8

Solar

Contents

Strategic insight

1. Introduction

Solar energy is the most abundant permanent energy resource on earth and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean etc.) forms. This commentary is limited to the direct use of solar radiation, the earth's prime energy resource.

The sun emits energy at a rate of 3.8×10^{23} kW per second. Of this total, only a tiny fraction, approximately 1.8×10^{14} kW is intercepted by the earth, which is located about 150 million km from the sun. About 60% of this amount or 1.08×10^{14} reaches the surface of the earth. The rest is reflected back into space and absorbed by the atmosphere. Even if only 0.1% of this energy could be converted at an efficiency of only 10% it would be four times the world's total generating capacity of about 3 000 GW. Looking at it another way, the total annual solar radiation falling on the earth is more than 7 500 times the world's total annual primary energy consumption of 450 EJ.

The solar radiation reaching the earth's surface in just one year, approximately 3 400 000 EJ, is an order of magnitude greater than all the estimated (discovered and undiscovered) non-renewable energy resources, including fossil fuels and nuclear. However, 80% of the present worldwide energy use is based on fossil fuels. Several risks are associated with their use. Energy infrastructures - power plants, transmission lines and substations, and gas and oil pipelines - are all potentially vulnerable to adverse weather conditions or human acts. During the summer of 2003, one of the hottest and driest European summers in recent years, the operations of several power plants, oil and nuclear, were put at risk owing to a lack of water to cool the condensers. In other parts of the world, hurricanes and typhoons put the central fossil and nuclear power plants at risk. World demand for fossil fuels (starting with oil) is expected to exceed annual production, probably within the next two decades. Shortages of oil or gas can initiate international economic and political crises and conflicts. Moreover, burning fossil fuels releases emissions such as carbon dioxide, nitrogen oxides, aerosols, etc. which affect the local, regional and global environment.

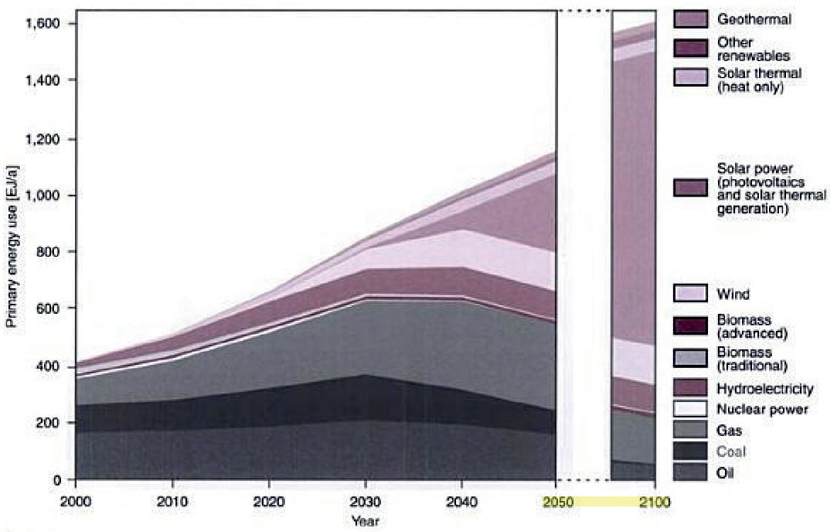
Concerns regarding present energy systems are therefore growing because of the inherent risks connected with security of supply and potential international conflicts, and on account of the potential damage they can do to the natural environment in many and diverse ways. World public opinion, international and national institutions, and other organisations are increasingly aware of these risks, and they are pointing to an urgent need to fundamentally transform present energy systems onto a more sustainable basis.

A major contribution to this transformation can be expected to come from solar radiation, the prime energy resource. In several regions of the world the seeds of this possible transformation can be seen, not only at the technological level, but also at policy levels. For example, the European Union has policies and plans to obtain 20% of its energy needs through renewable energy by 2020. The German Advisory Council on Global Change (WBGU) has conducted an analysis of energy needs and resources in the future to the years 2050 and 2100 (Fig. 10.1) which points to a major contribution by solar energy to global energy needs in the long term. This scenario is based on the recognition that it is essential to move

Figure 8.1

Transforming the global energy mix: the exemplary path to 2050/2100

Source: WBGU, 2003



energy systems towards sustainability worldwide, both in order to protect the natural life-support systems on which humanity depends and to eradicate energy poverty in developing countries. Of course, this new solar era can be envisioned mainly because of the tremendous scientific and technological advances made during the last century and the ongoing research and development.

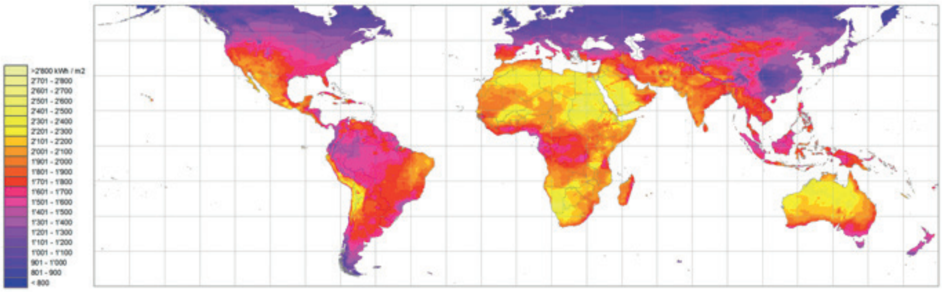
By 2100 oil, gas, coal and nuclear, as shown in Fig. 10.1 (above), will provide less than 15% of world energy consumption while solar thermal and photovoltaic will supply about 70%. Key elements of this long-term scenario are the energy efficiency and energy intensity policies that will make the contribution of renewable and solar energy a substantial factor. Those policies will deeply transform the building and construction, industry and transport sectors, increasing their reliance on renewable energy resources.

The transition towards this possible future has already started. In the following paragraphs an attempt will be made to show this by reviewing the state of the art regarding solar radiation resource assessment and the status and rate of growth of the major solar energy technologies, their technical and market maturity as well as institutional and governmental policies and approaches to promote their integration into the world's energy systems.

Solar Radiation Resources

The amount of solar radiant energy incident on a surface per unit area and per unit time is called irradiance or insolation. The average extraterrestrial irradiance or flux density at a mean earth-sun distance and normal to the solar beam is known as *the solar constant*, which is 1366.1 W/m^2 according to the most recent estimate. The energy delivered by the sun is both intermittent and changes during the day and with the seasons. When this power density is averaged over the surface of the earth's sphere, it is reduced by a factor of 4. A further reduction by a factor of 2 is due to losses in passing through the earth's atmosphere. Thus, the annual average horizontal surface irradiance is approximately 170 W/m^2. When 170 W/m^2 is integrated over 1 year, the resulting 5.4 GJ that is incident on 1 m^2 at ground level is approximately the energy that can be extracted from one barrel of oil, 200 kg of coal, or 140

Figure 8.2
Yearly sum of global horizontal irradiation, 1986-2005
Source: www.meteonorm.com



m³ of natural gas. However, the flux changes from place to place. Some parts of the earth receive much higher than this annual average. The highest annual mean irradiance of 300 W/m² can be found in the Red Sea area, and typical values are about 200 W/m² in Australia, 185 W/m² in the United States and 105 W/m² in the United Kingdom. These data show that the annual solar resource is almost uniform (within a factor of about 2), throughout almost all regions of the world. It has already been shown that economically attractive applications of solar energy are not limited to just the sunniest regions. Northern European countries offer good examples of this. Figure 10.2 shows the world yearly sum of global horizontal irra-

