table 10).

FIGURE 22
COST POTENTIAL FOR THIN FILM TECHNOLOGIES BASED ON PRODUCTION VOLUME AND MODULE EFFICIENCY
€/Wp



source: EU PV Technology Platform.

"When widely accepted by the industry standards, they contribute to reduce costs in design, production and deployment."

TABLE 10
PV TECHNOLOGY – 10-YEAR OBJECTIVES

Solar Europe Industry Initiative: PV technology roadmap for commercial technologies		2007	2010	2015	2020
Turnkey price large systems (€/Wp)*		5	2.5-3.5	2	1.5
PV electricity generation cost in Southern EU (€/kWh)**		0.30-0.60	0.14-0.20	0.10-0.17	0.07-0.12
Typical PV module efficiency range (%)	Crystalline silicon	13-18%	15-19%	16-21%	18-23%
	Thin Films	5-11%	6-12%	8-14%	10-16%
	Concentrators	20%	20-25%	25-30%	30-35%
Inverter lifetime (years)		10	15	20	>25
Module lifetime (years)		20-25	25-30	30-35	35-40
Energy payback time (years)		2-3	1-2	1	0.5
Cost of PV + small-scale storage (€/kWh) in Southern EU (grid-connected)***		-	0.35	0.22	<0.15

note: Numbers and ranges are indicative because of the spread in technologies, system types and policy frameworks.
* The price of the system does not only depend on the technology improvement but also on the maturity of the market (which implies industry infrastructure as well as administrative costs).
** LCOE varies with financing cost and location. Southern EU locations considered here range from 1,500 (e.g. Toulouse) to 2,000 kWh/m² per year (e.g. Siracusa).
*** Estimated figures based on EUROBAT roadmaps.

source: Solar Europe Industry Initiative Implementation Plan 2010-2012, Strategic Research Agenda.

f. Development of standards and specifications

The development of standards and consistent technical specifications helps manufacturers to work towards common goals. When widely accepted by the industry standards, they contribute to reduce costs in design, production and deployment. Standards also foster fair and transparent competition as all actors in the market must play by the same rules.

The industry targets for PV technology development in the period 2010 to 2020 are summarised in Table 10 and Figure 20.

"Next generation Photovoltaic present the greatest potential in cost reduction."

g. Next generation technologies

Next generation photovoltaics present the greatest potential in cost reduction. The main research activities in this field concentrate on increasing stability over the time and increasing the solar cell area. The industry targets for PV technology development of next generation technologies in the period 2010 to 2020 are summarised in Table 11 and Figure 20.

TABLE 11

MAJOR 10-YEAR OBJECTIVES AND MILESTONES FOR EMERGING AND NOVEL TECHNOLOGIES

Solar Europe Industry Initiative: PV technology roadmap for next generation technologies		2010	2015	2020
Commercial module cost for emerging technologies* (€/Wp)		N.A.	N.A	0,5-0,8
Typical PV module efficiency range (%)	Emerging technologies*	<7-12% Lab-scale***	10-15% Lab-scale***	>10% Commercial*****
		<5% Pre-Commercial****	<10% Pre-Commercial****	
	Novel technologies**	N.A	N.A.	>25%
Performance stability (years)		<5	5-15	>15

note: Numbers and ranges are indicative because of the spread in technologies, system types and policy frameworks.
* Emerging technologies include organic photovoltaics, dye-sentisised solar cells and advanced inorganic Thin Film technologies.
** Novel technologies include quantum technologies and technologies using nanoparticles.
*** Lab-scale: Cell Area below $10cm^2$.
**** Pre-commercial: Sub-module area (combination of ~10 cells) below $0.1m^2$ for consumer application.
***** Commercial: real scale module size $>0.5m^2$.

source: Solar Europe Industry Initiative Implementation Plan 2010-2012, Strategic Research Agenda.

3.3. PV in electricity networks and energy markets

With the development of on-grid systems, the integration of PV in electricity networks and energy markets has become a major challenge. This integration brings both benefits and issues for the PV sector.

a. High penetration of PV in the grids

In a typical electricity grid, electricity flows from the generation plants to the consumption devices via a distribution network. Electricity can also be transported between different areas to meet demand.

With small amounts of PV connected to the grid, most of the electricity produced is consumed at the site or in the immediate neighbourhood. As more PV electricity is added to the system, the transport network will also be used.

A recent study[14] has evaluated how much PV can be integrated into distribution networks without changing the network topology. The study found that Germany, which by end 2010 had more than 16,000 MW of PV electricity integrated into its network, is still a long way from exceeding grid limitations. Of course, local bottlenecks exist and the number will rise with the increasing penetration but this is not the general case. The study recommends that PV could account for up to 20% of supply without affecting the grid, under some technical developments.

Managing variability

Electricity network managers must ensure that the voltage and frequency of the electricity in the grid stays within predefined boundaries. To achieve this, managers must be able to forecast expected production and consumption each day to enable them to balance variations. PV electricity is, by nature, variable as it depends on Sun irradiation. For electricity network managers, predicting the available solar irradiation is generally quite accurate and easier than predicting wind patterns.

In large regions, the output from PV panels can be predicted easily and the network manager can plan how to best balance power supply. Local variability is smoothed out on the regional scale.

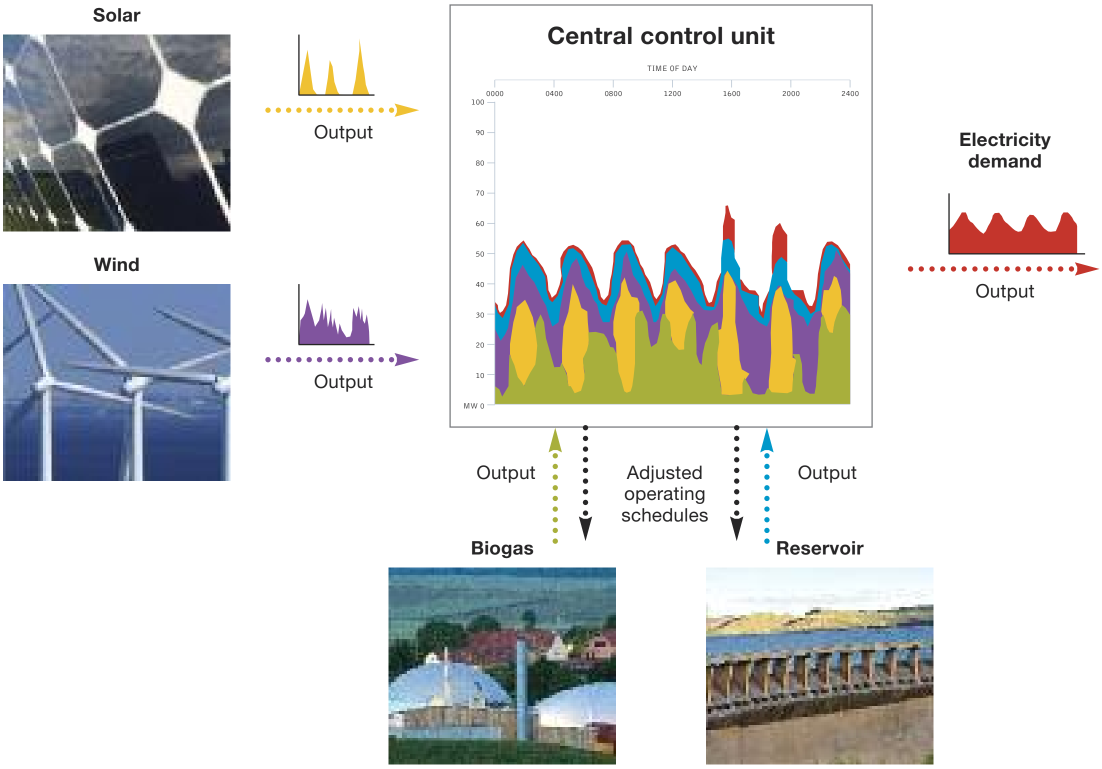
On an even larger scale, for example across a country, integrating large amounts of PV electricity into the grid requires network managers to dispatch balancing power in time to meet demand. Recent studies confirm that including a combination of different renewable energy sources on a large scale (such as across the European Union) can compensate for intermittent input from solar and wind sources. This enables managers to provide both peak load generation and also medium and base load. Network managers must also be able to dispatch part of the electricity load throughout the day (called Demand Side Management) to cope with the extra electricity coming from variable renewable sources.

"the integration of PV in electricity networks and energy markets has become a major challenge."

Virtual power plants (VPP)

Millions of small electricity generation devices, such as PV panels, cannot be managed in the same way as a handful of large power plants. The virtual power plant concept groups together large numbers of small- and medium-sized plants in the grid management system. This enables network operators to easily manage the electricity coming into the grid[15].

FIGURE 23
PRINCIPLE OF A 100% RENEWABLE POWER SUPPLY SYSTEM



source: www.solarserver.de/solarmagazin/anlagejanuar2008_e.html

b. From centralised to decentralised energy generation

In most developed countries electricity generation has been mainly centralised. However, many countries are now moving toward largely decentralised electricity generation. With wind turbines, small and medium biomass plants and solar power plants, electricity can be produced in a large number of places anywhere on the network.

The decentralised model means that electricity grid operators (DSO,* TSO**) must re-think how they guarantee the quality of the electricity delivery. This section discusses the main areas that require improvement and development.

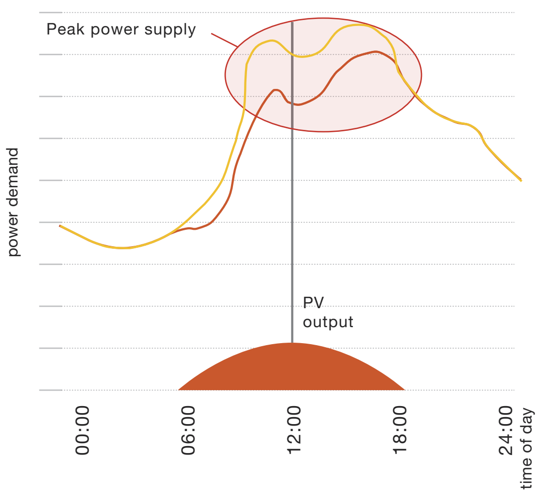
Peak load shaving

The daily electricity consumption curve has one peak at midday (in sunny countries) and sometimes (mainly in northern countries) a second peak in the evening. The pattern depends on climate conditions but the trend is clear. Figures 24 and 25 show how PV can play a key role effect on the midday peak. Known as peak shaving, the technique reduces the high power demand on the network at midday. Using storage systems, it is also possible to move some of the electricity produced during the day so the evening peak can also be shaved.

From smart grids to e-mobility

New renewable energy sources, decentralisation, and new ways of consuming electricity which modify load patterns require us to re-think grid management. The use of heat-pumps for heating (and cooling) and the future needs of electric vehicles (EVs) and petrol-hybrid electric vehicles (PHEVs) will require operators to improve their grids.

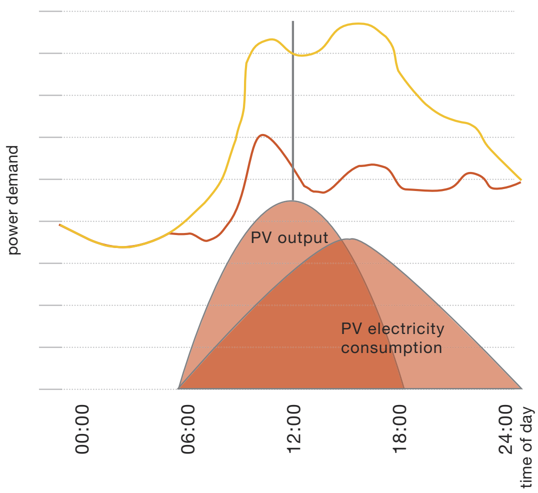
FIGURE 24
PEAK SHAVING NORTHERN EUROPE



ELECTRICITY DEMAND
ELECTRICITY TO BE SUPPLIED BY OTHER SOURCES THAN PV

source: IEA-PVPS, Task 10.

FIGURE 25
PEAK SHAVING NORTHERN EUROPE WITH STORAGE



ELECTRICITY DEMAND
ELECTRICITY TO BE SUPPLIED BY OTHER SOURCES THAN PV

source: IEA-PVPS, Task 10.

"Many countries are now moving toward largely decentralised electricity generation."

* Distribution System Operator: the operator of the low and medium voltage electricity grid.
** Transport System Operator: the operator of the medium and high voltage electricity grid.

Super grid

The intermittent nature of renewable energy sources can be smoothed and balanced over large regions. This requires the enhancement of interconnections between countries and global management of the grid. In this way, wind electricity from windy countries can be mixed and balanced with solar electricity from sunny countries.

Smart grids

"The enhancement of inter-connections can smooth the intermittent nature of renewable energy sources."

Smart grids are electricity grids that are more resilient and better able to cope with large shares of decentralised and intermittent energy sources. A better understanding of the demand and supply of electricity, coupled with the ability to intervene at the consumer level, enables supply to be balanced across a smart grid.

Decentralised storage

Decentralisation of electricity production also requires the decentralisation of energy storage. Today the major storage systems are hydro-pump facilities. In the future, small batteries and innovative concepts such as fly-wheels or hydrogen fuel-cells will be used as decentralised storage systems.

As electric-based transport develops, the many small batteries in electric vehicles can act as decentralised storage facilities while they charge overnight. The concept is known as vehicle to grid (V2G) and requires intelligent charge and discharge management.

Demand-side management (DSM)

Load shaving is already used by network managers to reduce demand from large electricity consumers. Instead of looking for new production capacity, which is only used during peak periods, the concept of demand-side management (DSM) applies load shaving to almost every electricity consumer.

The time that many domestic electrical appliances are used could be delayed (for example, heat-pumps for washing machines, delaying EV recharge). This would be hardly noticeable to consumers. However, the concept could be used to help balance intermittent sources and better use energy when it is available.

PV system integrated on a roof.

PV module, Morocco.

SOLAR POLICIES 4

4. SOLAR POLICIES

4.1. Policy drivers for the development of solar PV

Clear meaures are essential to create a successful renewable energy policy which provides long-term stability and security of supply[16]. The four main elements of a successful renewable energy support scheme are:

1. *A clear, guaranteed pricing system to lower the risks for investors and suppliers and to lower costs for the industry*
2. *Clear, simple administrative and planning permission procedures*
3. *Priority access to the grid with clear identification of who is responsible for the connection, and what the incentives are*
4. *Public acceptance and support.*

"FiT have been introduced around the world and helped to develop new markets for PV."

a. Public awareness Feed-in Tariffs: Key driver of solar success

It is surprising that Germany, not a particularly sunny country, has developed a dynamic solar electricity market and a flourishing PV industry. The reason is that the government has introduced a Feed-in Tariff (FiT) scheme that guarantees a price for all renewable electricity that is fed into the grid. Wind-powered electricity in Germany is currently up to 40% cheaper than in the United Kingdom[17] because of the FiT.

FiT have been introduced around the world and helped to develop new markets for PV. They have been supported in key reports by the European Commission (2005 and 2010 industry surveys[18]) and the *Stern Review on the Economics of Climate Change.* Globally, more than 40 countries have adopted some type of FiT system, with most adjusting the system to meet their specific needs.

Extending FiT mechanisms is a cornerstone to promote the production of solar electricity in Europe. The concept requires that producers of solar electricity:

- Have the right to feed solar electricity into the public grid
- Receive a premium tariff per generated kWh that reflects the benefits of solar electricity compared to electricity generated from fossil fuels or nuclear power
- Receive the premium tariff over a fixed period of time.

All three points are relatively simple, but significant efforts were required to be achieved.

The key attributes to a successful FiT scheme are:

- *They are a temporary measure.* FiT schemes are only required for the pre-competitive period until solar PV reaches grid parity.
- *Costs are paid by utility companies and distributed to all consumers.* This ensures the non dependence of the government budgets.
- *FiTs drive cost reductions.* The tariff should be adapted each year, for the newly installed PV systems.
- *FiT encourage high-quality systems.* Tariffs reward people who generate solar electricity, but not those who just install a system. It then makes sense for owners to keep their output high over the lifetime of the system.
- *FiT encourage PV financing.* Guaranteeing income over the life of the system enables people to get loans to install PV. It also makes this kind of loan structure more common and simpler for banks and PV system owners.

Large Thin Film power plant.

FIGURE 26
FIT – HOW DOES IT WORK IN PRACTICE?
AN EXAMPLE OF THE MECHANISM OF A FEED-IN TARIFF FOR SUSTAINED COMPETITIVE GROWTH

1. Government [GOV]
key responsibilities:
- setup legal framework for grid connection and distribution of electricity
- sets (decreasing) tariffs for all RE sources
- NO involvement in money flow

2. Renewable energy generator operator [RE]
key responsibilities:
- follows technical standards for grid connection and operation (-> LG)
- reports every technical failure directly to LG
- operates the RE power plant

6. Consumer [CON]
key responsibilities:
- pays electricity bill (including the extra charge for Feed-in Tariffs)
- gets renewable and conventional electricity

3. Local grid operator [LG]
key responsibilities:
- guarantees grid connection
- reports quantity of estimated RE electricity (forecast) to TM
- reports quantity of produced RE electricity to TM
- pays Feed-in Tariff to RE power plant

5. Distributor [DIS]
key responsibilities:
- collects money from consumer (based on forecast of TM) and transfers it to TM
- organizes billing for consumer
- distributes RE electricity

4. Transmission grid operator [TM]
key responsibilities:
- calculates the total estimated RE electricity generation based on forecasts from LG
- calculates the total generated RE electricity based on information from LG
- calculates needed total Feed-in Tariffs based on estimated RE electricity production
- breaks down the additional costs per kWh for distributor
- collects the money from Distributors (DIS)
- distributes money to LG to pay Feed-in Tariffs to RE operators

Supply [generation]

Demand [consumption]

source: Greenpeace International.

