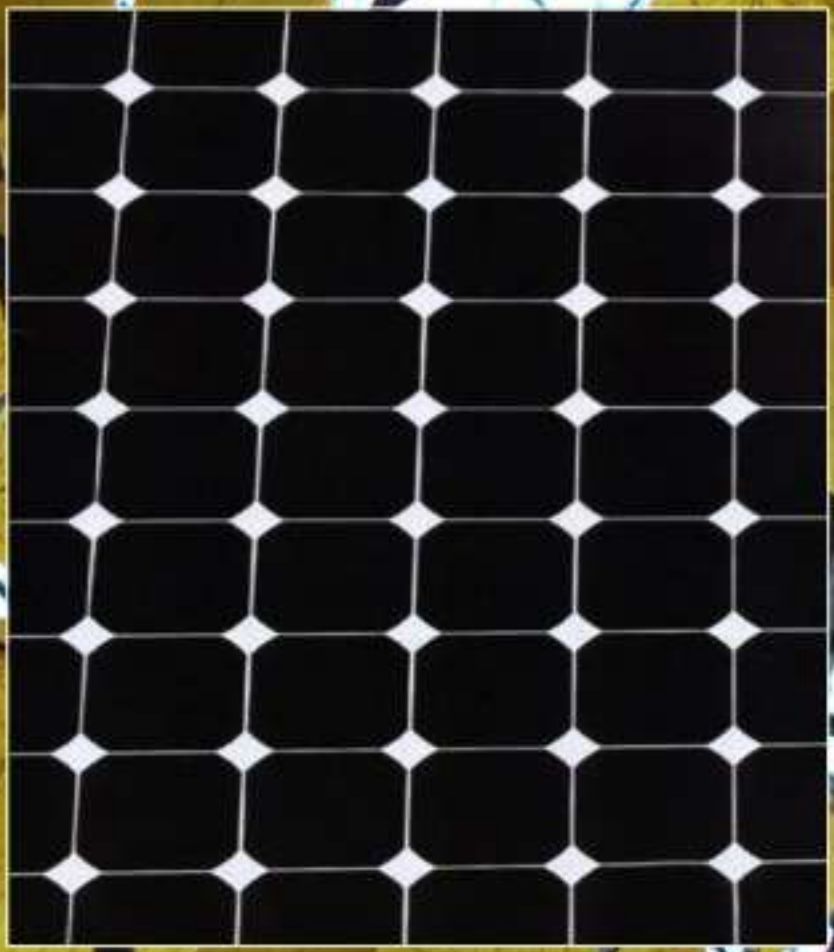
WORLD SOLAR ENERGY REVIEW: TECHNOLOGY, MARKETS AND POLICIES



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ABSTRACT

In recent years the market for solar energy technologies has experienced phenomenal growth. The realization of technological improvements, growing public awareness of environmental issues, the economic climate and number of policy instruments have facilitated and sustained this strong interest in these technologies. This report provides an overview of technical, economic and policy aspects of solar energy development. It reviews the status of solar energy in terms of resource potential, existing capacity, along with historical trends and future growth prospects of solar energy. A comparison of costs of solar versus other electricity generation resources is presented along with technical, economic, and institutional barriers to the development and utilization of solar energy technologies. The report reviews existing fiscal and regulatory policy instruments to support solar energy development, indicating how successful these policy apparatus are in achieving their goals. An analysis of the role of carbon finance mechanisms such CDM/JI in promoting solar power is also conducted. And finally a review based on existing studies of the future prospects of solar energy supply under various scenarios by 2020, 2030 and 2050 is provided.

A number of lessons have emerged from this review. Solar energy constitutes the most abundant renewable energy resource available and in most regions of the world even its technically available potential is far in excess of the current total primary energy supply. As such solar energy technologies are a key tool to lower worldwide carbon emissions.

The wide range of technologies available today, to harness the sun's energy, is classified into passive and active technologies. The active technologies, which formed the content of this review, are broadly divided along a continuum of size classes and include photovoltaic and solar thermal, where solar thermal can be further classified into solar-thermal electric and non-electric applications. The market for many of the solar energy technologies has seen dramatic expansion over the past decade – in particular the expansion of the market for grid-connected PV systems and solar hot water systems have been remarkable.