Figure 8.3
Average daily solar radiation for March
Source: NASA/SSE

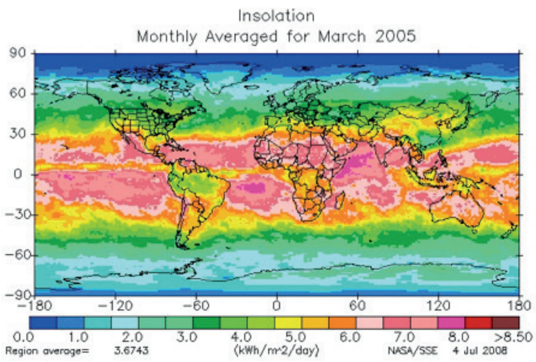


Figure 8.4
Average daily solar radiation for July
Source: NASA/SSE

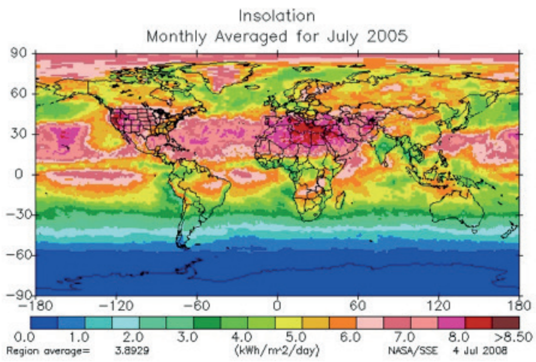


Figure 8.5
Average daily solar radiation for September
Source: NASA/SSE

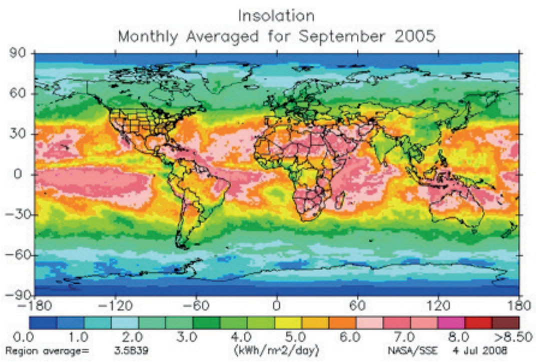
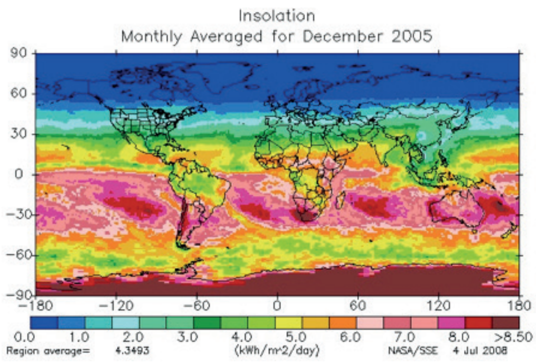


Figure 8.6
Average daily solar radiation for December
Source: NASA/SSE



diation. Figures 10.3 to 10.6 also show the monthly solar energy falling on the Earth in the months of March, July, September and December.

In a period of rapidly growing deployment of solar energy systems, it is imperative that solar resource parameters and their space/time specificity be well known to solar energy professionals, planners, decision makers, engineers and designers. Because these parameters depend on the applications (flat solar thermal collectors, solar thermal power plants, photovoltaic, window glass, etc.), they may differ widely, and might be unavailable for many locations, given that irradiance measurement networks or meteorological stations do not provide sufficient geographically time/site-specific irradiance coverage. This coverage is especially useful because it allows assessment of the output of a solar system in relation to the technical characteristics of the system, local geography and energy demand. It therefore allows a better assessment of the feasibility of a solar energy application and of its value.

Measured solar radiation data are available at a number of locations throughout the world. Data for many other locations have been estimated, based on measurements at similar climatic locations. The data can be accessed through internet web sites of national government agencies for most countries in the world. Worldwide solar radiation data are also available from the World Radiation Data Center (WRDC) in St. Petersburg, Russia. WRDC, operating under the auspices of the World Meteorological Organization (WMO) has been archiving data from over 500 stations and operates a web site in collaboration with the National Renewable Energy Laboratory (NREL) (http://wrdc-mgo.nrel.gov). Other sources of data are given in the references at the end of this commentary. Most recently, methods are being developed to convert measurements made by satellites to solar radiation values on the ground. Once these methods are developed and validated, they will be able to provide solar radiation data for any location in the world.

Solar Collectors

Solar thermal collectors are used to heat air, water or other fluids, depending on the applications, while solar photovoltaic (PV) collectors are used to convert sunlight to electricity directly. High-temperature solar thermal collectors are also used to produce electricity indirectly via thermodynamic cycles. Non-concentrating (or flat-plate) types of solar collectors can produce temperatures of about 100ºC or less, which is applicable for many uses such as building heating and cooling, domestic hot water and industrial process heat. Medium-temperature concentrating collectors such as parabolic troughs or parabolic dishes may be used to provide temperatures from about 100ºC to about 500ºC. Such collectors may be used for various applications from refrigeration to industrial process heat and electricity generation. Central-receiver types of solar concentrating collectors are able to produce temperatures as much as 1000C or even higher. Therefore, they are used to produce electrical power and as high-temperature furnaces in industrial processes. Solar thermal power plants based on these concentrating solar collectors, also known as Concentrating Solar Power or CSP is now being increasing considered and deployed by electrical utilities in the size range of 1 MW to 300 MW in many countries, including USA, Spain, India, China, Australia and South Africa.

PV panels are solid-state and are therefore very rugged, with a long life. At present, panels based on crystalline and polycrystalline silicon solar cells are the most common. However, thin-film solar panels, especially cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) are gaining market share because of their lower costs. Their efficiencies have gradually increased, while costs have decreased. For example, the efficiencies of multijunction cells and concentrating PV have been reported to be as high as 44%, and most panels available in the market have efficiencies of the order of 15%. The price of PV panels came down from about US$ 30/W about 30 years ago to less than US$ 1/W in 2013. Although thin-film solar cells increased their global market share in the last decade because of lower cost , manufacturers have been able to reduce the cost of producing silicon based solar panels to match the thin film panel costs. Therefore, silicon based panels have kept their market share close to 80%. To evaluate the efficiency of solar energy systems, a standard flux of about 1000 W/m^2 is used, which is approximately the solar radiation incident on a surface directly facing the sun on a clear day around noon. Consequently, solar systems are rated in terms of *peak watts* (output under a 1 kW/m^2 illumination).

2. Technical and economic considerations

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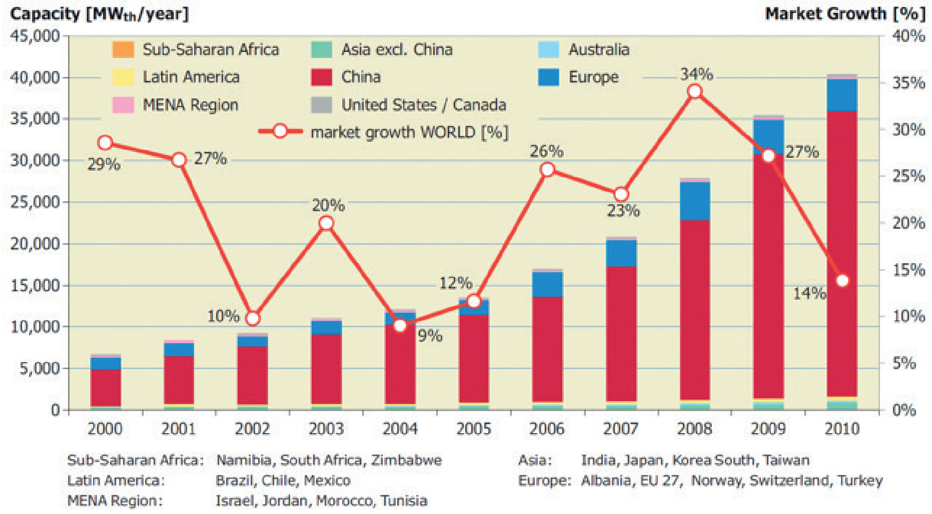
Figure 8.7
Worldwide market for glazed solar water heaters of flat plate and evacuated tube collectors from 2000 to 2010
Sources: IEA SHC



Solar Energy Applications

The energy in solar radiation can be used directly or indirectly for all of our energy needs in daily life, including heating, cooling, lighting, electrical power, transportation and even environmental cleanup. Many such applications are already cost-competitive with conventional energy sources, for example, PV in remote applications is replacing diesel generator sets. Some applications, such as photovoltaics and solar heating are better known and popular, while others such as solar detoxification of contaminated waters or solar distillation are less known.