> "It is necessary to foresee changes in market conditions and adapt FiT to ensure a sustainable growth path."

Key Recommendations for sustainable support for PV

EPIA has developed the following key recommendations for policy-makers so they can implement adequate support schemes for PV:

1. Use Feed-in Tariffs or similar mechanisms

Feed-in Tariff laws introduce the obligation for utilities to conclude purchase agreements for the solar electricity generated by PV systems. The cost of solar electricity purchased is passed on through the electricity bill and therefore does not negatively affect government finances. In markets, where FiTs were introduced as reliable and predictable market mechanisms, they have proven their ability to develop a sustainable PV industry that has progressively reduced costs towards grid parity. In order to be sustainable, it is critical that FiTs are guaranteed for a significant period of time (at least 20 years), without any possibility of retroactively reducing them.

Feed-in Premium (FiP) is a new mechanism that may prove to be a viable alternative to FiTs. Under the FiP, utilities pay a premium on top of the price of electricity while the invoice of the consumer is reduced by the amount of PV electricity produced. If PV electricity exceeds consumption, the difference should be eligible for a feed-in tariff. However, the FiP concept is new and unproven but should be considered and worked out in more detail before it is tested in the market.

With the growing penetration of PV in many countries, support policies can be fine-tuned to drive the development of a specific market segment where this is useful.

Direct consumption premiums, additional incentives for Building Integrated PV (BIPV), compensation for regional irradiation variations, orientation premiums (East or West-oriented PV systems and storage premiums are all examples of possible additional provisions.

2. Ensuring transparent electricity costs for consumers

As the cost of renewable energy sources such as PV is very transparent to the consumer through the FiT component on the electricity bill, it will be important going forward to create the same transparency for the cost of generating electricity from other, conventional, sources. These typically benefit from significant government support schemes that are not always reflected in the electricity price but are financed through other public means; in particular taxes paid by those same consumers but not accounted for on the electricity bill. On average, estimates suggest that conventional sources of electricity generation benefit from seven times as much support as renewable energy sources. In addition to this direct financial support comes the indirect support of non-renewable energy through the lack of including transparent carbon costs.

The increased mix of energy from renewable sources such as PV has created a greater awareness among consumers about the need to increase the efficiency with which they consume electricity. So while the FiT has a visible impact on the electricity bill, it is at least partially compensated by the decrease of electricity demand. In addition, marginal cost of electricity produced from PV systems after the expiration of the FiT period is close to zero which will benefit electricity prices in the long term.

Most importantly and in view of continued reduction of FiTs over time, the PV industry is committed to significantly reducing the cost of PV systems to make it an affordable, mainstream source of power.

3. Encourage the development of a sustainable market by assessing profitability on a regular basis and adapting support levels accordingly

Sustainable market growth allows industry to develop and creates added value for the society and the economy as a whole. A critical aspect of sustainable development is ensuring adequate levels of profitability that ensure the availability of capital for investments while avoiding speculative markets. Overall, investments in PV projects need to be at par with other investments with equivalent risk levels. The figure to the right illustrates market developments under different support strategies. The green line represents a sustainable market growth. The red line shows a rapid and uncontrolled market peak, followed by a collapse due to sudden policy adjustment, while the blue line illustrates a stagnating market due to an incentive deemed insufficient.

Assessing the profitability through IRR calculations. All available support scheme components (including FiT, tax rebates and investment subsidies) must be taken into account when calculating the Internal Rate of Return (IRR) of a PV investment. Its sustainability must be assessed considering all local factors that impact the relative profitability of a PV investment. The table 1 presents an estimate of average sustainable IRR levels in a standard European country. Those percentages need to be adapted depending on local market conditions.

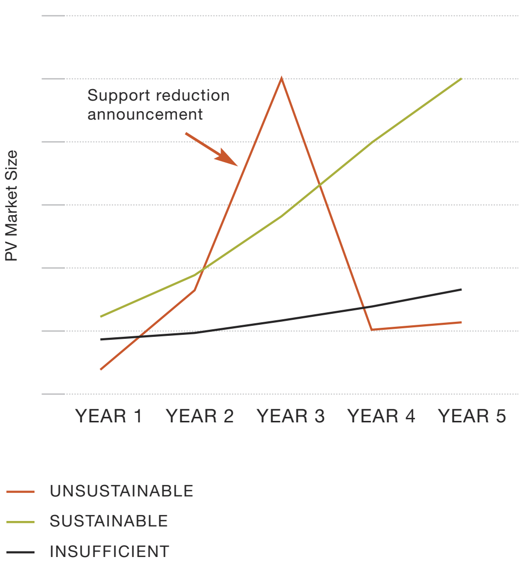
4. Gradual market development with the corridor concept

An uncontrolled market evolution tends to create "stop-and-go" policies that risk undermining stakeholders' confidence in and investor appetite for PV. In that respect, there is a need for a flexible market mechanism that is able to take into account more rapid cost digressions in the market and to adapt support schemes in order to ensure a sustainable growth path. The market corridor – as introduced in Germany for example - regulates the FiT based on market development over the previous period, thus allowing FiTs to be adapted so as to maintain growth within predefined boundaries. The FiT level is decreased on a regular basis in relation to the cumulated market level over a period passing below or above a set of predefined thresholds (quarterly or semi-annual revisions). The review periods should typically be set at once a year to keep the administrative burden manageable for governments and to remain compatible with the visibility needed for investment cycles.

5. Developing a national roadmap to PV competitiveness

With the ongoing decrease in installed PV system costs and the increase in conventional electricity prices, the use of financial incentives will progressively be phased out, as competitiveness is reached. A realistic roadmap to grid parity should be defined for every country along with concepts for market mechanisms that treat all electricity sources equally.

FIGURE 27
PV MARKET DEVELOPMENT UNDER DIFFERENT SUPPORT STRATEGIES



source: EPIA.

TABLE 12
ILLUSTRATIVE INTERNAL RATE OF RETURN LEVELS

	Insufficient Support	Sustainable Support	Unsustainable Support
Private investor	< 6%	< 6-8%	> 8%
Business investor	< 8%	< 8-12%	> 12%

b. Other drivers of a successful PV market development

Streamlining administration procedures

To help keep project costs down and avoid unnecessarily high levels of FiT, EPIA has made three recommendations for the management of FiT schemes:

1. *Assess the administrative process.* Policymakers should aim for a process that is transparent, linear in approvals, simple, cost-effective and proportional in effort for the owner. Long administrative delays or requirements that applicants contact multiple agencies or government bodies increases the lead time and cost of new projects. All authorisations, certifications and licensing applications should be assessed and delivered through a one stop-shop. In addition a reliable monitoring system must be ensured.
2. *Reduce administrative lead times to a reasonable period.* Short lead times must be a priority, especially for small-scale systems. Any delay in the authorisation process means less profitability for the investor. This reduces return and makes the project less attractive. Support schemes should provide automatic approval for small systems if no action is taken by the body responsible within a reasonable time limit.
3. *Simplify and adjust support schemes levels.* Once the administrative process has been simplified, the FiT should be adapted (lowered) when it has created cost reductions for suppliers. If this is not done, PV projects become too profitable, creating an unsustainable market that is likely to crash.

"Streamlining administration procedures help keep project costs down and avoid unnecessarily high levels of FiT."

Guaranteeing efficient grid connection

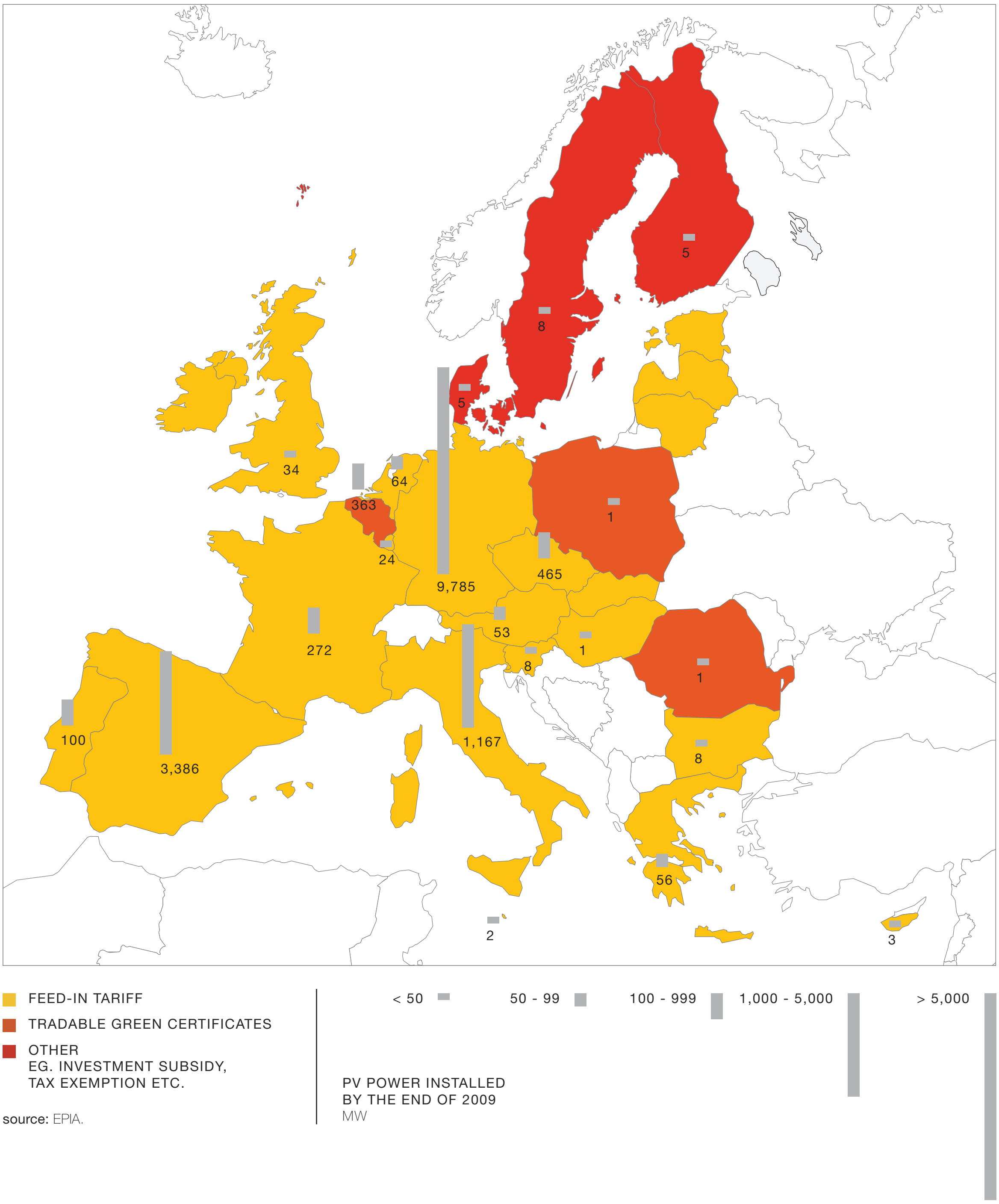
Grid connection agreements are crucial because they give confidence to the investor by guaranteeing that the electricity produced will be sold and transported. However, grid connection is often the most severe roadblock on a PV project. It can delay the project and dramatically increase its overall cost. EPIA recommends:

"Grid connection agreements are crucial because they give confidence to the investor by guaranteeing that the electricity produced will be sold and transported."

1. *Assess the grid connection process.* The assessment should focus on transparency, providing comprehensive information, an appropriate notification requirement, guaranteed lead times and cost-sharing between the PV operator and the distribution system operator DSO.
2. *Reduce grid-connection lead time to a few weeks.* Delays in the authorisation process must be avoided to guarantee short lead times and investor returns. Electricians should be accredited to connect small-scale systems to the grid with only a notification to the distribution system operator DSO.
3. *Ensure priority access to the grid.* Once the connection permit has been granted, the transport and distribution of the electricity produced by PV systems should be guaranteed for the lifetime of the installation.
4. *Deliver grid connection permits to reliable project developers.* Policy announcements can be followed by a flood of grid connection requests, in such a way that virtually all existing capacity could be exhausted. To avoid such a situation and counteract speculation, permits must only be issued to reliable investors. Validity of permits must be limited in time, and large project developers can be asked for bank guarantees to ensure they live up to their commitment.

6. *Ensure the financing of network operators.* The benefits that PV brings to electricity networks, especially at the distribution level, come at a cost, meaning that necessary investments must accompany the development of PV and its smooth integration on electricity networks. Ensuring funding for DSOs or TSOs can be necessary to secure maintenance and upgrade of the electricity grid.

FIGURE 28
SUPPORT SCHEMES
IN EUROPE



source: EPIA.

> "Levels of PV installations grow when a FiT scheme is established that is attractive to investors, well designed and accompanied by specific measures."

As shown on Figure 33, many EU Member States have implemented FiT, but not all of them have high levels of PV installation. Levels of PV installations grow when a FiT scheme is established that is attractive to investors, well designed and accompanied by specific measures (such as reduced administrative and grid connection procedures). The PV Legal project is analysing existing legal and administrative barriers in 12 EU countries that are preventing the PV market from developing to its full potential. Most of the countries under study have implemented a support scheme to deploy PV[19].

Supporting BIPV

Specific regulatory frameworks can be used to promote the inclusion of solar panels in the fabric of buildings (Building Integrated Photovoltaics or BIPV). The policies can be used to improve the energy performance of buildings and increase the amount of solar electricity in the overall energy mix.

In Europe, several countries have put measures in place to support BIPV. This is largely in response to the *Energy Performance of Buildings Directive* (EPBD)[20] from the European Commission. Examples include:

“BIPV policies can be used to improve the energy performance of buildings and increase the amount of solar electricity in the overall energy mix.”

- *France.* Legislation sets maximum energy consumption limits* for new and existing buildings. The limits indirectly promote the use of renewable energy and, in particular, solar technologies in new buildings and in existing buildings that are being substantially renovated.
- *Italy.* BIPV is promoted through a combination of specific requirements in the legislation to implement the EPBD Directive and the structure of the FiT.

Both in France and Italy, the requirements oblige owners of all new buildings, public or private, to install PV systems. For existing buildings, PV is mandatory if the building envelope is undergoing substantial refurbishment or, a building with a total useful surface exceeding 1,000 m² that is to be demolished and reconstructed.

- *Spain.* PV is compulsory on new buildings (see Table 13). According to the country's Technical Building Code (*Código Técnico de la Edificación*), the minimum requirements depend on the purpose of the building, the climate zone, and the dimensions of the building. Unfortunately, the obligations under this regulation are often not fulfilled. The local authorities do not always follow-up to ensure that PV has been installed.

In Ohta, Japan, an interesting experiment has been conducted. The entire town has been equipped with BIPV systems to test the feasibility of a large-scale implementation.

TABLE 13
PV OBLIGATIONS IN NEW BUILDINGS IN SPAIN

Building destination	Limits
Supermarkets	Over 5,000 m² built
Shopping and leisure malls	Over 3,000 m² built
Warehouses	Over 10,000 m² built
Administrative	Over 5,000 m² built
Hotels and hostels	Over 100 places
Hospitals and clinics	Over 100 beds
Fairground halls	Over 10,000 m² built

source: Spanish Technical Building Code.

* The limits for new buildings range between 250 and 80kWh primary/m2/year depending on the zone and the type of heating and from 130 to 80kWh primary/m2/year depending on the zone. For further information please consult the EPBD Country Energy Reports, available online at the following address: www.buildup.eu/publications/1916

4.2. Policies in the top ten markets

More than 40 countries in the world have introduced FiT for renewable energy systems including PV. The following case studies show the approaches of the top ten countries for PV deployment.

Germany

The German Feed-in Law (EEG) has inspired many other countries. It has been a strong driver for the German PV industry and has also shown the rest of the world that political commitment can achieve both environmental goals and industrial development at the same time. In June 2007, the German parliament decided to amend the EEG and introduced annual tariff decreases. In 2010, the first decrease in FiT occurred in January. Additional adjustments were made in July and October. Further decreases will be implemented in January each year. The drop in FiT has led to a sharp decline in both tariffs and system prices, putting a lot of pressure on the PV industry.

The bonus for facade-integrated systems has been suppressed and the tariff for ground-mounted systems on agricultural land has been abandoned.

Germany's scheme includes a corridor mechanism that automatically reduces the tariffs each year based on the level of the market during the past year. If the growth of the PV market (new installations) in a year is stronger or weaker than the defined growth corridor, FiT will be adjusted up or down the following year. The amount of the adjustment equals the percentage that the threshold was exceeded (or not met). In 2010, Germany reinforced the premium for auto-consumption of PV-generated electricity.

Italy

In Italy the FiT is paid by Gestore dei Servizi Elettrici (GSE). The tariffs change according to the plant size and the level of building integration.

A country that has naturally high levels of sunshine, Italy also offers an attractive support scheme. It mixes net-metering and a well-segmented FiT. In January 2009, the Italian government extended the net-metering *(Scambio sul posto)* to PV systems up to 200 kW. This ensures the PV system owners receive the same price for the electricity they produce and the electricity they consume from the grid. If, over a time period, there is an excess of electricity fed into the grid, the PV system owner receives a credit (unlimited in time) for the value of the electricity. This measure is quite attractive for the residential, public and commercial sectors. In addition to the value of the electricity they add to the grid, the PV system owners also receive a premium FiT on the total electricity produced by the PV system.

There are also higher tariffs for BIPV systems that support the development of innovative products and applications for roof-mounted systems. The incentives will remain the same until the end of 2010 and are granted for 20 years.

After long discussions, the Italian government has finally approved the third Energy Bill *(Conto Energia)* which will reduce the tariffs in multiple phases. The government hopes it will not put the development of PV at risk in Italy. The second Energy Bill included a cap at 1,200 MW which was enhanced with a grace period. The new Bill will push this limit to 3,000 MW under the same conditions.