While the cost of energy from many solar energy technologies remains high compared to conventional energy technologies, the cost trend of solar energy technologies demonstrates rapid declines in the recent past and the potential for significant declines in the near future. In addition to cost, this report has found that a number of barriers that appear to limit the rapid growth of such technologies. These include technical barriers such as low-efficiencies, challenges with energy storage, reliability of balance of system components; and institutional barriers such as lack of information, outreach and regulatory structure.

In response, a number of highly effective policy instruments have come together in some of the most successful markets for solar energy. These include fiscal and market based financial incentives (e.g. feed-in-tariff, rebates, tax credits), regulations (e.g. renewable portfolio standards, solar energy mandates) as well as a number of pilot demonstration projects. While the continued operation of such initiatives is imperative for the future growth of these markets it is also becoming apparent that innovative ways to reduce the fiscal burden of policy incentives are needed. As such, there is presently growing interest in market-based mechanisms to complement existing fiscal policy incentives.

In this context, the potential of Clean Development Mechanism (CDM) to complement the available support for solar energy technologies is discussed. Presently, it was found that the low cost of carbon emission reduction limit the ability of CDM to support solar energy technologies. The review thus identifies a variety of policy measures recently incorporated into the CDM framework to overcome this barrier.

Finally, the review finds that the future projections for solar energy technologies are broadly optimistic. According to the projections considered here, the market for solar energy technology is expected to grow significantly in the long-term as well as short-term. Further, despite its technical and economic limitations at present, it is expected that solar energy will play an important role in transportation sector in the future.

1. STATUS OF SOLAR ENERGY TECHNOLOGY

1.1 Global Solar Energy Potential

The energy influx from solar radiation is widely regarded as sufficient to meet the present primary energy needs of the world many times over (Brower, 1992). Solar energy is intercepted by the earth's atmosphere at an annual average rate of about 1.3 – 1.4 kW/m^2 (Rogner, 2000; Sorensen, 2000). Accounting for the fraction reflected by the atmosphere back to space, it is estimated that the maximum influx at the earth's surface is about 1 kW/m^2. At this rate, the ratio of potentially useable solar energy to current primary energy consumption is around 9,000 to 1 (Rogner, 2000: 162).

Useable solar influx is limited by diurnal variation, geographic variation and weather conditions (Rogner, 2000). Thus, worldwide, the yearly average values of effective solar irradiance reaching the earth's surface varies from a low of 0.06 kW/m^2 (~500 kWh/m^2/year), at the highest latitudes, to a high of 0.25 kW/m^2 (~2,200 kWh/m^2/year) in some desert areas of Africa and Australia (de Vries et al., 2007).

Conversion of this potential into secondary forms, such as electricity or process heat depends upon technical constraints (e.g., efficiency of converters such as photovoltaic (PV) cells or thermal collectors), economic constraints (e.g., absolute and relative costs of technology and fuels), and suitability considerations (e.g., the suitability of land use practices to locate the collection infrastructure.

Even so the abundance of solar energy compared with other sources of renewable energy is substantial. Estimates of the technical potential of solar energy versus wind, biomass, geothermal and ocean options are presented in Figure 1.1. In this respect solar energy represents our largest source of renewable energy supply and a key technology to lower worldwide carbon emissions.