Solar water heating is the most developed solar technology and is very cost-effective when life-cycle costs are considered. However, the initial costs (capital investment) of solar water heaters are many times higher than those for electric water heaters. Therefore, most people opt for electric water heaters. In many countries, governments have adopted policies and financing mechanisms that make it easier for consumers to buy solar water heaters. For this reason the adoption of solar water heating worldwide is growing at an average rate of more than 25 % per year, as shown in Fig. 10.7, although the rate of growth went down in 2009 and 2010 due to global economic downturn.

Adoption of solar water heating can have a great impact on the reduction of peak electrical load and thus greenhouse gas emissions. For example, if all the electric water heaters in the USA (approximately 100 million) were replaced by solar water heaters, it would reduce the peak load by about 100 GW.

Solar Industrial Process Heat (SIPH) is an ideal application of solar energy. As a matter of fact, 30-50% of the thermal energy needed in industrial processes is below 250C, which can be easily provided by low- and medium-temperature solar collectors. Consequently, this application of solar energy is expected to grow as the cost of fossil fuels goes up.

In industrialised countries, 35-40% of total primary energy consumption is used in buildings. However, if the energy used to manufacture materials and the infrastructure to serve the

Figure 8.8
Examples of Building Integrated Photovoltaics
Source: http://construible.es/

buildings is taken into account then buildings' share of total primary energy consumption can be around 50%. In Europe, 30% of energy use is for space and water heating alone, representing 75% of total energy use in buildings. Solar technologies can make a substantial contribution to the energy budget of modern buildings, and consequently to the world's energy use. Buildings can be the largest collectors of solar energy and therefore the electrical appliances (light bulbs, refrigerators, washing machines, etc.) with innovative energy-efficient models, can reduce electricity demand and increase the significance of, e.g. photovoltaic electricity, to the whole energy budget. Passive solar building designs can reduce the conventional energy consumption by as much as 75% and PV can provide the rest. Such designs use knowledge of the position of the sun either to allow sunlight to enter the building for heating or to shade the building for cooling, and employ natural ventilation and daylighting. There is thus a growing trend towards passive solar and Building Integrated Photovoltaics (BIPV) designs. In BIPV designs, PV panels replace some other component of the building such as roof shingles, wall panels or window shades etc. PV manufacturers are developing very attractive patterns, colours and designs of panels, and architects are integrating them into buildings, making them look even more attractive. These PV panels consequently become much more cost-effective than they would otherwise be. Fig.10.8 shows examples of a PV integrated building.

Globally, about 8-10 million new buildings are constructed every year, most of them in developing countries. Large areas of these countries do not have access to grid electricity, thus making solar energy an attractive alternative. Even if only a tiny fraction of these buildings were served by solar, the implications for the solar and energy industry could be enormous, not only from a technological point of view but also from a cultural point of view. It would be a contributory factor to changing the way people think about conventional sources of energy and solar energy.

Even though solar building applications can be cost-effective, they may not happen without appropriate policy intervention. New regulations and building codes, regarding energy-saving measures and the integration of energy-efficient and solar technologies in buildings, will be necessary to accelerate the deployment of solar energy. Such policy intervention has been the secret behind several success stories in the use of solar thermal collectors:

Figure 8.9
The Japanese Cosmotown Kiyomino SAIZ housing development
Source: Goswami

for example, the 1980 regulation in Israel requiring every new building with a height of less than 27 m to have a solar thermal system on its roof. Similar regulations adopted over the last few years by a number of large and small towns elsewhere have stimulated a significant growth in solar thermal installations.

Because buildings do not exist in isolation, the 'whole building' approach can be extended to blocks of buildings or to towns, as in the photovoltaic application shown in Fig. 10.9 (overleaf). This depicts Cosmotown Kiyomino SAIZ, a complex of 79 homes built by the Hakushin Company, with the Kubota Corporation supplying a roof-integrated 3 kW photovoltaic power generation system for each house. This illustration also underlines an argument, often raised against solar energy utilisation: namely land usage. Solar energy is often seen as a 'dispersed' source of energy compared with concentrated fossil fuels and nuclear energy. This argument is misleading because the solar energy systems installed on walls and roofs in Kiyomino do not use land additional to that used for the construction of the buildings themselves. Moreover, land usage for fossil-fuel infrastructures for transportation, distribution and waste storage can be considerable.

The extension of solar energy use from a block of solar buildings to an entire city is possible. There are several cities around the world that are working in this direction, aiming at greater use of solar energy within the context of a long-term plan for sustainable urban development. Such projects focus on cities as complete systems, in which passive solar heating and cooling, daylighting, solar photovoltaic, and solar thermal technologies are integrated.

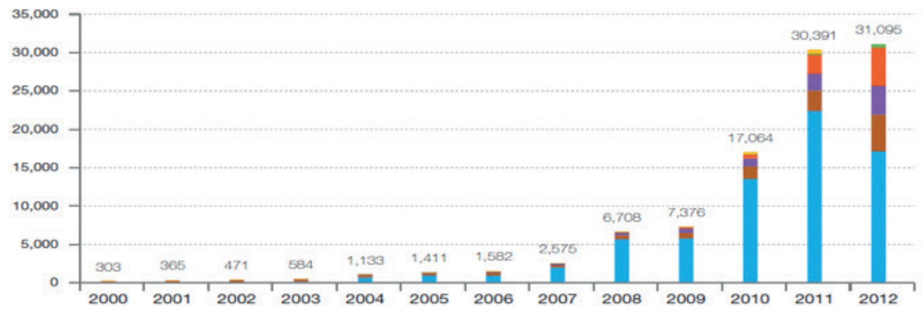
In the following paragraphs the most widely used solar systems for the production of electricity, heat and fuels are reviewed.

Solar Photovoltaic Systems (PV)

Photovoltaic conversion is the direct conversion of sunlight into electricity with no intervening heat engine. As indicated above, photovoltaic devices are rugged and simple in design and require very little maintenance. Perhaps the biggest advantage of solar photovoltaic devices is that they can be constructed as stand-alone systems to give outputs from microwatts to megawatts. That is why they have been used as the power sources for calculators, watches, water pumping, remote buildings, communications, satellites and space vehicles, and even multi-megawatt scale power plants. With such a vast array of applications, the demand for photovoltaics is increasing every year. In 2012, over 31 000 MWp of photovoltaic panels were sold for terrestrial uses and the worldwide market has been growing at a phenomenal rate since 2000 (Fig. 10.10 overleaf).

In the early days of solar cells in the 1960s and 1970s, more energy was required to produce a cell than it could ever deliver during its lifetime. Since then, dramatic improvements have taken place in their efficiency and manufacturing methods. The energy payback period has been reduced to about 2-4 years, depending on the location of use, while panel lifetime has

Figure 8.10
Worldwide market for photovoltaic panels
Source: EPIA and P. Maycock



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
ROW	88	56	80	77	29	10	105	42	76	80	284	508	-*
MEA	n/a	n/a	n/a	n/a	1	n/a	n/a	1	1	22	46	121	410
China	19	5	19	10	10	8	10	20	40	160	500	2,500	5,000
Americas	24	32	47	66	104	106	150	213	346	543	1,029	2,179	3,758
APAC	117	140	191	230	282	303	324	271	535	742	1,583	2,672	4,769
Europe	56	133	135	202	707	984	992	2,028	5,710	5,830	13,622	22,411	17,159
Total	303	365	471	584	1,133	1,411	1,582	2,575	6,708	7,376	17,064	30,391	31,095

increased to over 30 years. The energy payback period of multijunction thin-film Concentrating PV is projected to be less than one year. As mentioned above, the cost of photovoltaic panels has come down. The current retail cost of solar panels results in system costs of US$ 2.5-4/W which is cost effective for many Building Integrated applications. For MW-scale PV systems, however, the system costs have come down to less than US$ 2/W which moves the technology closer to cost effectiveness for on-grid applications considering their long lifetimes (over 25 years), no fuel costs and low maintenance costs. However, these dollar costs do not adequately portray the true environmental value of solar PV systems. Even at an energy payback period of 3 years and a lifetime of 25 years, the return on energy investment is more than 8:1 and return on CO_2 avoidance is more than 6:1.