"The German Feed-in Law (EEG) has inspired many other countries."

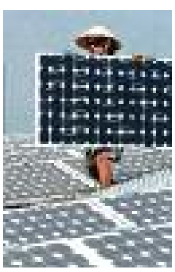
Japan

In 2009, Japan restarted its subsidy for residential PV systems and introduced a new programme to purchase surplus PV power. The changes were included in the *Promotion of the Use of Non-Fossil Energy Sources and Effective Use of Fossil Energy Source Materials by Energy Suppliers* Act. Almost 99% of the PV systems installed in Japan during 2009 were grid-connected, distributed applications, mainly residential PV systems.

The Ministry of Economy, Trade and Industry (METI) allocates budgets for market revitalisation, subsidies for the installation of residential PV systems, technology development for PV power generation, field testing of new technologies, grid testing with large-scale PV power generation systems, and the development of an electric energy storage system.

In July 2009, the METI enacted legislation which obliges electricity utilities to purchase surplus PV power. Incentives also take other types of clean power generation (such as fuel cells) into consideration. Prices are expected to be reviewed annually and all electricity customers will contribute towards the costs.

Looking forward, the New Energy and Industrial Technology Development Organization (NEDO) has reviewed its 2004 PV technology roadmap. NEDO has brought forward the original timeframe by three to five years, and renamed it PV 2030+ with an outlook now to 2050. The government also increased the target for PV installed capacity in Japan from 14 GW to 28 GW by the end of 2020. By the end of 2030 the goal is to reach 53 GW[21].



Worker installing PV on roof.

United States

The United States have been a sleeping PV giant until recently.

The US economy has been in turmoil since 2008 and state legislatures faced severe budget crises in 2009. To compensate, federal and state leaders have adopted policies to develop cleaner and more diverse energy sources as tools for economic revitalisation.

In 2009, the investment tax credit cap was removed and the 30% federal investment tax credit for commercial and residential PV systems was extended to 2016. This credit can now also be used by electricity utilities. The relative vigour of the PV market depends on the approach of individual states. California, New Jersey, Florida, Colorado and Arizona are the top five states for new installations.

Between September 2008 and September 2009, approximately 40 new solar incentive programmes were created in 19 states. Incentive levels were reduced in ten states. The performance-based incentives for PV in 2009 included:

- 14 production incentives (other than FiT)
- 11 FiT
- 14 renewable energy credit (REC) purchase programmes.

California established a law, effective from 2011, that enables utilities that purchase electricity through the state's FiT to be eligible for credits under the state's renewable portfolio standards (RPS). By the end of 2009, RPS existed in 30 states. Seveteen of these states have specified the amount of solar electricity and/or distributed generation that must be provided. New financing options have evolved rapidly at the city and county level.

Through *Property-Assessed Clean Energy* (PACE) programmes, several local governments offered loans to property owners to help pay for PV systems. Several such programmes arose from the Department of Energy's Solar America Cities initiative. By the end of 2009, 18 states had authorised PACE programmes and approximately 30 municipalities had implemented a PACE programme[22].

Czech Republic

The Czech market has skyrocketed under the combination of a very favourable FiT and low administrative barriers in 2009 and 2010. There are a large amount of ground-mounted systems in the country, demonstrating that FiT have the capacity to develop a strong market, and how important a dynamic market control mechanism is for long-term success.

Expectations for 2011 are quite pessimistic and no real market is expected there due to measures that the government has adopted that don't favour PV market development.

This illustrates the need to balance all market development drivers to ensure the continuous growth of PV.

Belgium

Belgium could be seen as a strange inclusion in this list. It's green certificates support schemes in each of the country's three regions which have succeeded in developing the PV market. The scheme differs in each of the country's three regions (Brussels, Flanders, Wallonia).

There has been a decrease in the level of support and at the end of 2009, the government bonus was abandoned in the region of Wallonia in order to control the rapid growth of the local PV market.

Green certificates are issued for all renewable energies, with values that depend on the energy source. Utilities must ensure they can produce enough renewable energy, either through their own production, or by acquiring green certificates. The proportion of renewable energy required in the system is increased every year by 1%.

In the region of Flanders, green certificates have a fixed price. In Wallonia, their value fluctuates on an exchange market according to the laws of supply and demand. The fluctuations are limited by a lower value which is arbitrarily defined. The maximum value is equivalent to the penalty that must be paid by utilities if they cannot meet their renewable energy target at the end of the year.

France

Despite an attractive FiT, administrative and grid connection burdens have slowed down the growth of PV in France. The French FiT was modified in January 2010, and reviewed again in September 2010. Now, BIPV systems are favoured with multiple tariffs that are amongst the highest in the world. A good tariff for ground-mounted systems rewards north located installations with a correction coefficient that depends on local irradiation levels. The comparatively low BAPV tariff was being misused until the end of 2009 – some buildings were constructed only to install PV systems. This was corrected in the January 2010 decree, when more constraints were placed on those who can receive the highest BIPV tariff. Due to the high BIPV incentives, the BAPV market is now almost non-existent.

Another correction of FiTs should follow at the beginning of 2011. The side effect of such frequent changes in policy is a severe loss of confidence by investors.

China

The largest PV producer in the world still has a small PV market. Some regional initiatives have created local FiT, but there is no support mechanism at the national level.

The *Golden Sun programme* has a target of 500 MW of PV systems installed in three years for both on-grid and off-grid applications. Some installations could come on-line in 2010 and 2011, but it is unclear whether this will be enough to generate a real growth in the market.

There is a huge potential in China. Today the country is preparing for a future of PV which could transform rural electricity generation. During 2009, there were discussions about a FiT to support PV deployment in China. However, only the province of Jiangsu (located on the east coast and the hub of China's considerable PV manufacturing resource base) introduced a FiT. It is capped at 400 MW up to 2011 for three categories of systems: ground-mounted, rooftop and BIPV systems. The authorities are likely to reduce the FiT over the first three years. However, the overall binding period of the scheme is unclear.

China's policies and strategies in support of PV operate at the national, provincial and local government levels. Central government issues national targets and encourages the provinces to propose strategies to meet the targets. The provinces then start a bidding process with industry and other key market actors. In late 2009, the National Energy Authority (NEA) raised the national goal of solar energy from 1.8 GW to 20 GW by 2020, with 5 GW to be installed by 2015. Of the 2020 target, more than half of the installations are expected to be utility-scale PV systems[23].

South Korea

In South Korea the FiT was reduced in 2009. The change cut the annual installed PV power that year to one-third of the 2008 level. The change affected the development of larger sized (multi-megawatt) plants the most. Grid-connected centralised systems accounted for almost 78% of the total cumulative installed PV power by the end of 2009. Grid-connected distributed systems amounted to 21% of the total cumulative installed PV power (up from 15% the previous year). Most of these were installed under the FiT scheme and the 100,000 roof-top programme.

The Ministry of Knowledge Economy's *Third Basic Plan on New and Renewable Energy Sources R, D&D* (released in 2008) proposed the construction of one million green homes and 200 green villages by 2020. In support of this, the government provides 60% of the initial PV system cost for single-family and private multi-family houses, and 100% of the cost for public multi-family rental houses. By the end of 2009, almost 40,000 households had benefited from this scheme.

From late 2008, the FiT rate was reduced but the cap was increased from 100 MW to 500 MW. Beneficiaries can also choose between periods of 15 and 20 years. It is planned that a renewable portfolio standard (RPS) will replace the existing FiT scheme from the year 2012. Grid parity is anticipated around 2020 in Korea. Prior to the start of the RPS, the Korean Government initiated an RPS demonstration programme to run from 2009 until 2011.

Spain

World leader in 2008, the Spanish market has since been almost completely blocked by unhelpful political decisions. Since 2009, Spain has had a market control cap that limits the PV installations to around 500 MW each year. Due to the introduction of severe legal and administrative barriers, the market has had difficulties in reaching the 100 MW level since 2009. Many installations were cancelled or delayed due to the uncertainty , at the end of 2010 a Royal Decree with retroactive effect on existing plants was adopted, putting at stake the viability of many investments.

The FiT has a classification of eligible PV plants which include:

- Roof-top plants or plants developed for similar surfaces that are smaller or larger than 20 kW
- Any other type of plant – essentially ground-based PV plants.

The maximum size of a plant (either rooftop or ground-based) is now 10 MW.

The Spanish government has decided to reduce the FiT for 2011 to favour small residential installations and reduce the large, ground-mounted systems.

Other countries

Many other countries have implemented FiT or green certificates. The FiT approach dominates, and green certificates are being progressively replaced by FiTs. This occurred in the UK in 2010. The complexity of certificates often discourages investors, while the ease and cost-effectiveness of a FiT encourages them.

In many countries, a maximum market value (or cap) is used to control market growth and limit the financial impact of too much solar entering the system. However, the cap can discourage investors, as can be seen in Spain.

4.3. Developing a world-wide PV policy outlook

a. The European Union: A driver of PV development in Europe and in the world

European energy policies

The overall goal of European energy policy is to guarantee that citizens can get safe, secure, sustainable and low-carbon energy at affordable and competitive prices. The EU understands that renewable energy technologies can help achieve this objective, and it is setting up a positive legislative framework to foster their deployment.

The European Commission published a White Paper in 1997 setting out a Community strategy for achieving a 12% share of renewables in the EU's energy mix by 2010. The indicative target for PV was 3 GW in cumulative installations. By the end of 2010, PV's capacity in the EU will have surpassed this level over nine times with probably more than 28 GW installed in EU at the end of 2010!

In 2001, the EU adopted the *Directive for the Promotion of Electricity from Renewable Energy Sources,* which included a 22.1% target for electricity for the EU-15 by 2010. The legislation was an important part of the EU's measures to deliver on commitments made under the Kyoto Protocol. However, the targets were not binding and it became evident that they would not be met.

In January 2007, the Commission published a *Renewable Energy Roadmap* outlining a long-term strategy. It called for a mandatory target of 20% renewable energies in the EU's energy mix by 2020. The target was endorsed by EU leaders in March 2007[24] and became binding with the approval in 2009 of the *Climate and Energy* legislative package. That package includes a specific Directive dedicated to the promotion of the use of renewable energy sources.[25]

The overall binding target applies to the EU's total energy consumption by 2020. The Directive also sets individual binding national targets. This Directive presents an unprecedented legislative framework in favour of RES development and will probably be the main driver for PV market growth in the EU.

The European Union is now preparing a roadmap towards a low carbon energy mix by 2050. This should include a very significant increase in the share of renewable energy sources. The renewable energy sector considers that a 100% renewable energy mix will be technically and economically feasible by this date.

The EU is also promoting both renewable energy sources and energy efficiency measures in buildings. There is major scope for improvement here because the building sector is responsible for about 40% of EU energy consumption at present.

According to the revised *Energy Performance of Buildings* Directive adopted in 2010,[26] all new buildings will have to be 'nearly zero energy buildings' by 2020. This target should accelerate the development of buildings with a very high energy performance rating. The revised Directive should help foster PV deployment in buildings, in particular BIPV.

Another piece of European legislation that benefits the deployment of renewable energy technologies is the *Third Energy Package.* The package was adopted in 2009[27] and its primary goal is to pursue the liberalisation of the electricity and gas markets.

The package provides different options for Member States to separate electricity transmission networks from production activities – a practice known as unbundling. The *Third Energy Package* also established a formalised cooperation mechanism between national energy regulators and transmission system operators. They will work on common network access rules and joint planning of infrastructure investments to ensure easy access to a modern network.

In the years to come, EU decision makers are expected to further improve the framework conditions to ease the creation of a modern EU-wide grid. This in turn would mean increased and better penetration of the market by renewable electricity[28].

"According to the EU, renewable energy can help to get safe, secure, sustainable and low-carbon energy at affordable and competitive prices."

European funding for renewable energy projects

Compared to other countries like Japan and USA, the European Union's spending on research and development (R&D) is low. However, the EU is using part of its budget to finance important R&D projects that can accelerate the deployment of renewable energy technologies.

The *European Research Framework Programme* and the *Intelligent Energy Europe Programme* are the main schemes used to allocate grants to renewable energy projects. The *Solar Europe Industrial Initiative,* initiated by the European Commission and launched in June 2010[29] in the framework of its *Strategic Energy Technology* (SET) *Plan,* is expected to make public funds available to co-finance key R&D projects with the industry. These projects will mainly accelerate PV cost reduction and integration of PV electricity into the grid.

It was recently agreed that a number of allowances set aside from the *European Emission Trading Scheme* (ETS) could be used to finance part of the *Solar Europe Industrial Initiative,* especially pre-commercial innovative PV projects[30]. The EU may also decide to support energy efficiency and renewable energy projects in urban areas by using some unspent funds from the *European Energy Recovery Plan,* an instrument launched in July 2009 to boost investments in key energy infrastructure projects[31].

b. The desert is a perfect place to develop PV energy

Deserts have both high irradiation and low populations. That makes them the perfect place to install very large scale PV systems. Projects up to 2 GW are already being planned in China's deserts that will be a showcase for the feasibility of such huge installations[32]. The main challenges are the integration to the electricity networks and the transportation of electricity over long distances. The weather conditions in the desert should favour PV systems, which require limited water compared with other technologies.

Europe, together with northern African countries and the Union for the Mediterranean have created the *Mediterranean Solar Plan.* The Plan represents the first real attempt to conceive large PV power plants in desert areas. According to the plans, the electricity generated will be conveyed to Europe using DC lines to minimise electricity losses over long distances. Despite the high potential of the region in renewable energies, the project aims to generate 20 GW from all renewable sources in the Mediterranean region. While this is a limited target, it could demonstrate the potential that deserts close to highly populated regions can offer.

The concept was developed in the framework of the Desertec project which initially planned to use only Concentrated Solar Thermal Power. The steep decrease in PV prices, combined with its natural advantages has seen PV welcomed into the mix of renewable energy sources. PV industry is confident that solar technology can be deployed on a massive scale in the deserts of the world.

c. PV in the Sunbelt region: Ongoing policy developments

PV markets have developed initially in northern countries, even though they lack a lot of sunlight. FiTs have helped the market to develop and to lower prices world-wide. This temporary situation is about to change. There are many countries in the Sunbelt region (the area around 30° north and south of the equator) that could benefit from off-grid and on-grid PV systems. That region represents 78% of the world population, 27% of global GDP, and a huge potential market for PV before 2020.

In the Middle East and North Africa, policy support is quite limited. A FiT exists in Israel and one has been recently been adopted in Turkey. In 2010, Morocco launched a call for 2 GW of solar systems to be installed by 2015, in which PV could play a role. In most situations, heavy administrative procedures and complex grid connection schemes have held up PV development.

China, already the world's leading maker of solar PV modules, has made enormous strides in developing its renewable energy sector in recent years, yet its installed base of PV still pales in comparison with its manufacturing base. The *Golden Sun programme*, launched in 2009, is a first step to righting this imbalance with targets for PV set at 20GW by 2020. The current incentive structure for PV still assumes a subsidy based on the cost of the initial investment rather than on the cost of generation, with a cap on overall capacity. However, PV support measures are expected to evolve further, especially with renewable energy being named one of the Magic 7 emerging strategic industries under the 12th Five-Year Plan (2011-2015), which will be officially unveiled in March 2011.

In India, legislation establishing the *Jawaharlal Nehru National Solar Mission* passed in 2009, with a target of 22 GW of solar power by 2022. Not all of this will be generated through PV, however, the move represents major progress.

In Latin America, support for renewable energy exists in some countries, particularly Chile, Brazil, Mexico and Argentina. However, PV is not yet everywhere on the top of the political agendas.

d. Smart cities

The smart city concept refers to an urban environment where investments in transport and modern information and communication infrastructure provide sustainable economic development and a high quality of life. The holistic concept also aims for wise management of natural resources and participatory governance[33]. Environmental sustainability is a cornerstone of smart cities. The integration of renewable energies like photovoltaics in the urban environment is an essential component.

While they sound utopian, smart cities are now becoming a reality. The European Commission launched recently a *Smart Cities Initiative*[34] to foster the transformation of 25 to 30 European cities into low carbon cities by 2020. The indicative cost is set at €10 to €12 billion.

Smart cities are a key concept promoted by EPIA. Within the framework of the *Solar Europe Industry Initiative,* EPIA expects Solar Cities and Solar Islands to be developed. They will demonstrate the many options for large-scale integration of solar PV in urban and remote environments.

Large ground-mounted PV plant, Mallorca, Spain.

Off-grid PV system in Morocco.

"The basic aim of FTSM is to help introduce Feed-in Laws in developing countries."

Access to energy in developing countries: The FiT Support Mechanism

The FiT Support Mechanism (FTSM) is a proposal from Greenpeace International[35] for a renewable support scheme for the power sector in developing countries. FTSM aims to rapidly expand renewable energy in developing countries with financial support from industrialised nations. Investment in and generation of renewables, especially in developing countries, will be higher than that for existing coal or gas-fired power stations over the next five to ten years.

The FTSM concept was first presented by Greenpeace in 2008. The idea has received considerable support from a variety of different stakeholders. Deutsche Bank Group's Climate Change Advisors, for example, have developed a proposal based on FTSM called GET FiT. Announced in April 2010, the proposal includes major aspects of the Greenpeace concept.

Technology transfer to developing countries For developing countries, FiT are an ideal mechanism to help implement new renewable energies. Effective technology transfer from developed to developing countries will require a mix of a Feed-in Law, international finance and emissions trading.

The FiT Support Mechanism The basic aim of FTSM is to help introduce Feed-in Laws in developing countries that provide bankable, long-term and stable support for a local renewable energy market. For countries with a lot of potential renewable capacity, it would be possible to create a new no-lose mechanism that generates emission reduction credits for sale to developed countries. The proceeds could then be used to offset part of the additional cost of the FiT system. Other countries would need a more directly funded approach to pay the additional costs to consumers that a tariff would bring.