Figure 8.11
World record efficiencies of various PV technologies
Source: NREL

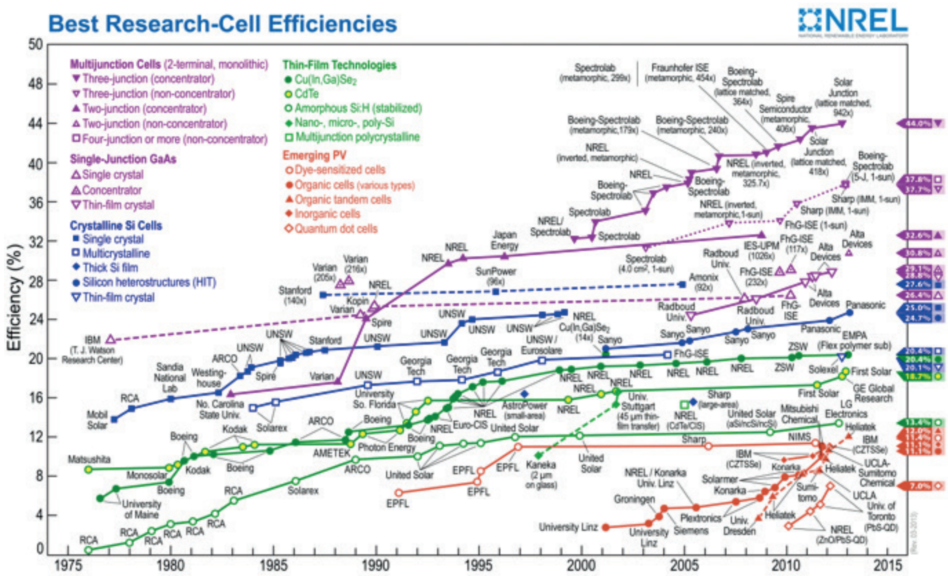
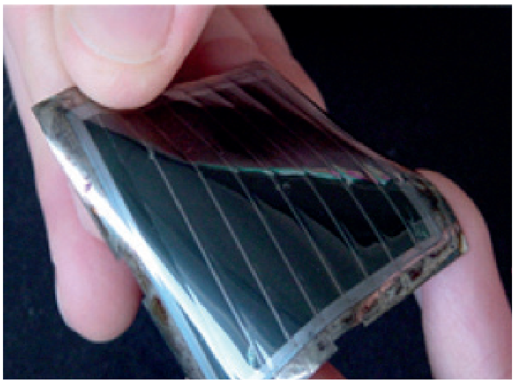


Figure 8.12
Flexible monolithic CIGS prototype mini-module on a polymer foil
Source: Goswami



The limits imposed on the efficiency of solar cells due to band gap can be partially overcome by using multiple layers of solar cells stacked on top of each other, each layer with a band gap higher than the layer below it. The efficiency would increase with the number of layers. However, for this concept to work the thickness of each layer must be extremely small; this has been achieved by the development of Thin-Film PV technologies. Some of the materials being developed for thin-film solar cells include cadmium telluride (CdTe), copper indium diselenide (CIS), copper indium gallium diselenide (CIGS), gallium arsenide (GaAs) and indium phosphide (InP). Of these, CdTe and CIGS are receiving the most commercial attention at this time. Multijunction thin-film solar cells give even higher efficiencies when exposed to concentrated sunlight. Therefore, a great deal of commercial attention is being focused on Concentrating Photovoltaics or CPV.

The current state of solar cell development is illustrated in Fig. 10.11 (above). While crystalline and polycrystalline silicon solar cells dominate today's solar industry, the rapid rise in efficiency vs time (experience curve) of the multijunction thin-film cells makes this a particularly attractive technology path.under concentrated sunlight, multijunction (GaInP/GaAs/Ge [germanium]) solar cells have demonstrated efficiencies twice (44%) that of most silicon cells. This means that, in sunny areas, a multijunction concentrator system can generate almost twice as much electricity as a silicon panel with the same cell area. The concentrating optics focus the light onto a small area of cells, reducing the area of the solar cells by a factor of, typically, 500-1 000 times. The reduced cell area overcomes the increased cell cost. The cell cost is diminished in importance and is replaced by the cost of optics. If the cost of the optics is comparable to the cost of the glass and support structure needed for silicon flat-plate modules, then the cost per unit area can remain fixed while the electricity production is essentially doubled. Thus, in high direct insolation locations, multijunction concentrator technology has the potential to reduce the cost of solar electricity by about a factor of two. The efficiency is a moving target; today's triple-junction cell efficiency is nearly 44%. Thus it may be reasonably extrapolated that multijunction cells may reach 50% efficiency in the future.

The biggest advantage of solar PV systems is that they can provide from a few watts to hundreds of megawatts. Development of flexible thin-film PV panels (Fig. 10.12) makes them ideal for integration in building design. In this way, they can utilise the solar exposure provided by the buildings and therefore not use any extra land.

Solar Thermal Power Plants

Concentrating solar collectors can achieve temperatures in the range of 200oC to 1000oC or even higher, which is ideal for generating electricity via thermodynamic power cycles. All of the present power plants based on fossil fuels and nuclear power work on the same principles. Therefore this technology takes advantage of the knowledge base relating to conventional power plants.

Another advantage of Solar Thermal Power is that it can easily use fossil fuels such as natural gas as a back-up fuel or store high-temperature heat to overcome the disadvantage

Figure 8.13
Flow diagram for a typical solar thermal power plant
Source: Goswami

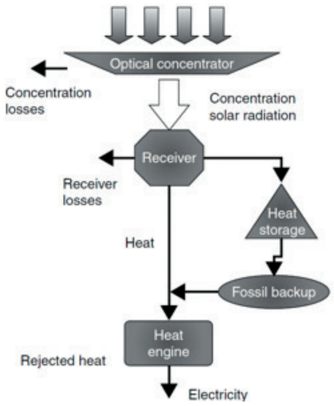


Figure 8.14
Schematic diagrams of the four types of Concentrating Solar Power (CSP) systems
Source: Goswami

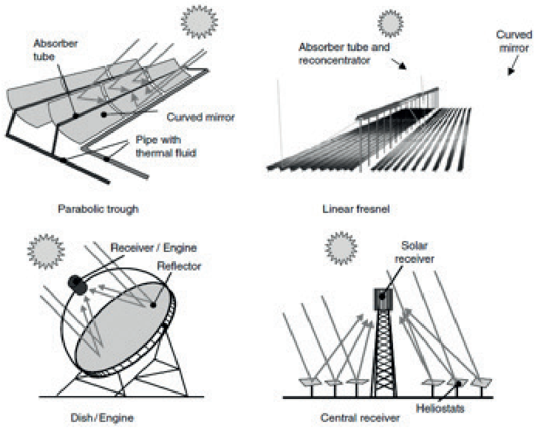
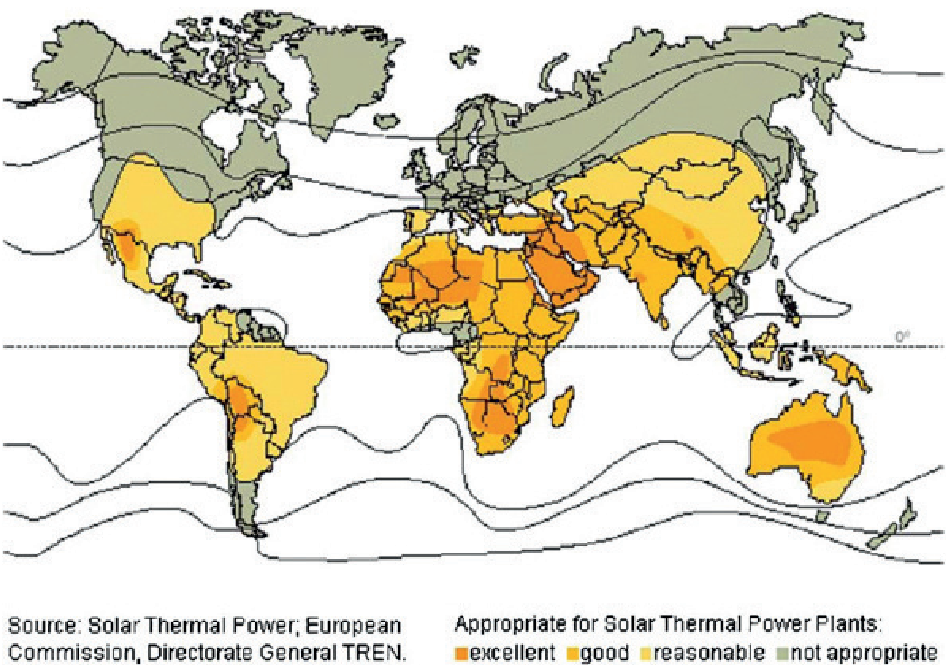


Figure 8.15
Regions of the world appropriate for Concentrating Solar Power (CSP)
Source: European Commission



of the intermittency of sunlight. Fig. 10.13 explains the concept of a solar thermal power plant operating with storage and/or a backup fuel. Fig. 10.14 shows schematic diagrams of the types of concentrating solar collector used for solar thermal power plants. Solar thermal power plants use direct sunlight, so they must be sited in regions with high direct solar radiation, as those shown in Fig. 10.15 (overleaf). Among the most promising areas are the south-western United States, Central and South America, Africa, the Middle East, the Mediterranean countries of Europe, south Asia, China and Australia.

CSP capacity of 364 MW was installed in California in 1990 (Figs. 10.16 and 10.17; pages 14 and 15), most of which (354 MW) is still operating. Each year the performance of the plant has

Figure 8.16
Parabolic-trough based solar thermal power plant in California (power plant [left]; parabolic trough collectors [right])
Source: Goswami


improved, due to the learning experience and better operations and maintenance procedures. This power plant is based on parabolic-trough technology, with natural gas as a backup fuel. Although investments in new solar power plants ceased for a while because of a lack of R&D and favourable policies, recently there has been a resurgence of interest in this technology. A number of plants are under construction or in the planning stage in USA and around the world, which when completed will increase worldwide capacity to about 3 000 MW.

The reported capital costs of Solar Thermal Power plants have been in the range of US$ 3000-3500/kW, although less than $2500/kW costs are being quoted now. These costs result in a cost of electricity of around US$ 0.15/kWh. Based on ongoing research and development, the capital costs are expected to decrease to below US$2000/kW and the capital cost of thermal energy storage is expected to decrease to less than $15/kWhth from the present costs of about $30/kWhth, which will bring solar thermal power closer to conventional power, even without considering the environmental costs/benefits.

New generation of solar thermal power systems are under development in various parts of the world. Trough technology with direct steam generation is under experimentation at the Plataforma Solar de Almería, part of the Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT) on Spain's Mediterranean coast. At the same time, central receiver tower, also known as "Power Tower" technologies are being developed to achieve temperatures of more than 10000C and to run on "combined cycle" or a supercritical CO_2 cycle. Active research on central receiver tower technologies is underway in USA, India and other countries.

Solar Energy Storage Systems

As a result of solar energy's intermittent nature, the growth in worldwide usage will be constrained until reliable and low-cost technology for storing solar energy becomes available. The sun's energy is stored on a daily basis by nature through the process of photosynthesis in foodstuffs, wood and other biomass. The storage of energy from intermittent and random solar radiation can be achieved artificially, by using energy storage technologies (thermal storage, chemically-charged batteries, hydro storage, flywheels, hydrogen, and compressed air), some well-known and widely-applied, whilst others are still under development. By adding Thermal Energy Storage to a CSP plant, the levelized cost of energy (LCOE) from such plant can go down by as much as 30%.

Figure 8.17
Central receiver power plant in California
Source: Goswami

Thermal storage for solar heat and chemically-charged batteries for off-grid PV systems are the most widely used solar energy storage systems today. However, there are many who think that hydrogen produced using solar energy will provide the long-term solution for solar energy storage and much research is being undertaken around the world. Only the future will tell whether hydrogen will become cost-effective as compared with other storage options.

Other Solar Energy Applications

Availability of drinking water is expected to be the biggest problem to face mankind over the next few decades. Even though there is an abundant water resource in the oceans, it must be desalinated before use. Solar energy can play a very important role in this application. Although simple solar desalination and distillation technology has been known for a long time, there has not been much research to improve the technology for large-scale use.

Other lesser known applications of solar energy include its environmental applications such as solar photocatalytic detoxification and disinfection. This application has been shown to clean contaminated ground water and industrial waste water. It can also be used to disinfect water for potable use.

3. Market trends and outlook

Conclusion and Outlook

Great advances have been made in the development of solar energy technologies. Efficiencies have been improved and costs have been brought down by orders of magnitude.

The technologies have become cost-effective for some applications. However, they are still too expensive for other applications such as grid electricity, unless environmental costs are accounted for or incentives are given for these technologies.

At present, the markets for solar PV technologies are increasing at a rate of more than 35% per year and solar thermal power growth is expected to be even higher. However, these applications are starting from a very small or negligible base. Therefore, an even higher growth rate would be needed to reach the levels envisioned for the future. Strong public policies and political leadership are needed to move forward the application of solar and other renewable energy technologies, while maintaining robust research efforts to advance present technologies and develop new ones.

Countries whose governments have established firm goals for the penetration of renewable energy into primary energy and electricity generation, or have adopted specific policy mechanisms, are achieving great success. Examples are the successful feed-in laws adopted in several European countries, India; the Renewables Portfolio Standard (RPS) adopted by the majority of the American states, which ensures that a minimum amount of renewable energy is included in the portfolio of electricity production; and city ordinances requiring solar systems to be used for water heating in residential and commercial buildings. Appropriate policy measures have shown that solar applications can be boosted with many positive side effects, from the creation of new industries, new jobs and new economic opportunities, to the protection of the environment.

Energy conservation - through improvements in energy efficiency and decreases in energy intensity - is essential to increase the fractional contribution of renewable energy while meeting the energy needs of society. Based on a review of the ongoing research in solar energy technologies, it is clear that they will continue to improve, promising higher efficiencies and lower costs. Examples of such promising new technologies beyond the horizon include continued development of new thin-film technologies, nano-scale antennas for conversion of sunlight to electricity, biological nano-scale PV, new concepts in solar desalination, visible light photocatalytic technologies for PV or environmental applications, new thermodynamic combined cycles, and efficient low-cost thermal energy storage for solar thermal power. These developments are expected to help achieve the projected solar energy penetration levels by 2050 and beyond. However, in the meantime, it is essential to adopt policies that will ensure accelerated deployment of the present solar energy technologies.