The key parameters for FiTs under the FTSM are:

- Variable tariffs for different renewable energy technologies, depending on their cost and technological maturity, paid for 20 years.
- Payments based on actual generation in order to achieve properly maintained projects with high performance ratios.
- Payment of the additional costs for renewable generation based on the German system, where the fixed tariff is paid minus the wholesale electricity price, which all generators receive.
- Payment could include an element for infrastructure costs such as grid connection, grid re-enforcement or the development of a smart grid. A specific regulation needs to define when the payments for infrastructure costs are made to achieve a timely market expansion of renewable power generation.

A developing country which wants to take part in the FTSM would need to establish clear regulations for:

- Guaranteed access to the electricity grid for renewable electricity projects.
- Establishment of a Feed-in Law based on successful examples.
- Transparent access to all data needed to establish the FiT, including full records of generated electricity.
- Clear planning and licensing procedures.
- Funding could come through the connection of the FTSM to the international emissions trading system or specific funds for renewable energies.

The design of the FTSM would need to provide stable flows of funds to renewable energy suppliers. There may need to be a buffer between the price of CO_2 emissions (which can fluctuate) and stable, long-term FiTs. The FTSM will need to secure payment of the required FiTs over the whole lifetime (about 20 years) of each project.

The FTSM would also seek to create the conditions for private sector actors, such as local banks and energy service companies, to gain experience in technology development, project development, project financing, operations and maintenance. This would help to develop and track projects, further reducing barriers to renewable energy development.

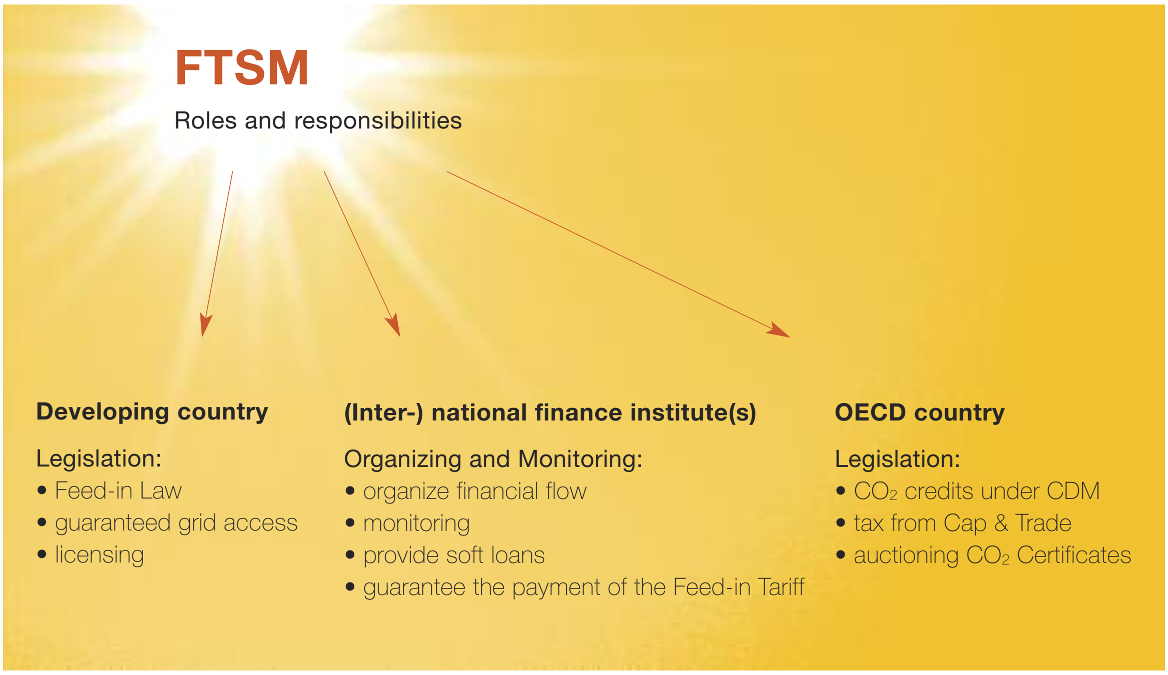
For this, Greenpeace proposes a fund, created from the sale of carbon credits and taxes. The key parameters for the FTSM fund would include:

- The fund guarantees payment of the FiTs over a period of 20 years as long as the project is operated properly.
- The fund receives annual income from emissions trading or from direct funding.
- The fund pays FiTs annually only on the basis of generated electricity.
- Every FTSM project must have a professional maintenance company to ensure high availability.
- The grid operator must do its own monitoring and send generation data to the FTSM fund. Data from the project managers and grid operators will be compared regularly to check consistency.

Ground-up participation While large-scale projects have fewer funding problems, there are difficulties for small, community-based projects, even though they have a high degree of public support. Strong local participation and acceptance can be achieved. There have been good examples in micro-credit schemes for small hydro projects in Bangladesh and wind farms in Denmark and Germany. The projects provide economic benefits that flow to the local community when carefully planned based on good local knowledge and understanding. Generally, when the community identifies the project – rather than the project identifying the community, the result is a renewables sector that grows faster from the ground-up.

"Ground-up participation is essential for the success of the model."

FIGURE 29
THE GREENPEACE
– PROPOSED FEED IN TARIFF MECHANISM



5 SOLAR POWER MARKETS

5. SOLAR POWER MARKETS

5.1. History of PV markets

The solar power market is booming. More than 22 GW were installed across the world by the end of 2009, and provisional figures show a global installed capacity exceeding 37 GW by the end of 2010.

In Spain and Germany, the average contribution from PV to electricity generation is more than 2% of the total on average per year. But PV provides much more in key regions with the right mix of Sun and good government support. For example, in the Spanish region of Extremadura, PV had made-up 15% of the electricity mix in 2010, with peaks of up to 25% in the summer. Without a doubt, PV has shown that it can compete with other electricity generation sources.

a. Europe at the forefront of PV development

Germany remains the world's largest PV market with a cumulative installed PV power of almost 10 GW at the end of 2009. By the end of 2010 this probably exceeded 15 GW. This is equivalent to two standard nuclear power plants.

Italy is one of the most promising mid-term markets with an additional 711 MW installed in 2009. The target for 2010 is more than 1.5 GW, possibly 2 GW. The country has high levels of Sun, and the new *Conto Energia* law announced in mid-2010 will continue to support the strong momentum of the Italian market.

The Czech Republic showed an important growth in 2009 with 411 MW installed. However, due to unsustainable support schemes, the market is expected to shrink significantly in 2011, after a hectic 2010 year marked by strong opposition from conventional stakeholders and more than 1.4 GW of cumulative installed capacity.

Thanks to favourable political will, Belgium made its entry into the top ten markets with 292 MW installed in 2009. The market had, however, slowed down or stagnated in 2010 due to a revision of the financial support scheme in early 2010.

France follows with 185 MW installed in 2009 and an additional 100 MW installed but not yet connected to the grid. France has huge potential but must solve grid connection issues in order for PV to penetrate decentralised power sources and to allow the market to develop. In the first six months of 2010, grid connection became easier and the market grew in response.

In Spain, a new market cap created in 2008, combined with the effects of the financial crisis, constrained the market to almost zero in 2009. In 2010, instability in political decisions created turmoil in the PV industry, holding the Spanish market back significantly.

"The solar power market is booming."

Greece, the UK, Slovakia and, to a certain extent Portugal, are showing a strong potential for growth.

b. Japan and USA lead outside Europe

Outside Europe, Japan became third largest market in 2009 with 484 MW installed and shows more growth potential thanks to favourable political support. The US market finally took off significantly with around 475 MW installed in 2009. It appears to be a potential leading market in coming years, with many ground-mounted systems starting production in 2010.

China and India are also expected to boom in the next five years with huge market potential and impressive projects in the pipeline. Canada and Australia showed significant market development in 2009 and are expected to open the way to the development of new markets. Brazil, Mexico, Morocco, Taiwan, Thailand, South Africa and many others are also seen as promising countries.

c. Distribution of the world PV market in 2009

The development of PV in the last ten years has been exponential. Driven by smart incentives such as FiT and other policies, the PV market surged and will continue to do so in the coming years.

Figure 31 shows the evolution of the cumulative installed capacity in the entire world since 2000. The split clearly shows the importance of the European Union in that development and how Japan, which was one of the initiators, was overtaken by Europeans. The development of PV in the rest of the world has now begun and will rapidly rebalance the market. The current domination of European countries shows how the right political choices influence the energy sector in general and PV in particular.

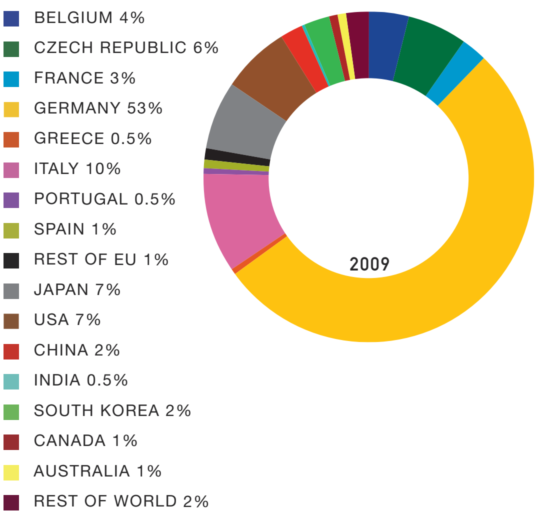
d. Root causes of PV market development

Photovoltaic electricity is becoming more prevalent progressing towards grid parity. However, in many cases today, PV remains more expensive than conventional electricity production methods. The price decrease is so fast that the competitiveness of PV with other energy sources will be achieved in around five years in several countries.

Political support and, especially in Germany, the introduction of FiT has closed the gap with conventional energy sources and triggered greater market deployment. This kind of support is currently the main driver to PV development. Other incentives complement the support schemes depending on the country.

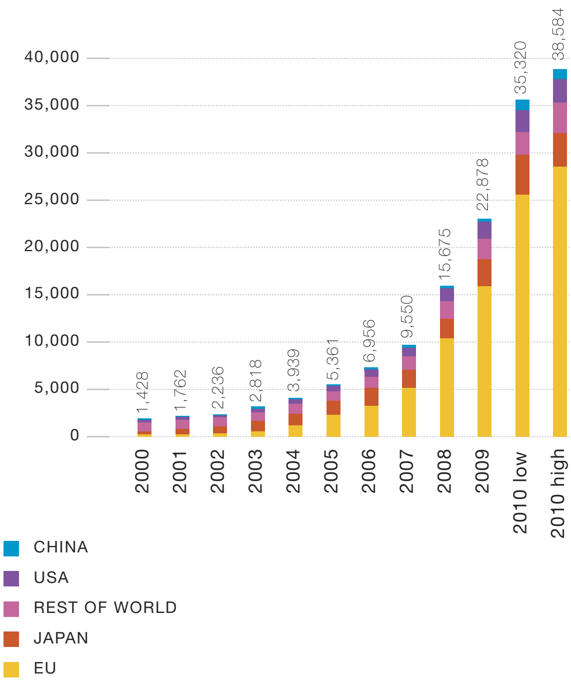
"Political support and the introduction of FiT has closed the gap with conventional energy sources and triggered greater market deployment."

FIGURE 30
THE WORLD PV MARKET IN 2009



source: EPIA.

FIGURE 31
GLOBAL EVOLUTION OF PV INSTALLED CAPACITY
MW



source: Global Market Outlook for Photovoltaics until 2014, EPIA, May 2010.

Electricity markets are driven by profitability rules; investors are keen to invest in power plants if they can benefit from an added value. This is why tariff schemes work. PV is now considered to be a reliable investment in many countries, in the same way conventional energy sources were viewed in the past.

In the 27 EU countries during 2009, PV took third place in terms of new electricity capacity, behind wind and gas, but ahead of coal and nuclear.

Depending on the amount of new gas power plants installed in Europe in 2010, PV could score the first or second place in terms of new added capacity. It will overtake all other power generation sources, from wind to coal and nuclear.

e. Future PV markets: The Sunbelt region

The technology is mature and is available. Developed economies have contributed to achieve this. Lower system prices make PV more and more affordable and competitive in other regions of the world.

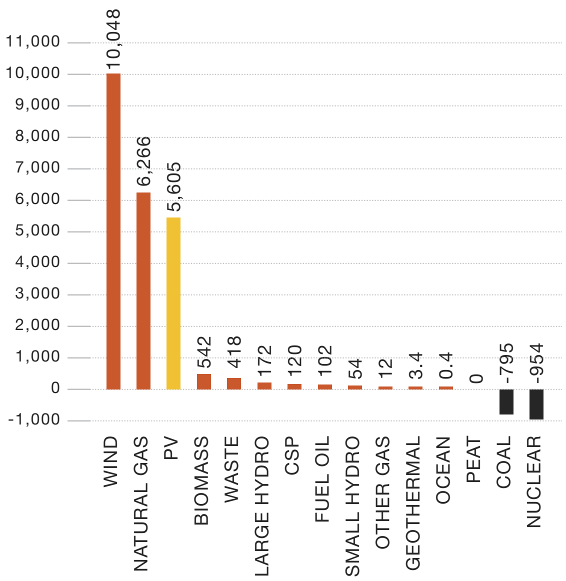
The Sunbelt region provides a massive opportunity to develop PV in the coming years. Moreover, sunny regions are not the only ones where PV can be part of the energy mix. Denmark's high electricity prices could help the country to reach grid parity before other, sunnier European countries.

New PV markets will appear progressively, driven by the falling cost of the technology and an appetite for energy. The combined effects of energy scarcity and the urgent need to mitigate climate change will drive the emerging PV markets.

f. A bright future for PV

New PV installations could have reach between 12 and 15 GW in 2010 globally, another year of significant growth. The future is somewhat harder to predict. While PV system prices are continuing to go down, an increase in conventional electricity prices will open new markets all over the world. Continued political support in Europe and elsewhere will be required to help PV get passed the pre-competitive phase and become a major global energy source within a decade.

FIGURE 32
NEW INSTALLED ELECTRICAL CAPACITY IN 2009 IN THE EU
MW



source: EPIA, EWEA, ESTELA, OEA-EU, Platts PowerVision.

"In 2009, in the EU 27, PV took third place in terms of new electricity capacity, ahead of coal and nuclear."