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Global tables

Table 8.1
Installed Capacity (MW) in 2011

	Solar PV		Solar Direct	
	Installed capacity	Actual Generation	Energy Prod (Active)	Energy Prod (Passive)
Country	MW	GWh	TJ	TJ
Argentina	16			
Australia	1 400			
Austria	187	174	6 930	5 445
Bangladesh	46			
Belgium	1 391			
Brazil	1	2	2 500	
Bulgaria	153	0		
Canada	559	1	1 770	n/a
China	3 300			
Croatia	0	0	254	n/a
Cyprus	10			
Czech Republic	1 971	2 182	366	n/a
Denmark	17			
Egypt	20			
Ethiopia	5			
Finland	11	8	39	
France	2 760	2 400		
Germany	25 039			
Greece	612			
Guadeloupe	65			
Hong Kong	1			
Hungary	2			
India	941			
Indonesia	1	1		
Ireland	0			
Israel	61			
Italy	12 773	11	2 151 751	
Japan	4 914			
Korea (Republic)	730			
Latvia	0			
Lithuania	0			
Luxembourg	41			
Malaysia	68			
Malta	7			
Martinique	14			
Mexico	37	38	15	
Monaco	0	0	1	
Netherlands	145			
Norway	9			
Peru	4			

Poland	1	0		
Portugal	172	278	2 604	
Réunion	145			
Romania	1	1		
Russian Federation	0			
Slovakia	188			
Slovenia	57			
South Africa	2			
Spain	4 332			
Sri Lanka	1			
Sweden	16	0		
Switzerland	192	149	1 655	406
Taiwan	19			
Tanzania	2			
Thailand	67			
Turkey	4	6	420 000	
Ukraine	190			
United Kingdom	976			
United States of America	5 171			
Total World	**68 850**	**-**	**-**	**-**

Country notes

The following Country Notes on Solar provide a brief account of countries with significant resources. They have been compiled by the Editors, drawing upon a wide variety of material, including information received from WEC Member Committees, national and international publications. The figures in Table 10.1 relate to 2011 to ensure comparability between the countries. The figures in country notes are the most recent available.

Australia

Total Solar Capacity MWe in 2011	1 400
Solar Capacity added in 2011 MWe	837

Australia represents 2% of the global solar market and was the only non European country besides China and Japan to have added at least 1 000 MW of PV capacity in 2012, which means that PV capacity in Australia has increased by about 400% in just 2 years. Today, the Australian Renewable energy industry employs more than 24 000 people, 17 000 of which work in the solar industry.

The solar industry is equally distributed across the Australian Continent. New South Wales has about 500 MW of solar capacity as of December 2012. Victoria has about 400MW while South Australia and Western Australia have PV installations with peak capacities of 341MW and 283MW respectively. Small scale solar projects dominate the PV industry and CEC reports that more than 10% of the households have installed solar panels in their rooftops.

Large Scale solar projects remain few and account for less than 0.5% of the total clean energy generation in Australia. Only 39 large "large scale" solar plants are currently in operation with the largest of 10MW capacity located in Western Australia. The Australian Renewable Energy Agency, which operates under the Ministry of Resources and Energy, has provided hundreds of millions of dollars in funding for large scale solar projects such as the Broken Hill and Nyngan project with the cost of 170 million AUD and capacity of 159MW. Another large project which is under way is located in Victoria with a capacity of 100 MW. It will use solar concentrator technology rather than Photovoltaic.

Australia has many feed in tariffs for solar installation depending on the territory. The State of Victoria for example has adopted a flat rate of 0.08AUD regardless of the size of the installation. On the other hand, in South Australia the rate is 0.16 AUD for the first 45 kWh exported back to the grid. If the permission to connect to the grid is received after 30th September 2013, the customer will not get any feed in tariff. Customers will then qualify for "minimum retailer payment" which currently is 0.098 AUD per KWh. This rate is subject to review after 2013. Queensland has the most generous feed in tariff of 0.44 AUD per KWh but to qualify, strict requirements should be met. For example, the house must not use more than 100MWh of electricity each year.

Belgium

Total Solar Capacity MWe in 2011	1 391
Solar Capacity added in 2011 MWe	996

Belgium represents about 2% of the cumulative global solar market as of 2013 and was the 11th largest solar market in 2012. Belgium added nearly 1000 MW of solar capacity in 2011, but only about 600MW the following year. The reason for this decline is that the country had a national target of 1 340 MW of Solar Capacity by 2020 which was reached in 2011. Belgium has the potential to reach 7 000 MW of solar capacity by 2020.

Belgium is one of the few European nations not to operate any large scale PV power plants. Over 60% of the PV capacity is in residential installations. 20% of installations are commercial and a further 18% of solar capacity is in the industrial sector. Of the 599MW of solar capacity added in 2012, nearly 500MW was in the residential sector and the rest was split between the commercial and industrial sectors.

Since Belgium has already reached its 2020 target, the government has decided to reduce feed in tariff incrementally to focus on other areas of the economy. In the first half of 2011 the feed in tariff was 0.33€/kWh which was reduced to 0.30€/kWh in July and finally to 0.27€/kWh in October. In 2012 the Belgian government decided to reduce the tariff by 2 cents every 4 months.

Chile

Total Solar Capacity MWe in 2011	4
Solar Capacity added in 2011 MWe	4

The Solar Energy market in Chile is still in the early stages of development with most of electricity being generated by fossil fuels and hydro. However, Chile is home to the Atacama Desert, the driest desert in the world with an annual rainfall of only 0.6mm. According to an extensive study conducted by “Global Energy Network Institute” (GENI) the Atacama Desert has the highest solar irradiance in the world. GENI has also estimated that if a very large hypothetical solar power plant was to be built in Atacama desert, it can potentially have a capacity of 3 000 GW using solar cells with only 8% efficiency.

Business interest in solar has remained relatively low over the last decade and Chile continues to be one of the smallest market for solar energy. Some business activity has taken place. First Solar has purchased “Solar Chile”, which was a state controlled firm to promote solar investments. First Solar plans to invest USD370 million to build a solar power plant in the Atacama Desert, with an estimated capacity of 162 MW. The Environmental Evaluation Service, which is part of the Ministry of the Environment, is the entity which normally approves solar projects. It has approved nearly 4 000 MW of solar projects and more than 2 000 MW of projects are currently under review.

China

Total Solar Capacity MWe in 2011	3 300
Solar Capacity added in 2011 MWe	2 500

China represents 8% of the global solar market and is the largest market for solar outside Europe. Since 2011 China has nearly tripled its solar capacity from cumulative capacity of 3300MW in 2011 to over 8000 MW as of 2013. By 2020, China intends to install about 50GW of solar capacity. This high growth in recent years can be explained by the action of the Chinese government to mitigate coal pollution which affects millions of people each year. China decided to spend USD45 billion a year from 2010 on renewable energy in an effort to reduce its dependence on coal.

China has abundant potential for solar energy, since 17% of mainland China receives annual solar radiation of more than 1750 Kwh/m^2 and more than 40% of China receives between 1400-1750KWh/m^2. The Gobi desert in China has an area of 1.3 million square km and if it was covered in photovoltaic cells, it would have a potential capacity of 17 TW. However the regions that receive the most sunlight are predominantly rural and relatively far from the national power grid.

China has become the world's largest solar cell manufacturer, producing more than 10GW worth of solar cells in 2010 alone. China exports 95% of all solar modules. Ten companies now control more than half of the global production for solar modules and 4 of these are Chinese, namely, Suntech, JA solar, Yingli green energy and Trina solar. China is one of the largest exporters of solar modules to the United States with exports worth about USD2.8 billion worth of solar cells in 2011 alone. In 2008 the average selling price of solar cells produced by Chinese companies was just over USD4 per Watt or twice as much as the global average, whereas just two years later, the price dropped to about USD1.80 per Watt, 30 cents lower than the global average.

Czech Republic

Total Solar Capacity MWe in 2011	1 971
Solar Capacity added in 2011 MWe	6

The Czech Republic has over 2000 MW of installed PV capacity. Since 2010, additions to the Czech Republic's solar power sector have been small. The reason for this is the decision by the government to reduce subsidies by 25%, since the country had already reached its national solar target of 1 695 MW in that year. The Czech Republic was one of the two countries in the European Union to reach its "National renewable energy action Plan" ten years in advance of the target date. The EPIA also estimates that the Czech Republic has a potential market of 241 MW annually and therefore should easily achieve 4 000 MW of solar capacity by 2020.

More than 60% of the installed capacity is in the residential sector. In 2012 out of the 113MW of solar capacity added to the national grid, more than 50MW was added in the commercial sector and no large or utility scale plants were added. About 56MW of residential solar was also added to the grid in 2012. In 2011 total installed PV capacity was about 10% of the total, but PV contribution to total electricity generated in the country in the same year was only 3%. The Czech Republic has a target of generating 13.5% of total electricity by 2020 from renewables.

France

Total Solar Capacity MWe in 2011	2 924
Solar Capacity added in 2011 MWe	1 756

France accounts for slightly less than 4% of global cumulative PV capacity. However in just 2 years solar capacity has almost quadrupled in France from 1168MW in 2010 to 4003MW in 2012. France was the 3rd largest market for PV in Europe in 2012 and was the 6th largest market in the world narrowly ahead of Australia.

About half of France's PV capacity is in the commercial and the industrial sector while utility sized PV farms represent 30% of the cumulative PV installations. The remaining 20% of the cumulative PV market is residential. Of the 1079MW of PV added in 2012, about 320MW was in the form of Utility sized power plants the largest of which was built by EDF Energy in north eastern France called the "toul-Rosieres solar park" with a peak capacity of 115MW. Completed in 2012, it was the largest solar park in Europe and one of the largest in the world.

France has a target of installing 4860 MW PV capacity by 2020 therefore it only needs to install just over 100MW of capacity every year to reach it. EPIA however estimates that France has a potential market of over 3000 MW every year therefore should be able to have 20-25 GW of solar capacity by the year 2020.

The French government uses two mechanisms to help facilitate the development of solar. A feed in tariff scheme is used to finance the small scaled solar projects. This can range from 0.289€/kWh to 0.46€/kWh for installations with a peak capacity of up to 100kW. All installations with a capacity between 100kW and 12MW are eligible for feed in tariff of 0.12€/kWh.

Germany

Total Solar Capacity MWe in 2011	25 039
Solar Capacity added in 2011 MWe	7 485

Germany is currently the global market leader in solar power. The Photovoltaic market has been growing at a spectacular pace since the turn of the century, partly due to government subsidies. With over 32 GW of installed capacity, Germany accounts for over 30% of global solar capacity. While global solar capacity increased from just over 70 GW in 2011 to 100GW in 2012 (approximately a 40% increase), Germany's solar capacity increased by 7604 MW, an increase of about 30%. According to the National Renewable Energy Action plan, Germany has a target of 50GW for solar power by 2020, but by 2020 it is expected to reach 80GW of installed capacity. According to the German Ministry of Economy, the total electricity production is 125 GW; solar therefore represents approximately 25% of the German electricity market.

The German Federal government has shown considerable interest in the Research and Development of solar and in 2011 it granted more than 70 million Euros for 96 R&D projects in solar. The positive investor environment for the solar industry can be seen by the number of international companies that have built factories in Germany, including "Masdar PV", a company based in UAE, which has built a module manufacturing facility.

According to Global Equity Research by UBS solar power has already reached grid parity in Germany, and over the course of next 5 years, the retail price of electricity is expected to increase faster than the solar. UBS estimates that by 2020, solar power would be about 25% cheaper than conventional electricity in Germany.

Germany has one of the largest solar power plants in the world with “Solar Park Meuro” being the largest with a peak generation capacity of 166MW it was completed in 2012. Another solar park completed in 2012 was Neuhardenberg Solar Park with a peak capacity of 145 MW.

India

Total Solar Capacity MWe in 2011	941
Solar Capacity added in 2011 MWe	190

India is expected to become one of the largest markets for the solar power industry. The federal government’s plan to have 20GW of solar capacity in the country by 2022 has been widely taken up at the state level.

India added slightly less than 1 GW of solar capacity in 2012, a considerable increase on the 190MW added the year before. The largest solar power plant in India is in Gujarat, Western India. With a peak capacity of more than 200 MW, it is the third largest solar power plant in the world built by Gujarat Power Corporation. Currently the state of Gujarat has about 850MW of PV installed. Other states with high solar irradiance have developed a number of solar projects in the last few years such as the state of Tamil Nadu, which has a regional target of 3 GW of solar capacity by 2015 according to Mercom Capital Group, a market research company based in Bangalore. Maharashtra has 160 MW of solar capacity installed and the state government has plans under way to install more in the coming years.

According to a report published by KPMG last year, the Indian government has several mechanisms to promote the growth of its solar industry. One of which is the exemption from customs and excise duty on products to be used in a solar project. Renewable energy plants built before 31st March 2013 have been allowed a 10 year “tax holiday”. The federal government has also introduced “generation based incentives” such as a feed in tariff for solar INR 12.41 per kW/h for independent power producers. Under the guidance of the Ministry of New and Renewable Energy, an Energy Development Agency has been set up with the sole purpose of financing renewable energy projects across India. The most proactive measure taken by India to increase the share of renewable energy is the enactment of the “Renewable Purchase Obligation Programme”, which compels distribution companies, open access consumers and captive consumers to purchase a certain proportion of their power from renewable energy sources.

According to IRENA, in 2011 the average cost of solar system with 5 to 10 kW of capacity in India ranged between 2.5 - 3.0 USD per Watt. The average price of large scale solar plants was just under 2.4 USD per Watt. The cost of PV dropped very little in the following year, as IRENA reported in its 2012 report that the average cost of large scale PV is about 2.2USD per watt.

Italy

Total Solar Capacity MWe in 2011	12 773
Solar Capacity added in 2011 MWe	9 454

Italy is one of the largest players in the global solar market with about 16% share. In 2012 3.4 GW of capacity was added to the grid which was significantly lower than the 2011 figure. According to the European Photovoltaic Industry Association, a lot of the PV systems were installed at the end of 2010 but connected to the grid only in 2011. New PV installations in 2010 were about 4-5 GW, in 2011 about 6-7GW and in 2012, roughly 3.5GW of PV was installed.

According to the IRENA, the average size of a utility scale PV plant was about 13 MW. The price of PV per watt was approximately 5 USD. Between December 2010 and August 2011, ABB has built solar parks with a total maximum capacity of 100MW. This was done in collaboration with Renewable Energy Corporation (REC) BNP Paribas.

The Italian Ministry of Economic Development released a press release on 12 of October 2012, in which it laid out a new “National Energy Strategy” with the intention to address energy costs and the environment. The Ministry expects the wholesale sale price of all energy sources to be in line with the European price levels. The Italian government also has a target to increase the share of renewable energy sources from 10% in 2010 to 20% by 2020.

Japan

Total Solar Capacity MWe in 2011	4 914
Solar Capacity added in 2011 MWe	1 296

Japan is the second largest market for solar energy in Asia after China. It accounts for about 7% of the global solar market and added 2 GW of solar capacity in 2012, up from 1296 in 2011. After the Fukushima nuclear incident, the Japanese government was forced to reconsider its energy policy and as a result set a target for solar energy of 28GW by 2020. Consequently, Japan is expected to break the record for aggregate solar capacity installed in a single year in 2013.

Japan has one of the largest markets for small scale PV projects and unlike in Europe, the share of small scale PV projects has increased significantly. Spending on small scale solar projects was just over 8 billion USD in 2011 and 13 billion USD in 2012, an increase of 56%, according to the report published by the Frankfurt School UNEP Centre titled “Global Trends in Renewable Energy Investments” The average cost of small PV systems is just over 6 USD per Watt, one of the highest costs in the world and substantially higher than the small PV systems in China, which is about 0.90 USD according to the “Renewable Energy Technologies: Cost Analysis” published by IRENA.

According to RTS Corporation, a consultancy based in Tokyo, the Hokkaido region in Northern Japan is the largest sub national solar market. Residential solar power accounted for more than 80% of the Japanese solar market and utility sized power plants represented less than 5% of the market. In mid-2012 the Japanese government reintroduced subsidies to boost further investment in solar power. The feed in tariff starts at JPY 40 (0.42 USD) per kilowatt hour for large installations.