FIGURE 33
PV IN THE SUNBELT COUNTRIES

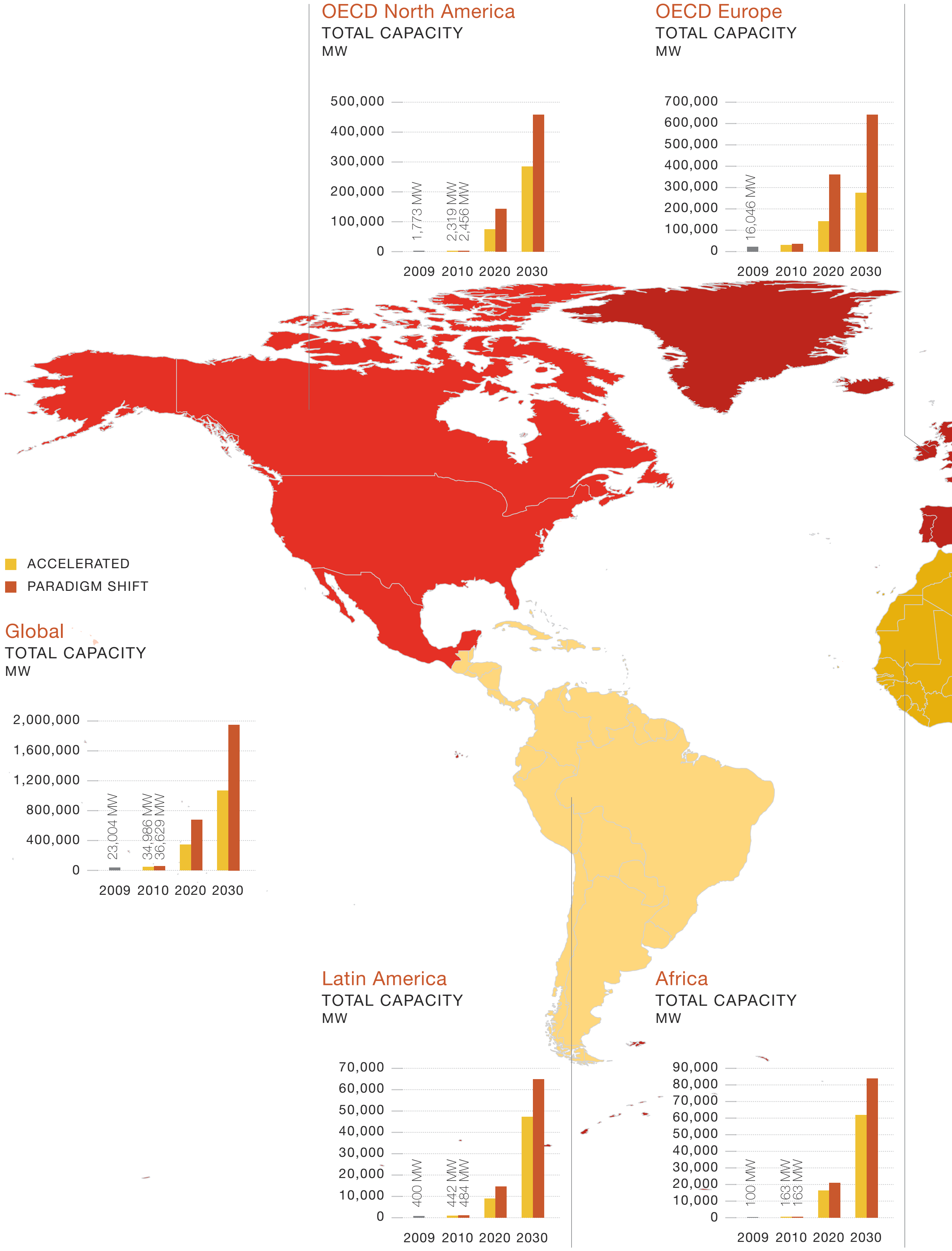
COUNTRIES IN SCOPE OF STUDY

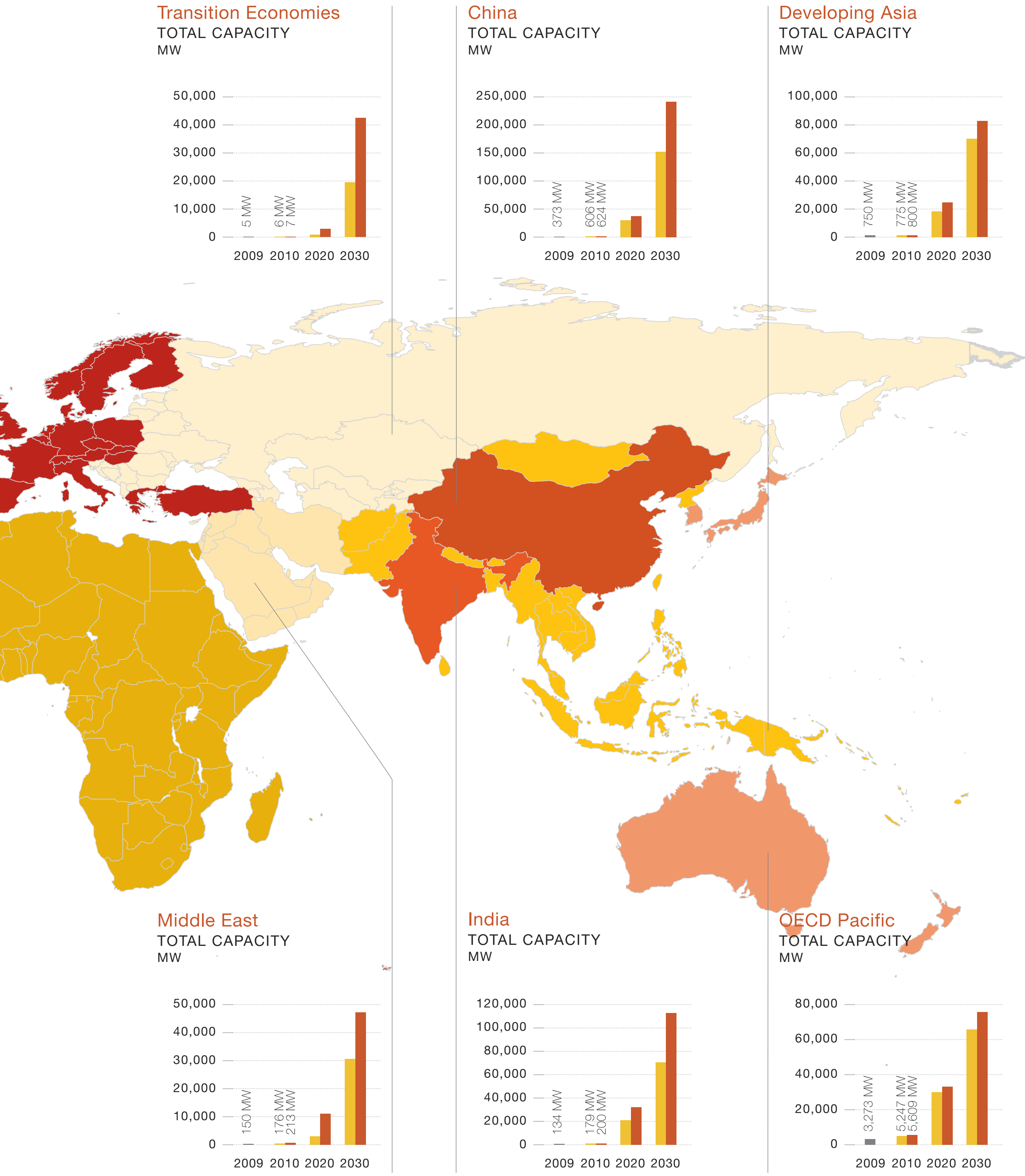
	Sunbelt countries in scope	All countries in Sunbelt	World
# countries (2008)	66	148	201
Population (2008)	5.0 billion	5.3 billion	6.7 billion
GDP (2008)	15.7 trillion	16.4 trillion	60.0 trillion
Electricity consumption (2007)	6,800 TWh	7,000 TWh	17,900 TWh

source: World Bank, IMF, A.T. Kearney analysis.

WORLD MAP GLOBAL CUMULATIVE CAPACITY SHOWING THE ACCELERATED AND PARADIGM SHIFT SCENARIOS BY REGION

MW




Transition Economies
TOTAL CAPACITY
MW
50,000
40,000
30,000
20,000
10,000
0
5 MW
6 MW
7 MW
2009 2010 2020 2030
China
TOTAL CAPACITY
MW
250,000
200,000
150,000
100,000
50,000
0
373 MW
606 MW
624 MW
2009 2010 2020 2030
Developing Asia
TOTAL CAPACITY
MW
100,000
80,000
60,000
40,000
20,000
0
750 MW
775 MW
800 MW
2009 2010 2020 2030
Middle East
TOTAL CAPACITY
MW
50,000
40,000
30,000
20,000
10,000
0
150 MW
176 MW
213 MW
2009 2010 2020 2030
India
TOTAL CAPACITY
MW
120,000
100,000
80,000
60,000
40,000
20,000
0
134 MW
179 MW
200 MW
2009 2010 2020 2030
OECD Pacific
TOTAL CAPACITY
MW
80,000
60,000
40,000
20,000
0
3,273 MW
5,247 MW
5,609 MW
2009 2010 2020 2030

“The Paradigm Shift scenario estimates the full potential of PV in the next 40 years.”

5.2. The Greenpeace/EPIA Solar Generation scenarios

a. Methodology and assumptions

Greenpeace and EPIA have joined their resources to work out how much photovoltaic electricity could be available across the whole world in the coming decades. These scenarios have been developed using the extensive knowledge in both organisations of renewable energy and PV in particular.

The scenarios put forward details of potential markets up to 2030 and also provide global figures up to 2050.

The scenarios make projections for installed capacity and energy output. They also assess the level of investment required, the number of jobs that could be created and the crucial effect that increased input from solar electricity will have on greenhouse gas emissions.

The Paradigm Shift scenario

Called the Advanced scenario in previous editions of Solar Generation, this scenario estimates the full potential of PV in the next 40 years.

It has been renamed Paradigm Shift in order to reflect the need, over the next two decades, to shift energy policies from conventional electricity generation to renewable energy in general and PV in particular. It represents the real technical potential of PV as a reliable and clean energy source, in all parts of the world.

In the Paradigm Shift scenario, PV would produce up to 12% of the electricity needs in European countries by 2020 and in many countries from the Sunbelt (including China and India) by 2030 (this difference originates from the early development of PV in Europe). It is ambitious, but also feasible, providing some boundary conditions are met before 2020, especially in the EU. Even if this strong growth cannot be achieved in the first decade, the 2050 targets remain reachable without too many changes. At that point, a real global paradigm shift needs to happen.

The assumption is that current support levels will be strengthened, deepened and accompanied by a variety of instruments and administrative measures that will push the deployment of PV forward.

The Accelerated scenario

Called the Moderate scenario in previous Greenpeace Outlook reports, the name has been changed to Accelerated to reflect expectations. The scenario foresees the ability to deploy PV faster, in line with market developments, than has been seen in recent years.

In the Accelerated scenario there is a lower level of political commitment than the Paradigm Shift scenario. It can be viewed as a continuation of the current support policies and it could easily be achieved in 20 years without any major technology changes in electricity grids.

TABLE 14
SUMMARY OF EPIA/GREENPEACE PARADIGM SHIFT SCENARIO

	2011-2020	2021-2030	2031-2040	2041-2050
Average market growth rates under the Paradigm Shift	42%	11% for 5 years then 9%	7% for 5 years then 5%	4%

TABLE 15
SUMMARY OF EPIA/GREENPEACE ACCELERATED SCENARIO

	2011-2020	2021-2030	2031-2040	2041-2050
Average market growth rates under the Accelerated scenario	26%	14% for 5 years then 10%	7% for 5 years then 6%	4%

Over the longer term, the gap between the Accelerated and Paradigm Shift scenarios widens. Fast market deployment is difficult with insufficient additional global political support. Without the potential for economies of scale, PV production costs and prices will fall at a slower rate than in the Paradigm Shift scenario. This will result in a lower level of PV deployment, which impacts the final target.

The growth rates presented in this scenario represents an average calculated from varying rates of annual growth.

The Reference scenario

The Reference scenario is based on the scenario of the same name in the International Energy Agency's *2009 World Energy Outlook* (WEO 2009) analysis. The data has been extrapolated forward from 2030. Compared to the previous (2007) IEA projections, the WEO 2009 assumes a slightly lower average annual growth rate in world Gross Domestic Product (GDP) of 3.1% (down from 3.6% in the previous forecast) over the period 2007 to 2030. At the same time, the report expects energy consumption in 2030 to be 6% lower than in the WEO 2007 report. China and India are expected to grow faster than other regions, followed by the Other Developing Asia group of countries, Africa and the Transition Economies (mainly the former Soviet Union).

b. Scenario assumptions

The scenarios are based on many different country and regional scenarios from Greenpeace and EPIA released in recent years.* The value of PV in each scenario takes into account the limitations produced by the combination of different technologies. It also assumes little progress in storage systems in the short-term.

* Current PV market data from reliable sources (national governments, the International Energy Agency, PV industry). PV market development over recent years both globally and in specific regions. National and regional market support programmes. National targets for PV installations and manufacturing capacity. The potential for PV in terms of solar irradiation, the availability of suitable roof space and the demand for electricity in areas not connected to the grid. Existing EPIA and Greenpeace studies (such as EPIA's SETfor2020, Unlocking the Sunbelt potential for PV and EREC's RE-thinking 2050).

Regional split

The scenarios present a view of the future using global figures. They also estimate regional values for PV growth. The regions defined are European Union (27 countries), rest of Europe, OECD Pacific (including South Korea), OECD North America, Latin America, East Asia, Developing Asia (excluding South Korea), India, China, the Middle East, Africa and the Transition Economies (mainly the former Soviet Union).

Electricity consumption

This outlook also considers two estimates of growth in electricity demand over the first decades of the 21st century.

The Reference scenario for global electricity demand simply utilises the projections made by the IEA (WEO 2007[36]). These show global demand for power increasing without much constraint. Demand is expected to be:

- 17,928 TWh in 2010
- 22,840 TWh in 2020
- 28,954 TWh in 2030.

By 2050, the demand would top 39,360 TWh. The contribution from PV power is expressed as a percentage of this value.

The Alternative scenario for future electricity demand is based on the Greenpeace/European Renewable Energy Council *Energy [R]evolution* report (January 2007) and takes into account extensive energy efficiency measures. Those measures should ensure consumption of electricity is significantly lower in 2030 than today. This reflects what has to happen in order to meet the ambitious targets for CO_2 emissions required to keep the Earth's warming below two degrees centigrade. The scenario shows a global demand for power following a more controlled growth:

- 17,338 TWh in 2010
- 19,440 TWh in 2020
- 20,164 TWh in 2030.

In 2050 demand should reach 31,795 TWh. The contribution of PV (as a percentage) is therefore higher under this projection.

"Fast market deployment is difficult with insufficient additional global political support."

Carbon dioxide savings

An off-grid solar system which replaces a typical diesel unit will save about 1 kg of CO_2 per kilowatt hour of output. The amount of CO_2 saved by grid-connected PV systems depends on the existing energy mix for power generation in different countries. The global average figure is taken as 0.6 kg of CO_2 per kilowatt-hour.

Over the whole scenario period it has been assumed that PV installations will save, on average, 0.6 kg of CO_2 equivalent per kilowatt-hour. This takes into account emissions during the lifecycle of the PV system of between 12 and 25 g of CO_2 equivalent per kWh.

"On average, 30 full-time equivalent jobs are created for each MW of solar power modules produced and installed."

Employment generated

On average, 30 full-time equivalent (FTE) jobs are created for each MW of solar power modules produced and installed. While there are discrepancies between countries, between companies and between technologies, it is a useful estimate that represents a world-wide average.

The figure for employment takes into account the whole PV value-chain including research centres, installers, and producers of silicon, wafers, cells, modules and other components. The figure does not take into account the jobs lost in the conventional energy sector. This depends on the energy mix in each country. A reasonable decrease is around 20 FTE per installed MW in 2050. Maintenance jobs are expressed separately in the scenarios.

Capacity factor

The capacity factor for PV technology expresses how much of the Sun's energy is converted into electrical energy for PV. This is estimated to grow from around 12 to 17% by 2050 in both the Paradigm Shift and Advanced scenarios. The estimate takes into account all technologies, not only the most advanced ones. It assumes a reasonable penetration of more efficient technologies in the coming decades. However, the estimate is reasonably conservative considering how fast technologies are actually evolving and the arrival of concentrator photovoltaic (CPV) in regions with more Sun than in the current PV markets.

Learning curve

In the last 30 years, PV costs have dropped by more than 20% with each doubling of the production capacity. The rate of cost reduction will probably not be as strong in the coming decade. In the Paradigm Shift and Advanced scenarios we consider a reduction of 18% from 2020, 16% from 2030 and 14% from 2040 to 2050.

Cost of PV systems

PV markets in many countries are not yet mature. However prices today in Germany reflect the reasonable minimum prices that could be reached in other parts of the world. The outlook considers those prices, starting from an average €2.80/Wp in 2010 for PV systems. By mid-2010 one could find prices as low as €2.20/Wp for large ground-mounted systems in some countries. Costs will decrease with volume of production. Prices would decrease faster in the Paradigm Shift scenario than in the Accelerated scenario.

The SET For 2020 study:
Photovoltaic electricity, a mainstream power source in Europe by 2020

Published by EPIA in 2009, *SET For 2020* outlines how photovoltaics (PV) can become a mainstream energy supplier in Europe by 2020. The study provides a unique, wide-ranging combination of facts, figures, analysis and findings. *SET For 2020* is indispensable for anyone with an interest in the future of the European energy market. It contains an intensive and broad-based analysis of existing data as well as interviews with around 100 key people in industry, research institutes, utilities, regulatory agencies and governments across Europe and other parts of the world. The study concludes that boosting photovoltaic electricity's share of energy market will yield huge benefits to European society and its economy. This requires the active support of policy makers, regulators and the energy sector at large.

Among the findings:

- Europe needs to dramatically increase the share of PV to meet its 20/20/20 energy goals.
- A 12% market share for PV in Europe is a demanding, but achievable and desirable objective.
- Supporting the development of PV is an investment that will yield important positive returns for the European economy.
- The deeper and earlier the penetration of PV, the greater the net benefits.
- Mass penetration of PV will support European competitiveness, employment and energy security of supply.
- PV is the fastest-growing renewable energy technology, and costs are expected to drop faster than those of other electricity sources.
- By the end of 2020, PV can be competitive in as much as 75% of the European electricity market.

www.setfor2020.eu

"Supporting the development of PV is an investment that will yield important positive returns for the economy."

Polycrystalline silicon system integrated on a façade,St. Moritz, Switzerland.

5.3. Key results

a. Global scenario

At the end of 2009 the world had 23 GW of installed PV electricity. By 2020, we could see a Global installed capacity of:

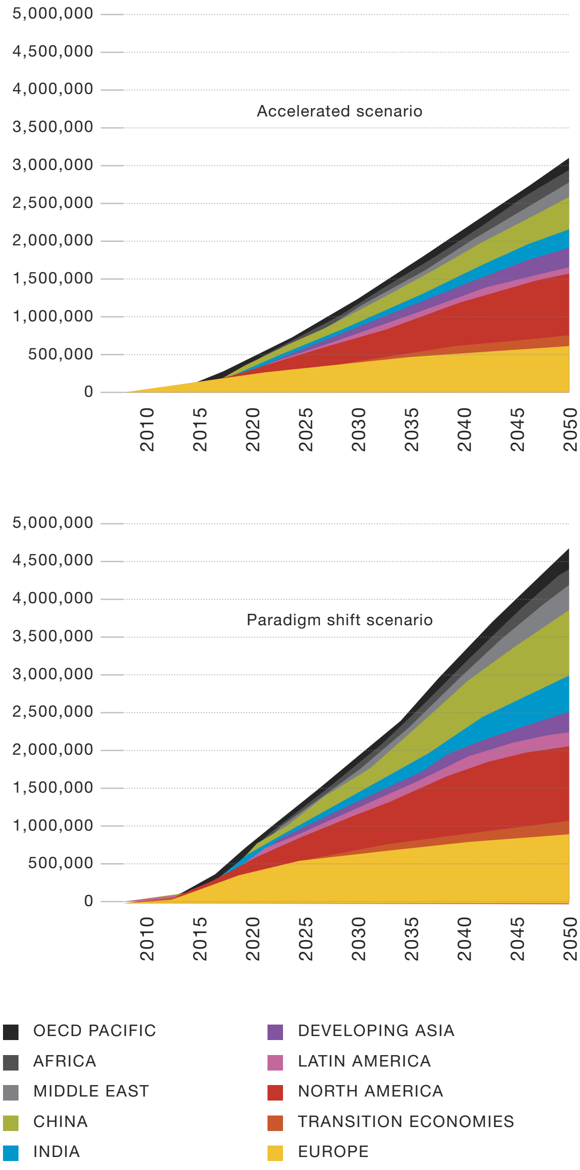
- 345 GW in the Accelerated scenario
- 688 GW with an achievable Paradigm Shift scenario.

By 2030, there could be around 1,082 GW and 1,845 GW of clean PV energy installed under the two scenarios respectively. After a decade, the initial rate of growth would slow down, taking into account repowering from 2025-2030 onwards.