Mitsubishi Electric is one of the largest manufacturers of solar cells in Japan. It had started research and development in solar power back in 1974 and since then has grown to become one of the major industry players. In 2010 Mitsubishi Electric created the most efficient polycrystalline cells with the efficiency of 19.3%. Kyocera Solar, Kaneka and Sharp Solar also hold significant share in the Japanese solar market.

Pakistan

Total Solar Capacity MWe in 2011	< 1
Solar Capacity added in 2011 MWe	< 1

Pakistan is one of the few countries that has huge solar potential but yet no government plan to facilitate the growth of solar energy. Pakistan is home to part of the Great Indian Desert (Thar), with about 77 000 sq miles of land area.

There has been a change of government in May 2013 and it is possible that solar energy may be revisited in the coming years. The newly elected Prime Minister has stated that there is a 3 GW shortfall in the electricity supply, and country needs to increase its total capacity from 16 GW to 19 GW. A Korean Company of “CK Solar” has expressed interest in investing in large scale solar power plant in the province of Baluchistan. With a planned capacity of 300 MW, it would be the largest solar power plant in the world and would potentially kick start the development of a solar industry in this country.

Spain

Total Solar Capacity MWe in 2011	4 890
Solar Capacity added in 2011 MWe	472

The Spanish solar market represents about 5% of the global PV market and in recent years its growth has slowed down significantly compared to rest of Europe. This decrease in growth can be explained by the end of all subsidies to solar energy in 2012 as a result of a wider economic review by the Spanish government. According to the European Photovoltaic Industry Association (EPIA), Spain’s national target for solar capacity is 8,367 MW by 2020. With over 5GW already installed, the EPIA estimates that Spain only needs to add 400MW of solar capacity every year to reach the necessary target. The EPIA also estimates that Spain should be able to add over 1500 MW of solar energy every year.

According to IRENA, Spain has a target to meet 3% of total energy demand from solar by 2020. The report goes to say that Spain has a target to generate 38% of its electricity from renewable energy by 2020 however by 2011 Spain already surpassed that target and more than 40% of its electricity is was being generated through renewable energy in that year.

Spain has one of the highest levels of solar irradiance in Europe. With some regions receiving 2000 kWh per square metre annually, Southern Spain receives sunlight comparable to Northern Africa making this part of the country particularly suitable PV deployment.

According to EPIA, ground mounted solar farms account for about 80% of the total Spanish solar market and the rest of solar capacity is built for commercial and industrial use. Spain’s residential solar market is only about 1% of the national solar market.

The largest PV power plant in Spain is the Olmedilla Photovoltaic Park which was completed in 2008. It has a peak capacity of 60MW and at the time of completion it was the largest solar plant in the world. A larger solar power plant in the South Western near Cadiz is currently being built by Tentosul and when completed, it will have a peak capacity of 250 MW. This project is the first unsubsidised utility-scale solar project in Spain with an estimated cost of €275 million.

Castilla La Mancha is the largest regional market with about 1000 MW solar capacity installed, Andalucia is the second largest with over 800 MW. Other regions which have significant amount of solar installations include Castilla y Leon, La Comunidad Valenciana, Extremadura and Murcia. All four of these regions have more than 300 MW of installed capacity each.

United Kingdom

Total Solar Capacity MWe in 2011	904
Solar Capacity added in 2011 MWe	813

The United Kingdom represents just under 2 % of the global solar market; 1 GW of solar was installed in 2012. Most of the additions in the solar market happened in the last three years. The United Kingdom has a national target to generate 15% of its total energy from renewable sources by 2020. It also has a solar target of 2 680 GW by 2020, which EPIA estimates should be reached by 2014.

More than 50% of the British solar market is residential and approximately 23% of the solar capacity installed is utility-scale. Of the 925 MW of solar capacity added last year, more emphasis was seen in the power generation market with over 35% (323 MW) installed as ground mounted projects. However a further 400 MW of residential installations were also recorded. The EPIA reports that the UK needs an annual capacity increase of just over 100 MW solar to reach its target. The EPIA estimates that the United Kingdom has the potential to add more than 2.5 GW of solar capacity every year and by 2022, the total installed capacity of solar could reach 22GW.

The government introduced incentives for solar producers in April 2010 at the rate of 41.3p per kWh for all grid connected electricity. Currently however the incentives for solar depend very much on the size of the installation. Systems smaller than 4 kW receive a feed in tariff of 14.9p /kWh; larger systems attract a smaller tariff. For systems between 250kW and 5MW the feed in tariff is only 6.85p per kWh. The government has stated it will increase these feed in tariffs in October 2013 for all scales of systems.

Ukraine

Total Solar Capacity MWe in 2011	190
Solar Capacity added in 2011 MWe	188

Ukraine is one of the smaller markets for solar energy in Europe. Most of the solar capacity was added in the last two years although further capacity is planned. The Ukraine is notably the home of the one of the largest solar parks in Europe: the "Perovo Solar Park". Constructed by Vienna based developer, Activ Solar, it has an estimated peak capacity of 105 MW costing a total of €387 million according to Bloomberg. Activ Solar has completed other solar projects in Ukraine such as the Ohotnikovo Solar Power station located in the Crimea region. It has the peak capacity of 82.65 MW and was completed in October 2011. The third largest solar power station in Ukraine was also built by Activ Solar, based in the Odessa Region called the "Priozernaya solar power station" finished in March 2013 with peak capacity of 54.8 MW.

In recent years legislation promoting renewable energy in the Ukraine such as the "Green Tariff Law" has encouraged the growth of the solar industry. The resulting feed in tariffs are among the highest in the world. For installations larger than 100kW capacity, the feed in tariff is 2.68 UAH per kWh, which is about 0.32 USD. It increases at peak times to 4.84 UAH per kWh, equivalent to 0.60 USD. For installations smaller than 100 kW the basic rate is the same however at peak times the feed in tariff is 4.63 UAH per kWh.

United States of America

Total Solar Capacity MWe in 2011	5 171
Solar Capacity added in 2011 MWe	1 867

The United States accounts for just under 8% of the global solar market. However a report published in June 2012 by the United States Congress estimated that by the end of 2012, the United States would have at least 10% of the global solar market. In 2012 the solar market has doubled compared with 2011 in terms of capacity added on a yearly basis. The United States was the third largest PV market after the European Union and China. California is the largest solar market within the US with over 1 GW of new solar power installed in 2012 alone. About 700 MW was installed in Arizona in 2012.

The largest solar power plant in United States is the "Agua Caliente Solar Project" in Yuma County, Arizona with a peak capacity of 250 MW and is one of the largest in the world. This plant was constructed by First Solar and operated by NRG Energy. First Solar has plans to add 40 MW of additional capacity in the near future.

In 2011 alone, United States imported nearly 5 Billion USD worth of solar modules, 56% of which came from China, yet it only exported about 1 Billion USD worth of solar modules in the same year. PV exports have doubled from 442.7 million USD in 2006 to just over 1 Billion USD in 2011. According to Congressional research this rapid expansion in exports could be a sign of the maturity of the domestic market and increasing diversification.

The United States Federal Government has taken significant steps to promote solar power within its borders. "Advanced Energy Manufacturing Tax Credit" (MTC) is one specific example of legislation with this aim. Through the MTC, energy manufacturers involved in the construction of a new facility in the United States get a 30% tax credit on their investment. MTC had a cap of $2.3 Billion USD which was exhausted in 2010. Since the MTC has been so successful, the Obama Administration has proposed an extension of a further 5 Billion USD for the MTC program. Solar was also supported heavily through the executive branch of the Federal government in the form of Department of Energy Loan Guarantee Programs. The Department of Energy provided loan guarantees worth more than 16 billion USD for renewable energy projects, 13 billion USD of which went to solar.

In the United States about 120,000 people work in the solar industry according to Congressional research and employment in the solar industry has risen significantly since 2006 when only about 20,000 worked in the industry. Approximately half of this labour market relates to the installation of PV equipment and a further 20% in the manufacture of said equipment. The remaining 30% work in related fields including sales and distribution, project development, research and finance.