Even with slower growth after 2030, the world should still reach impressive levels of solar power globally.

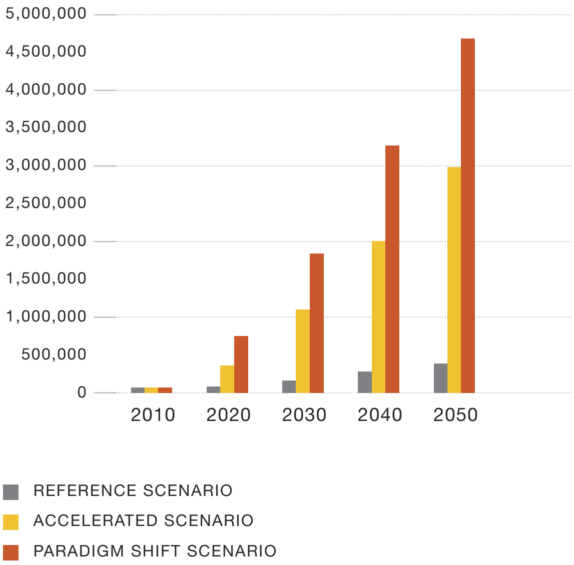
"By 2050, under a Paradigm Shift scenario there could be over 4,500 GW of PV installed world-wide."

FIGURE 34
EVOLUTION OF CUMMULATIVE INSTALLED CAPACITY BY REGION UNDER TWO SCENARIOS
MW



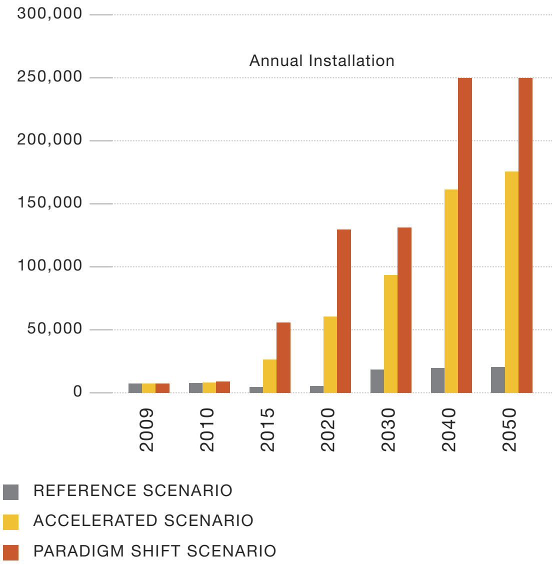
source: Greenpeace/EPIA Solar Generation VI, 2010.

FIGURE 35
TOTAL OF WORLD CUMULATIVE PV INSTALLED CAPACITY UNDER THREE SCENARIOS
MW



source: Greenpeace/EPIA Solar Generation VI, 2010.

FIGURE 36
ANNUAL MARKET TO 2050 UNDER THREE SCENARIOS
MW



source: Greenpeace/EPIA Solar Generation VI, 2010.

"About 250 GW of PV could be installed annually from the year 2040."

TABLE 16
WORLD-WIDE CUMULATIVE PV INSTALLED CAPACITY AND PRODUCTION TO 2050 USING THE REFERENCE, ACCELERATED AND PARADIGM SHIFT SCENARIOS

		2007	2008	2009	2010	2015	2020	2030	2040	2050
Reference	MW	3	15,707	22,999	30,261	52,114	76,852	155,849	268,893	377,263
	TWh	0	17	24	32	55	94	205	377	562
Accelerated	MW	3	15,707	22,999	34,986	125,802	345,232	1,081,147	2,013,434	2,988,095
	TWh	0	17	24	37	132	423	1,421	2,822	4,450
Paradigm	MW	3	15,707	22,999	36,629	179,442	737,173	1,844,937	3,255,905	4,669,100
	TWh	0	8	24	39	189	904	2,266	4,337	6,747

source: Greenpeace/EPIA Solar Generation VI, 2010.

b. Regional development

Europe will continue to lead the PV world until 2020 under the Accelerated and Paradigm Shift scenarios. By this date, North America will have developed enough capacity. China's capacity should be 29 GW in the Accelerated scenario, however, it could almost double that figure (38 GW) in the Paradigm Shift scenario.

Erlasee Solar Park, one of the largest tracking PV solar power station in the world.

The real take-off for non-western regions will happen during the period from 2020 to 2030. China and India both have massive potential for growth during this timeframe.

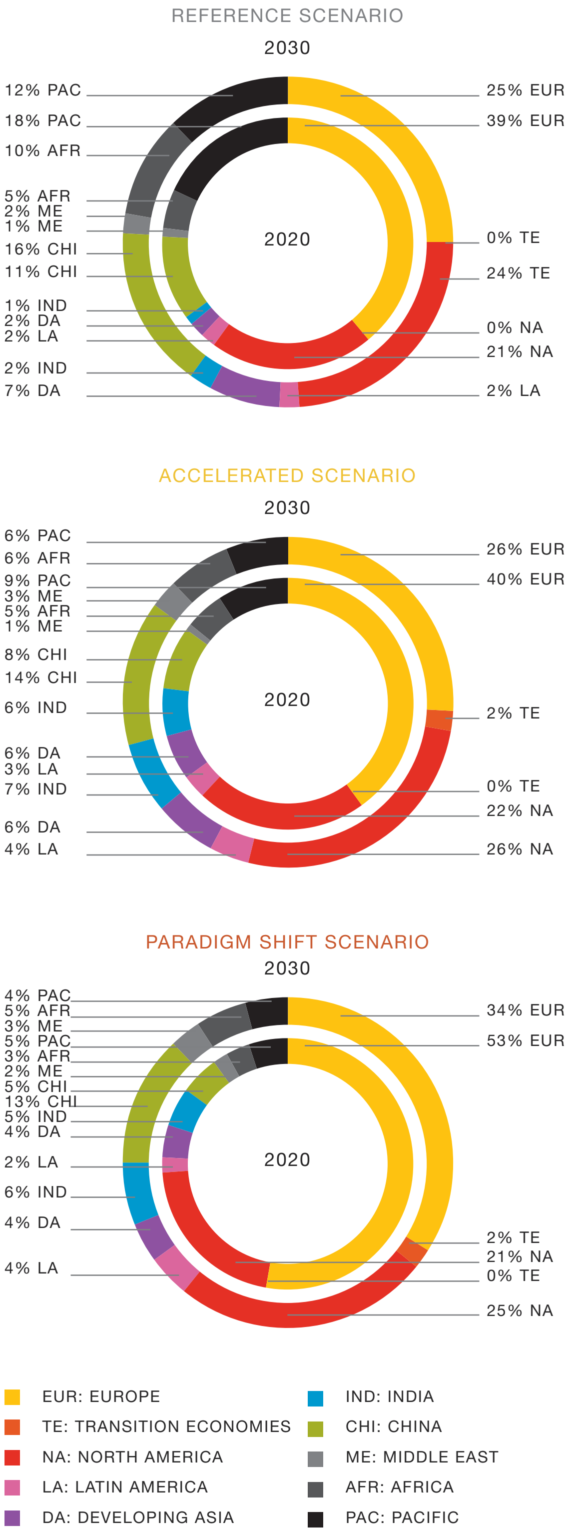
"Europe will continue to lead the PV world until 2020."

TABLE 17
PV INSTALLED CAPACITY EVOLUTION BY REGION UNTIL 2030
GW

Reference Scenario	OECD Europe	Transition Economies	OECD North America	Latin America	Developing Asia	India	China	Middle East	Africa	OECD Pacific	Total
2020	30	0	16	1	2	1	8	1	4	13	**77**
2030	38	0	37	3	11	4	25	4	15	19	**156**
Accelerated Scenario											
2020	140	1	77	9	19	20	29	3	16	31	**345**
2030	280	20	285	47	70	71	150	30	62	64	**1,081**
Paradigm Shift Scenario											
2020	366	3	145	15	24	33	38	11	21	33	**688**
2030	631	42	460	66	83	113	242	47	85	77	**1,845**

source: Greenpeace/EPIA Solar Generation VI, 2010.

FIGURE 37
REGIONAL DEVELOPMENT LINKED TO PV EXPANSION UNDER THREE SCENARIOS
%



source: Greenpeace/EPIA Solar Generation VI, 2010

The solar market has initially grown in developed countries; however it is expected to shift to developing countries in the coming decades. After 2020, North America, China and India will drive the PV market. After 2030, Africa, the Middle East and Latin America will also provide very significant contributions. Grid connected systems will continue to dominate the market in developed countries. In developing countries PV will be integrated into the electricity network in towns and cities, while off-grid and mini-grid installations are expected to play an increasing role in Asian and African countries to power remote villages.

Solar electricity is an efficient way to get power to people in developing countries, especially in regions with lots of Sun. While a standard household of 2.5 people in developed countries uses around 3,500 kWh annually, a 100 Wp system (generating around 200 kWh in a country from the "Sunbelt") in developing countries can cover basic electricity needs for 3 people per household. In Europe, the generation of 500 TWh of electricity would mean delivering electricity to 357 million of Europeans at home. In the non-industrialised world, each 100 GW of PV installed for rural electrification can generate electricity for 1 billion people.

"The solar market is expected to shift to developing countries in the coming decades."

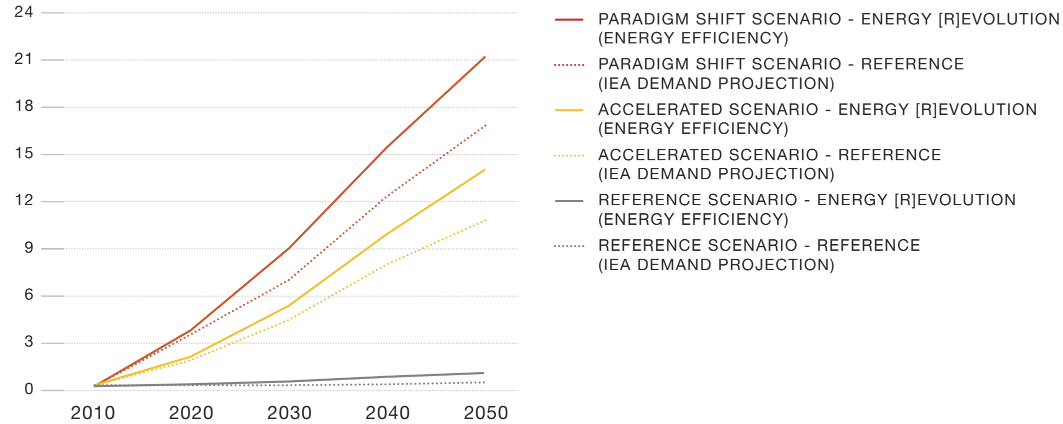
Electricity production

The share of PV in the electricity market will depend on what happens to electricity consumption in light of global efforts to reduce greenhouse gas emissions. PV could provide as much as 11.3% to 21.2% of electricity demand by 2050.

By 2020, the penetration of PV in the world electricity market could reach a global average of 3.9%. However, in Europe the share could be up to 12% in a Paradigm Shift scenario.

"PV electricity could provide over one fifth of the global electricity demand by 2050."

FIGURE 38
AMOUNT OF SOLAR PV ELECTRICITY AS A PERCENTAGE OF WORLD POWER CONSUMPTION
%



Reference Solar market growth - IEA Projection		2010	2020	2030	2040	2050
Solar power penetration of World's electricity in % - Reference (IEA Demand Projection)	%	0.2	0.4	0.7	1.1	1.4
Solar power penetration of World's electricity in % - Energy [R]evolution (Energy Efficiency)	%	0.2	0.4	0.8	1.3	1.8
Accelerated Solar Market growth						
Solar power penetration of World's electricity in % - Reference (IEA Demand Projection)	%	0.2	1.9	4.9	8.2	11.3
Solar power penetration of World's electricity in % - Energy [R]evolution (Energy Efficiency)	%	0.2	2.0	5.7	10.1	14.0
Paradigm Shift Solar Market Growth						
Solar power penetration of World's electricity in % - Reference (IEA Demand Projection)	%	0.2	4.0	7.8	12.6	17.1
Solar power penetration of World's electricity in % - Energy [R]evolution (Energy Efficiency)	%	0.2	4.2	9.1	15.5	21.2

source: Greenpeace/EPIA Solar Generation VI, 2010

c. Employment and investment

As mentioned, 30 FTE jobs are created for each MW of solar power modules produced and installed. Using this assumption, more than 228,000 people are employed in the solar energy sector in 2009. Using the Reference scenario, this figure would fall to around 136,000 jobs in 2015, and rise to 187,000 in 2020 and reach almost 509,000 by 2030.

In the Accelerated scenario, the solar electricity sector would become a powerful jobs motor, providing green-collar employment to almost 1.7 million people by 2020 and 2.63 million by 2030.

The Paradigm Shift scenario would see employment levels in solar electricity as high as 1.37 million as early as 2015, rising to 3.78 million in 2020 and 3.55 million in 2030.

In terms of global investment, the PV industry could attract €79 billion per year in 2020, increasing to €93 billion in 2030 under the Accelerated scenario. With a Paradigm Shift, investment in the world's PV electricity market would attract investment of €129 billion a year by 2020. The scenario foresees that this would level off over the next two decades, reaching €149 billion per year in 2050.

Worker installing PV module, Wesco court, Woking, UK.

"Over 3.5 million people could be employed in the PV sector in 2030."

TABLE 18
INVESTMENT AND EMPLOYMENT POTENTIAL OF SOLAR PV

Reference Scenario	2008	2009	2010	2015	2020	2030	2040	2050
Annual Installation MW	4,940	7,262	7,550	4,117	5,920	18,740	19,928	20,129
Cost €/kW	3,000	2,900	2,800	2,351	2,080	1,703	1,487	1,382
Investment € billion/year	15	21	14	12	13	27	30	28
Employment Job/year	156,965	228,149	237,093	136,329	187,464	508,944	476,114	692,655
Accelerated Scenario								
Annual Installation MW	4,940	7,262	12,091	27,091	59,031	96,171	162,316	174,796
Cost €/kW	3,000	2,900	2,800	1,855	1,340	966	826	758
Investment € billion/year	15	21	34	50	79	93	134	133
Employment Job/year	156,965	228,149	374,319	810,228	1,690,603	2,629,968	4,027,349	4,315,343
Paradigm Shift Scenario								
Annual Installation MW	4,940	7,262	13,625	47,000	135,376	136,833	250,000	250,000
Cost €/kW	3,000	2,900	2,500	1,499	951	744	645	596
Investment € billion/year	15	21	34	70	129	100	161	149
Employment Job/year	156,965	228,149	417,010	1,372,185	3,781,553	3,546,820	5,563,681	5,346,320

source: Greenpeace/EPIA Solar Generation VI, 2010.

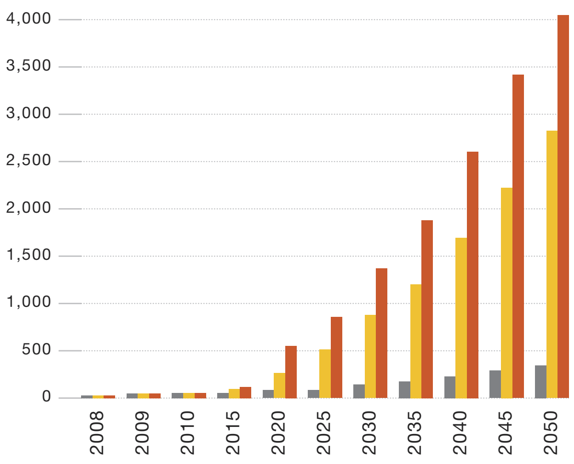
d. CO_2 reduction

Tackling climate change using PV

Under the Paradigm Shift scenario, up to 4,047 million tonnes of CO_2 equivalent would be avoided every year by 2050. The cumulative total from 2003 to 2050 would represent up to 65 billion tonnes of CO_2 equivalent saved. There is no doubt that PV can be an efficient tool to replace conventional power generation and fight climate change.

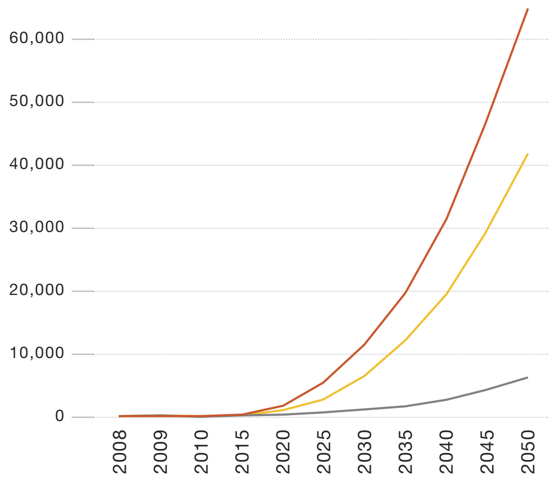
"PV could save over 4 billion tonnes of co_2 equivalent in the year 2050."

FIGURE 39
ANNUAL CO_2 REDUCTION
MILLION TONNES CO_2



source: Greenpeace/EPIA Solar Generation VI, 2010.

FIGURE 40
CUMULATIVE CO_2 REDUCTION
MILLION TONNES CO_2



source: Greenpeace/EPIA Solar Generation VI, 2010.

Reference Scenario	2008	2009	2010	2015	2020	2030	2040	2050
CO_2 reduction (with 600g CO_2/kWh) [annual Mio tCO_2]	10	15	19	33	57	123	226	337
Avoided CO_2 since 2003 [cummulative Mio tCO_2]	35	50	69	208	438	1,300	3,031	5,911
Accelerated Scenario								
CO_2 reduction (with 600g CO_2/kWh) [annual Mio tCO_2]	10	15	20	73	254	853	1,693	2,670
Avoided CO_2 since 2003 [cummulative Mio tCO_2]	61	75	95	327	1,160	6,580	19,153	41,460
Paradigm Scenario								
CO_2 reduction (with 600g CO_2/kWh) [annual Mio tCO_2]	5	15	20	113	540	1,358	2,603	4,047
Avoided CO_2 since 2003 [cummulative Mio tCO_2]	56	70	90	404	2,014	11,085	30,559	64,890

source: Greenpeace/EPIA Solar Generation VI, 2010.

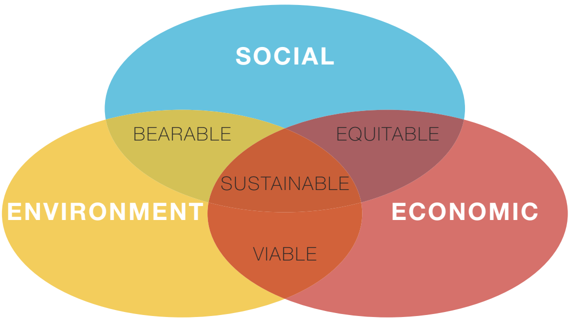
SOLAR BENEFITS AND SUSTAINABILITY 6

6. SOLAR BENEFITS AND SUSTAINABILITY

Sustainable development can be described as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[37]. The concept of sustainability is based on three pillars: social, environmental and economic sustainability. This chapter summarises how the benefits of PV electricity can contribute to each of these three pillars.

"PV electricity generates a number of economic benefits for the entire society."

FIGURE 41
DEFINITION OF SUSTAINABILITY



source: IUCN – The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century, 2006.

6.1. Economic benefits

Apart from being a clean and reliable source of electricity, PV generates a number of economic benefits for the entire society. The *SET For 2020* study has analysed the net economic benefits of PV to society for the European Union.

Figure 41 illustrates the benefits of PV in Europe expressed in €ct/kWh as calculated in the study. All contributing factors are shortly explained below including the cost of Feed-in Tariffs. It demonstrates that Feed-in Tariffs generate more benefits than what they cost initially to electricity consumers[38].

Support schemes benefits

The Feed-in Tariffs received by PV plant owners are a benefit to them. The overall costs for the Feed-in Tariffs are usually rolled over to final electricity consumers and included in their electricity bills. In practice, Feed-in Tariffs are thus creating an income transfer from the whole society to people that decided to invest in PV. As such, their net effect on society is neutral

A study investigating the effect of the Feed-in Tariff cost on the electricity price in Germany was conducted by Phoenix Solar AG with the consulting firm A. T. Kearney. It shows that the net effect of the penetration of PV on the electricity price in Germany is about 1.28€ct/kWh. This represents about 5% of the current electricity price (23.7€ct/kWh).

Reduction of greenhouse gas emissions

The cost of greenhouse gas emissions from power generation can be easily decreased using PV. The manufacturing of PV systems emits between 15 g and 25 g of CO_2-equivalent per kWh, to be compared with the average 600g that each kWh produced in the world emits. And during their operational lifetime, PV systems do not emit any greenhouse gases. Moreover, the carbon footprint of PV systems is decreasing every year. Currently, the external costs to society incurred from burning fossil fuels are not included in electricity prices.

In Europe 1.2 €ct can be saved for each kWh produced by PV electricity. On a world-wide basis the current electricity mix is even more carbon intensive than in the European Union, which means that savings on a global scale will be even larger. It can be assumed that with the current global electricity mix more than 600g/kWh CO_2 equivalent emissions are emitted. The value of avoided emissions by PV on a world-wide scale can be therefore as high as 2.3€ct/kWh.*

* Assumption on the price of carbon dioxide emissions from fossil fuels: 38€/tonne CO_2.

Reduction of grid losses

PV can be considered as a distributed and decentralised source of energy. Producing electricity near the place where it is consumed implies a reduction in the distribution and transmission losses (costs) which are linked to the distance between the point of generation and the point of use. The *SET For 2020* study shows that with the avoidance of grid losses in Europe, the added value of PV would be of 0.5€ct/kWh.

Energy security (hedging value)

Once installed, a PV system will produce electricity for at least 25 years at a fixed and known cost. Conventional power plants must deal with fluctuating prices for fossil fuels such as oil, gas or coal on the international markets. The certainty of being independent from such fluctuations has been valued for Europe at 1.5 to 3.1€ct/kWh depending on the assumptions of the oil, gas and coal prices evolution.

Operating reserve

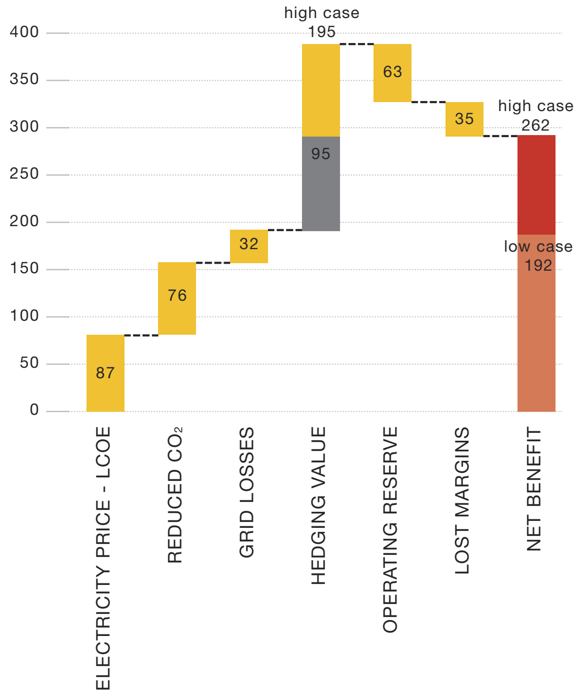
PV requires additional operating reserves to ensure the full reliability of PV electricity systems. This cost is due to the variable nature of PV electricity production and is well-known. In Europe, the additional balancing cost linked to PV operating reserves has been evaluated around 1€ct/kWh.

Lost margins for utilities

Every kWh of PV is produced by a PV plant owner or an Independent Power Producer (IPP) instead of a traditional utility. Therefore, margins of utilities will definitely shrink because of PV. In Europe, this effect has been quantified to be approximately 0.6€ct/kWh.

However, this offers also opportunities for utilities as they will have to adapt their business models transforming into new generation utilities that can take up important tasks in the future electricity grids as aggregators, facilitators and network service providers.

FIGURE 42
EXAMPLE OF CUMULATIVE BENEFITS OF PV (EUROPE, SET FOR 2020 PARADIGM SHIFT SCENARIO).
€Bn



source: EPIA, Set for 2020, 2009.

"PV contribute to reduce gas emissions , grid losses and increase energy security, all these benefits should be quantified."

There are a couple of additional benefits related to PV, apart from those mentioned above. However, it is less straightforward to measure them, as a clear calculation base is lacking.

Industry development

PV requires industrial capacity: raw material providers; module manufacturers; machinery and equipment providers; installers; and other services linked to the electricity system. This generates added value for the community; not only in terms of jobs, but also in terms of industrial development, and business generation.

Moreover, PV contributes to the structural change needed to build an efficient and distributed energy world. PV enables the development of smart grid technology and integrated, innovative applications, such as electric vehicles and energy-positive buildings. It also contributes to the enhancement of competition in the currently rather concentrated power generation market.

Clean and democratic investment

PV can be an alternative, democratic and low-risk investment for all PV plant owners. Instead of investing directly in non-transparent financial funds, PV offers clean and sustainable investment opportunities.

Effects on the electricity generation cost

“PV influences electricity spot prices resulting in lower overall electricity prices.”

PV influences the electricity spot prices during periods of peak demand. The spot price for electricity is the highest during such periods. Electricity network operators typically run special power plants during peaks to meet demand. Investing in and operating these highly flexible plants is an expensive practice. As in many countries most of the PV electricity is generated during the periods of high demand, PV electricity generation helps shave the peak-load, thus reducing spot prices. The high correlation between PV generation and prices of electricity on the spot market[39] is a reality, as seen with the German electricity market. In other words, PV lowers the generation cost of electricity.

Value of PV electricity production after the period of support

Feed-in Tariffs are normally granted for a period of 20 years. However, PV modules can generate electricity for at least 25 years. Experiments have even shown that over 30 years of lifetime is feasible. Therefore, PV systems will generate free electricity during a period of at least 5 years after the end of the support schemes payment period.

6.2 Environmental factors

a. Climate change mitigation

The damage we are doing to the climate by using fossil fuels (i.e. oil, coal and gas) for energy and transport is likely to destroy the livelihoods of millions of people, especially in the developing world. It will also disrupt ecosystems and significantly speed up the extinction of species over the coming decades.

International Climate Policies

Recognising these threats, the signatories to the 1992 UN Framework Convention on Climate Change (UNFCCC) agreed the Kyoto Protocol in 1997. The Protocol finally entered into force in early 2005 and since then its member countries meet twice annually to negotiate further refinement and development of the agreement. Only one major industrialised nation, the United States, has not ratified the agreement made in Kyoto.

The Kyoto Protocol commits its signatories to reduce their greenhouse gas emissions from their 1990 level by 5.2% by the target period of 2008-2012. Nations and regions have adopted a series of reduction targets in order to meet their obligations under the Protocol. In the European Union, for instance, the commitment is to an overall reduction of 8%. To help get there, the EU has agreed to increase its proportion of renewable energy from 6 to 12% by 2010.

International climate negotiations have entered a difficult stage following the Copenhagen Climate Conference (COP 15) which failed to deliver the legally binding international treaty. The treaty would be crucial in providing investment security and a clear direction for the green transformation of the world economy. The Copenhagen Accord, a non-binding letter of political intentions, contains a number of provisions on mid-term targets for developed countries as well as mitigation actions by developing countries. Furthermore, it contains provisions for financial and technological support for developing countries carrying out actions combating climate change. However, the international community is still in search of an internationally accepted formula on how these provisions are to be carried out.

The sixteenth Conference of the Parties (COP 16) took place in Cancun from 29 November to 10 December 2010. After two weeks of talks led by the skilful chairmanship of the Mexican government, delegates at the United Nations Climate Change Conference delivered a balanced package of decisions on adaptation, mitigation technology transfer and finance. The deal reached in Cancun was not rich in content, rather in confidence, especially towards the UNFCCC process. Still, governments have a strict work program ahead to follow through on the Cancun Agreement in order to reach a binding agreement in South Africa on 2011, including major efforts to cut emissions to keep the global temperature rise below 2 degrees, as well as securing fast track and long term finance commitments and the future of the Kyoto Protocol.

EPIA and Greenpeace believe that it is possible to reach a binding deal before the expiration of the end of the first commitment period of the Kyoto Protocol. Such an agreement will need to ensure that industrialized countries reduce their emissions on average by at least 40% by 2020, compared to their 1990 levels. They will need to provide a further $140 billion a year in order to enable developing countries to adapt to climate change, protect their forests and achieve their part of the energy revolution. On the other hand, developing countries themselves need to reduce their greenhouse gas emissions by 15%-30% with regards to their projected growth by 2020 and raise their mitigation ambitions through the Nationally Appropriate Mitigation Actions (NAMAs). NAMAs is a vehicle for the emission reduction actions in developing countries as foreseen in the Bali Action Plan. Thereby a joint commitment from developed and developing economies is needed to limit the growth of greenhouse gas emissions. This is to be done by complying with legally binding emissions reduction obligations and adopting the necessary measures to reduce the use of highly polluting technologies whilst replacing fossil fuel dependency with renewable energy sources.

"EPIA and Greenpeace believe that it is possible to reach a binding deal before the expiration of the Kyoto Protocol."

Greenhouse Effect and Climate Change

The greenhouse effect is a natural process whereby the Earth's atmosphere traps some of the Sun's energy which then warms the planet and controls the climate. However, human activities which produce greenhouse gases have enhanced this effect, thereby artificially raising global temperatures and disrupting our climate. Greenhouse gases include carbon dioxide - produced by burning fossil fuels and through deforestation; methane, -released from agriculture, animals and landfill sites; and nitrous oxide which comes from agricultural production and a variety of industrial chemicals.

The reality of climate change can already be witnessed in the disintegration of polar ice, thawing permafrost, rising sea levels and fatal heat waves. It is not only scientists who are witnessing these changes. From the Inuit of the far north to islanders near the Equator, people are already struggling with impacts of climate change.

An average global warming of more than 2°C threatens millions of people with an increased risk of hunger, disease, flooding in some areas and water shortages in others. Never before has humanity been forced to grapple with such an immense environmental crisis. If we do not take urgent and immediate action to protect the climate, the damage could become irreversible. This can only happen through a rapid reduction in the emission of greenhouse gases into the atmosphere.

If we allow current trends to continue some of likely effects are:

- Sea levels rising due to melting glaciers and the thermal expansion of the oceans as global temperature increases. Massive releases of greenhouse gases from melting permafrost and dying forests.
- A greater risk of more extreme weather events such as heat waves, droughts and floods. Scarily enough, the global incidence of drought has already doubled over the past 30 years.
- Severe regional impacts such as an increase in river flooding in Europe in addition to coastal flooding, erosion and wetland loss. Low-lying areas in developing countries such as Bangladesh and South China could as well be severely affected by flooding.
- Severe threats to natural systems, including glaciers, coral reefs, mangroves, alpine ecosystems, boreal forests, tropical forests, prairie wetlands and native grasslands.
- Increased risk of species extinction and biodiversity loss.

The greatest impacts will be on poorer countries in sub-Saharan Africa, South and Southeast Asia and Andean South America as well as small islands least able to protect themselves from increasing droughts, rising sea levels, the spread of disease and a decline in agricultural production.

Indeed, policy-makers need to ensure that the green industrial revolution happening in the energy sector will accelerate in the coming decade and fully harness the economic opportunities inherent to the promotion of renewable energies. Photovoltaic energy can play an important role in reducing greenhouse gases while generating electricity and jobs on a global scale. Not only is the sun an unlimited fuel source, it also provides the cleanest form of energy available at any scale, large or small. The photovoltaic industry is ready to provide the technological solutions and capacity to support climate mitigation measures in developing and developed countries alike. The obstacles continue to be political, not technical.

"The main drivers to reduce the EPBT of PV systems are to *reduce, reuse* and *replace* materials used."

b. Energy payback time (EPBT)

The production of PV modules requires energy. The energy payback time (EPBT) indicates the number of years a PV system has to operate to compensate for the energy it took to produce, install, dismantle and recycle. The EPBT depends on the level of irradiation (in sunny areas like southern Europe the EPBT is shorter than in areas with relatively low solar irradiance), the type of system (integrated or not, orientation, inclination) and the technology (because of different manufacturing processes and different sensitivities to solar irradiation).

Figure 43 illustrates the EPBT for several PV technologies. The calculation assumes an irradiation of 1,700 kWh/m2/year (southern Europe levels) and that the system is installed on a rooftop benefiting from optimal inclination. The data is extracted from the Ecoinvent database[40], the world's leading database of consistent, transparent, and up-to-date life cycle inventory (LCI) data.

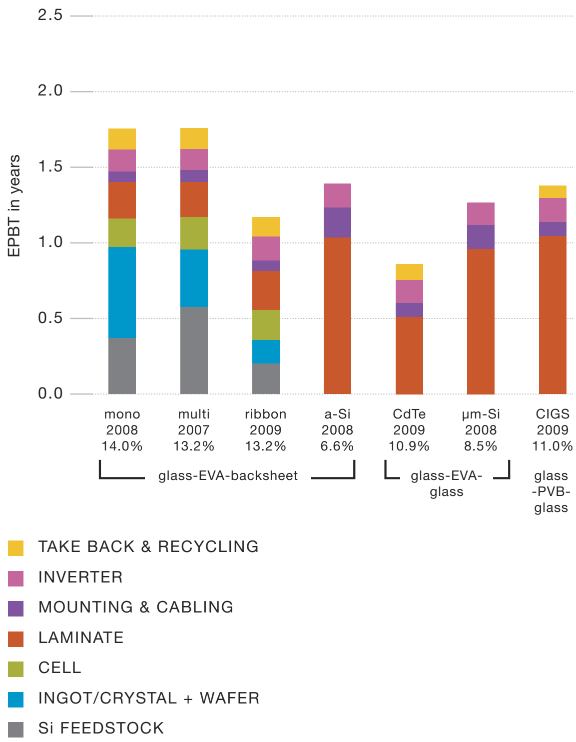
As shown in Figure 43, the production of Si feedstock and ingot is quite energy intensive for c-Si technologies. Hence, new techniques have been developed to reduce energy consumption during these steps of the value chain. This will lead to further decreases in the EPBT of PV systems, improving their sustainability.

TABLE 19
GENERAL INDICATIVE ENERGY PAYBACK TIMES:

EPBT for all PV systems	1 to 3 years
Operational lifetime of PV modules:	25 years (or even more)
Production time for clean electricity:	22 to 24 years (or even more)

source: EPIA.

FIGURE 43
PAY-BACK TIME FOR SEVERAL PV TECHNOLOGIES IN THE SOUTH OF EUROPE



source: Wild-Scholten (ECN) Sustainability: Keeping the Thin Film Industry green, 2nd EPIA International Thin Film Conference Munich, 2009.

The main drivers for further reduction of the EPBT are:

- *Reduce:* using less materials (for example by reducing the thickness of the silicon wafers)
- *Re-use:* recycling of materials
- *Replace:* using materials that generate less CO_2.

Higher system efficiencies for converting solar energy into electricity and continuous improvements in the manufacturing processes will contribute to further decrease the EPBT.

c. Water consumption

The world's population could grow by approximately 25% (from 6 to 8 billion people) by 2030. The demand for water will also increase, but even by about 30%.

Unlike other technologies, PV systems do not require water during their operation. This makes PV a sustainable electricity source in places where water is scarce.

Some water is used during the production process. Approximately 85% of it is used for material extraction and refinement, while module assembly (manufacturing wafers, cells and modules) accounts for the remaining 15%.

Most of the water indirectly used for PV production comes from the electricity consumption of PV factories: conventional power generation uses water, amongst others, for cooling. Hence, an increased share of PV in the electricity mix would lower the water requirements during the production process of PV modules. Moreover, even while water needs for PV are already lower than for other power generation technologies, the industry is working continuously to reduce water consumption during the manufacturing process.

d. Recycling

PV modules are designed to generate clean, renewable energy for at least 25 years. The first significant PV systems were installed in the early 1990s. Full-scale end-of-life recycling is still another ten years away. The PV industry is working to create solutions that reduce the impact of PV on the environment at all stages of the product life cycle: from raw material sourcing through end-of-life collection and recycling.

In 2007, leading manufacturers embraced the concept of producer responsibility and established a voluntary, industry-wide take-back and recycling programme. Now up and running, the PV CYCLE association (www.pvcycle.org) is working towards greater environmental sustainability.

PV CYCLE's more than 100 members represent over 85% of the total European PV market. They have agreed to implement the collection and recycling system developed by PV CYCLE, which will be operational soon.

Recycling technologies exist for almost all types of photovoltaic products and most manufacturers are engaged in recycling activities.

The environmental benefits and burdens of recycling have been assessed through the Chevetogne (Belgium) recycling pilot project. The project shows that the environmental benefits of recycling clearly outnumber the additional environmental burdens (heat, chemical treatment to recover the basic materials enclosed in the modules) that recycling of the modules demands.

PV CYCLE

For moore information: www.pvcycle.org

"The PV industry is working to create solutions that reduce the impact of PV on the environment at all stages of the product life cycle."

6.3. Social aspects

a. Employment

Close to 220,000 people were employed by the solar photovoltaic industry at the beginning of 2010. This number includes employment along the entire value chain world-wide: production of PV products and equipment needed for their production, development and installation of the systems, operation and maintenance as well as financing of solar power plants and R&D.

"Manufacturing jobs are concentrated in some global production hubs while downstream jobs are mainly local."

While manufacturing jobs could be concentrated in some global production hubs, the downstream jobs (related to installation, operation and maintenance, financing and power sales) are, for the moment, still mainly local.

The market expectations for 2010 show that installations could double. This could bring the number of people employed by the PV industry around the world to more than 300,000.

b. Skilled labour and education

PV will provide an increasing number of jobs during the next decades. However, the need for quality installations calls for skilled labour and appropriate education.

Qualifications required will vary, but some of the most relevant qualifications according to the steps of the PV value-chain are the following:

- *Solar module production:* Skilled staff with a clear background in chemistry, physics or related academic studies with a great level of specialisation and knowledge in the PV sector.
- *PV system integrators:* Technicians for the integration of roof-top mounted systems and engineers for the integration of ground-mounted systems. In addition, highly skilled staff is required to provide services such as management, contracting, design and marketing.
- *Installation:* Qualified and certified installers. Ideally; electricians, roofers, plumbers and other construction workers are to bring their knowledge together in a new kind of job description which could be called "solar installer".
- *Operation and maintenance:* No academic or scientific background required.
- *Recycling of PV modules:* Qualified and trained staff in chemistry, physics or related academic studies and with a clear understanding of recycling issues in relation to solar cells, silver, glass, aluminium, foils, electrical components, copper and steel components.
- *Research and development:* Experienced scientists and engineers with a high level of specialisation in PV.

Capacity building is needed at all levels of education to meet the labour demand. Hence, appropriate programmes and measures are needed from education institutions. They should:

- *Strengthen and adapt the quality of their current curriculum:* Academics and technicians attending the courses need to acquire a high level of specialisation.
- *Increase considerably the offer for specific courses in PV:* This will be necessary to meet demand for 50,000 new direct jobs created annually between 2006 and 2030.

  PV education should ideally be provided in the form of a specialised PV Masters degree, or as additional post-graduate training in photovoltaic energy.

  Experts highlight the importance of early practical training in PV. Project-oriented education, external trainings in the industry, and/or lab courses where practical experience can be obtained, are strongly encouraged.

6.4. Rural electrification

While we advocate for a clean power to alleviate climate change, it is important to recognise that many parts of the world operate with no electricity at all. Solar can help address this, in a more sustainable way than fossil fuel power does.

There are three options available to bring electricity to remote areas:

1. *Extend the national grid*
2. *Provide off-grid technologies*
3. *Create mini-grids with hybrid power*

Extension of the national grid

The huge cost of infrastructure and extra generation capacity prevents many countries from developing their national grids. The demand for electricity in cities is growing due to the increase in population, creating conflicts with utilities that need to stabilise the grid and follow the demand.

According to the World Bank, grid extension prices can vary from \$6,340/km in densely populated country such as Bangladesh to \$19,070/km in country like Mali[42]), making grid extension a difficult and expensive choice.

Off-grid solutions

Off-grid power generation using renewable energy sources is becoming more competitive in remote communities. It does not suffer the power losses that come with long transmission lines. Energy Home Systems (EHS) are designed to power individual households and are relatively cheap and easy to maintain.

PV is probably the most suitable type of technology for EHS as shown by the hundreds of thousands of solar home systems deployed around the world. PV systems can cover the energy needs of single households, public buildings and commercial units. In rural areas they can replace the candles, kerosene and biomass traditionally used for lighting and run other applications that are usually driven by dry-cell batteries or diesel generators.

The main types of off-grid PV systems which have been widely tested world-wide are found in Table 18 on the following page.

"Solar can help access clean power in non electrified parts of the world."

Energy and Equality

According to the IEA's report on the world's access to energy[41], in 2008 approximately 1.5 billion people or 22% of the world's population did not have access to electricity, with 85% of those people living in rural areas. Energy alone is not sufficient to alleviate poverty; however, it is an important step in any development progress. Access to electricity for significant amounts of people helps towards a number of Millennium Development Goals (MDG), set by the United Nations. Those goals include:

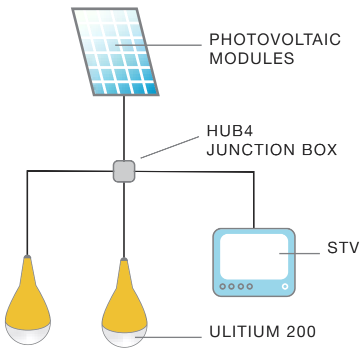
- Reducing hunger by enabling cold food storage (MDG 1)
- Providing access to safe drinking water through pumping systems (MDG1)
- Improving education by providing light and communication tools (MDG2)
- Creating gender equality by relieving women of fuel and water collecting tasks (MDG3)
- Contributing to the reduction of child and maternal mortality, the incidence of disease and the fight against pandemics by providing refrigeration for medication as well as access to modern medical equipment (MDG 4, 5 and 6)
- Using environmentally sound technologies to provide electrical connections in order to contribute to global environmental sustainability (MDG 8).

TABLE 20
MAIN TYPES OF OFF-GRID PV SYSTEMS WHICH HAVE BEEN WIDELY TESTED WORLD-WIDE

New generation of Pico PV systems (PPS)	Classical Solar Home Systems (SHS)	Solar Residential Systems (SRS)
• Used for small loads like highly-efficient LED lamps • Powered by a small solar panel and uses a battery which is often integrated into the lamp itself • Provides a power output of 1 to 10 W, mainly used for lighting and to replace unhealthy and inefficient sources • Depending on the model, can also charge small applications such as mobile phones and radios • User-friendly interface, easy plug-and-play installation, and low investment and maintenance costs.	• Generally cover a power output of up to 250 W. • Normally composed of several independent components such as modules, charge controller and the battery • Technologically mature, has been used for decades and offers more power output than Pico systems • Long-term, reliable source of power for households. • Limited by the need for energy storage which is difficult to improve later. • Require a trained technician for optimum installation and maintenance.	• Off-grid systems with output up to 2,000 W • Usually include a converter, which allows the use of AC loads and usually supply public services or companies • Represent flexible, scalable and adaptable solutions • Stand-alone off-grid PV systems primarily provide electricity for small loads and are not always in use to supply motive

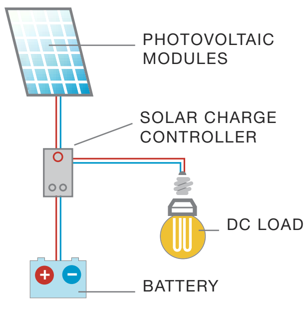
source: Alliance for Rural Electrification.

FIGURE 44
PICO POWER SYSTEM



source: Phaesun.

FIGURE 45
SOLAR HOME SYSTEM



source: Phaesun.

Mini-grid combined with hybrid power

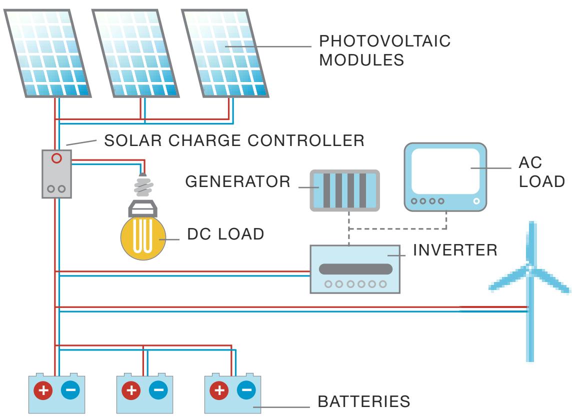
The third approach is a combination of the first two, providing local grids powered by more than one source of generation. PV plays a tremendous role to rural electrification within this approach.

Centralised electricity generation at the local level can power both domestic appliances and local businesses using village-wide distribution networks. They can be driven by fossil fuel or renewable energy sources, or by a combination of both. Backup systems (genset) or battery storage can complement the installation.

Figure 49 shows a village grid that is supplied by a hybrid system. It uses different, but complementary, renewable energy technologies (RET), often with a genset backup and battery storage.

This solution offers many advantages, not only in terms of cost, but also with regard to the availability of energy for small communities. It improves the quality of the electricity delivered and the reliability of the system compared to connections with fluctuating grids. It can be easily scaled up and introduce a large percentage of clean energy into the electricity generation mix. Finally, it can be connected to the national grid when the grid reaches that location.

FIGURE 46
MINI GRID AND HYBRID SYSTEM



source: Phaesun.

Competitiveness of renewable energy in developing countries

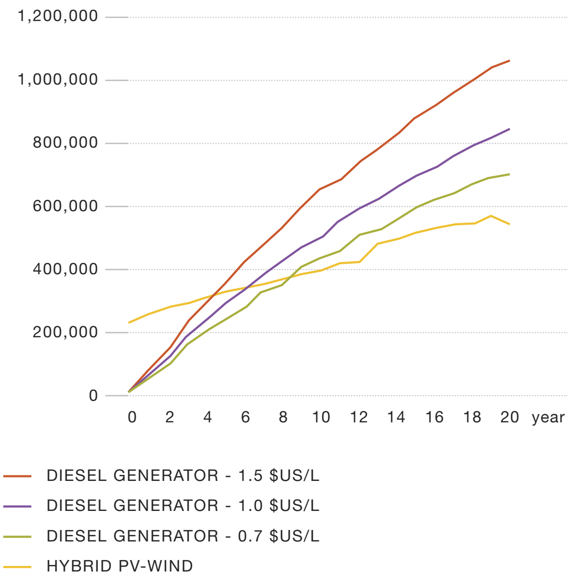
In many cases, off-grid renewable energy solutions offer the lowest generation costs for off-grid electrification with a mini-grid.

If public money and support mechanisms can play an important role in accelerating energy access and supporting renewable systems, some companies already develop and operate large systems without any support, such as in Laos[43] or Gambia[44]. Off-grid renewables are not only a clean and sustainable solution, but they are also economically sound.

Figure 47 shows the cost comparison of several power systems over 20 years, starting in 2010. While the investment in PV systems is higher than in diesel generators, the cost evolution quickly favours the hybrid PV-Wind system.

"off-grid renewable energy solutions offer the lowest generation costs for off-grid electrification with a mini-grid."

FIGURE 47
COST COMPARISONS OF ENERGY POWER SYSTEMS ON A LIFECYCLE BASIS[45]
$US



source: the Alliance for Rural Electrification Projections made from a case study based in Ecuador with real natural conditions.

Challenges

While renewable energy in off-grid and mini-grid solutions is often the most competitive solution, major challenges exist which include:

- Complex financial and organisational questions
- Bottlenecks in the financing, management, business models, sustainable operations and maintenance
- Local social and economic conditions.

"Long term sustainable energy policy strategies are a key challenge for developing countries."

Solutions that are being tried and tested at the minute include:

- Providing stand-alone solutions such as solar home systems with micro credits or a fee for service
- Installing mini-grids via a different business model, using capital subsidies and cost recovery via tariffs.

Policy changes are another challenge that developing countries have to face. Energy policies are often short sighted. Many countries remain focused on grid extension, urban electrification or on large hydro, gas or coal power plants without any long-term strategy for sustainability and supply. When demand outstrips supply, this approach is costly (power shortages, losses for the economic sector) and shows how much diversified electricity generation capacities, especially in rural areas where off-grid technologies can bring reliable electricity, is needed.

More information

The Alliance for Rural Electrification (ARE – www.ruralelec.org) is the key partner of EPIA regarding the development of off-grid PV in developing countries. ARE is the only renewable energy industry association in the world exclusively working for the development of off-grid renewable energy markets in developing countries. They represent companies, organisations, research institutes and unite all relevant private actors in order to speak with one voice about renewable energies in developing countries.

Alliance for Rural Electrification
Shining a Light for Progress

More information: www.ruralelec.org

Solar helps provide access to energy.

LIST OF ACRONYMS

LIST OF FIGURES

µc-Si	micro-crystalline silicon
AC	alternating current
ARE	Alliance for Rural Electrification
a-Si	amorphous silicon
BAPV	building adapted photovoltaic system (built on top of a roof)
BIPV	building integrated photovoltaic system (forms part of a building)
BOS	balance of system
CdS	cadmium sulphide
CdTe	cadmium telluride
CHP	combined heat and power (system)
CIGS	copper, indium, gallium, (di)selenide/(di)sulphide
CIS	copper, indium, (di)selenide/(di)sulphide
CPV	concentrating photovoltaic
c-Si	crystalline silicon
DC	direct current
DSM	demand-side management
DSO	distribution system operator
DSSC	dye-sensitised solar cells
EC	European Commission
EEG	German Feed-in Law
EHS	energy home system
EPBD	Energy Performance of Buildings Directive (EC)
EPBT	energy payback time
EPC	engineering, procurement and construction (of PV systems)
EPIA	European Photovoltaic Industry Association
ESTELA	European Solar Thermal Electricity Association
ETS	Emissions Trading Scheme (EU)
EU	European Union
EU-27	Twenty-seven member countries of the European Union
EU-OEA	European Ocean Energy Association
EV	electric vehicle
EVA	ethyl vinyl acetate
EWEA	European Wind Energy Association
FiT	Feed-in Tariff
FTE	full-time equivalent
FTSM	FiT Support Mechanism
FTSM	FiT Support Mechanism
GaA	gallium arsenide
GDP	gross domestic product
GW	gigawatt
IEA	International Energy Agency
IEA-PVPS	IEA Photovoltaic Power Systems Programme

LIST OF ACRONYMS & REFERENCES

IRR	internal rate of return
JRC	European Joint Research Centre
km	kilometre
kW	kilowatt
kWh	kilowatt hour
kWp	kilowatt-peak units
LCI	life-cycle inventory
LCOE	levelised cost of energy
mc-Si	mono-crystalline silicon
MDG	Millennium Development Goals (UN programme)
METI	Ministry of Energy, Trade and Industry (Japan)
MW	megawatt
NEA	National Energy Authority (China)
NEDO	New Energy and Industrial Technology Development Organisation (Japan)
OPV	organic photovoltaic
PACE	property-assessed clean energy programme
pc-Si	photo-crystalline (multi-crystalline) silicon
PHEV	petrol-hybrid electric vehicle
p-n junction	potential difference junction
PPS	Pico PV system
PV	photovoltaic
PVB	polyvinyl butyral
PVPS	See IEA-PVPS.
R&D	research and development
R2R	roll-to-roll (manufacturing process)
REC	renewable energy credit
RET	renewable energy technology
RPS	renewable portfolio standard
SET-Plan	Strategic Energy Technology Plan
SHS	solar home system
SME	small- to medium-sized enterprise
SRS	solar residential system
TCO	transparent conducting layer
TPV	thermo-photovoltaics
TSO	transport system operator
TWh	terawatt hour
UNFCCC	United Nations Framework Convention on Climate Change
V2G	vehicle to grid
VPP	virtual power plant
WEO 2009	*World Energy Outlook 2009* (IEA report)
Wp	watt-peak. A measure of the nominal power of a photovoltaic solar energy device

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SOLAR GENERATION 6

SOLAR PHOTOVOLTAIC ELECTRICITY EMPOWERING THE WORLD

2011

About EPIA

With over 230 Members drawn from across the entire solar photovoltaic sector, the European Photovoltaic Industry Association is the world's largest photovoltaic industry association and represents about 95% of the European photovoltaic industry. EPIA Members are present throughout the whole value-chain: from silicon, cells and module production to systems development and PV electricity generation as well as marketing and sales.

About Greenpeace

Greenpeace is a global organisation that uses non-violent direct action to tackle the most crucial threats to our planet's biodiversity and environment. Greenpeace is a non-profit organisation, present in 40 countries across Europe, the Americas, Asia and the Pacific. It speaks for 2.8 million supporters worldwide and inspires many millions more to take action every day. To maintain its independence, Greenpeace does not accept donations from governments or corporations but relies on contributions from individual supporters and foundation grants.

Greenpeace has been campaigning against environmental degradation since 1971 when a small boat of volunteers and journalists sailed into Amchitka, an area north of Alaska, where the US Government was conducting underground nuclear tests. This tradition of 'bearing witness' in a non-violent manner continues today and ships are an important part of all its campaign work.

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