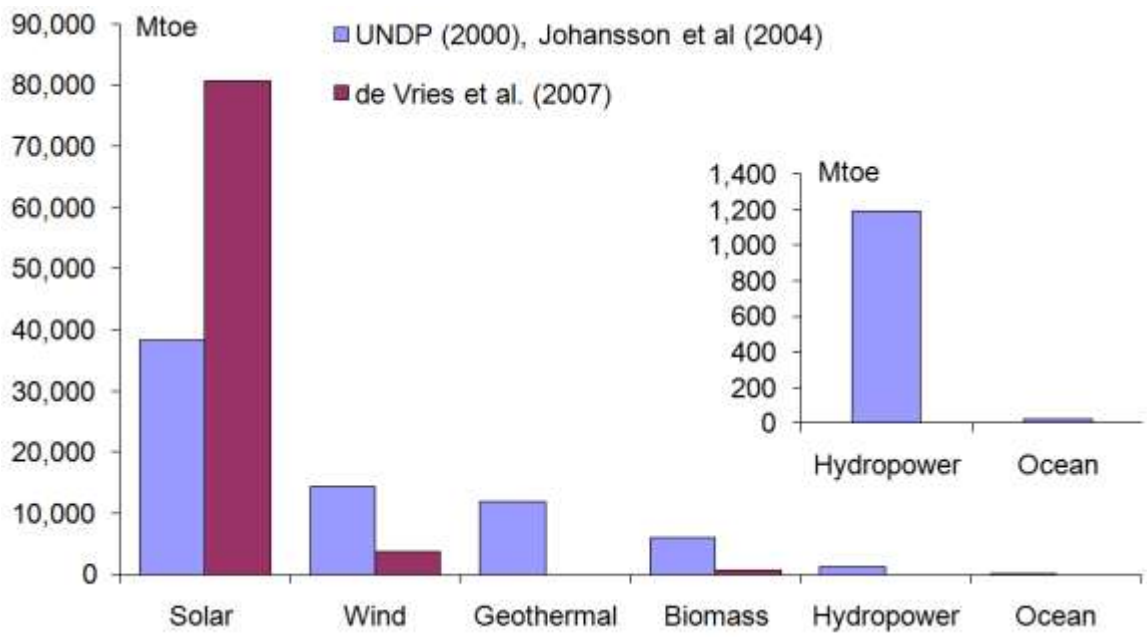

Figure 1.1 Technical Potential of Several Renewable Energy Technologies.
Data source: UNDP, 2000; Johansson et al., 2004; de Vries et al., 2007

1.2 Regional Solar Energy Potential

While global estimates of technical potential underscore the importance of solar energy to address climate change it is important to evaluate the resource's technical potential compared to regional need. Recently, estimates by major regions have been made (Rogner, 2000; Johansson et al., 2004) and are summarized in Table 1.1.

Estimates of regional solar energy potential and electricity demand in 2000 can be constructed using data from de Vries et al. (2007) and IEA (2007 a and 2007 b). These are presented in Table 1.2. These authors incorporate an explicit "suitability factor" derived from the distribution of land use types and assumptions about land availability for solar PV, within each of these land use types. Comparing Tables 1.1 and 1.2,[1] it is

[1] Table 1.1 presents the maximum and minimum estimates presented by the solar energy section in UNDP's World Energy Assessment (Goldemberg et al., 2000). Table 1.2 numbers are based on studies conducted by de Vries et al. (2007), using explicit criteria for estimating technical potential. The estimates arrived at by de Vries et al. (2007) are roughly in the middle of the maximum and minimum values presented by Goldemberg et al. (2000).

evident that regional solar supply is significantly greater than demand and will exceed growth in demand for a long time.[2]

Table 1.1 Annual Solar Energy Potential

Region	Minimum (Mtoe)	Maximum (Mtoe)
North America	4,322.3	176,950.8
Latin America & Caribbean	2674.6	80,833.8
Western Europe	597.0	21,826.3
Central & Eastern Europe	95.5	3,677.5
Former Soviet Union	4,752.1	206,681.4
Middle East & North Africa	9,838.6	264,112.8
Sub-Saharan Africa	8,859.5	227,528.6
Pacific Asia	9,79.1	23,736.7
South Asia	907.4	31,975.3
Centrally Planned Asia	2,746.2	98,743.8
Pacific OECD	1,719.4	54,040.4
Total	**37,491.6**	**1,190,107.6**

Data source: Derived from Johansson et al., (2004)
The minimum and maximum reflect different assumptions regarding annual clear sky irradiance, annual average sky clearance, and available land area.

Assessing the land requirement for harnessing solar energy to supply electricity, Kurokawa et al. (2007) note that covering only 4% of the surface area of the world's deserts, with photovoltaic cell technology,[3] would produce enough electricity to meet the world's energy consumption. Similarly, estimates suggest that only 0.71% of the European land mass, covered with current solar electric modules, will meet the continent's entire electricity consumption (EPIA, 2007). In the case of the United States too, total incident solar energy, at the rate of about 5×10^{13} kWh/day, far exceeds the average daily electricity consumption in the US of about 1×10^{10} kWh/day (for 2004) (Denholm et al., 2007).

Considering land requirements for another prominent solar technology, namely, concentrating solar power (CSP),[4] in many regions of the world 1 km^2 of land is enough

[2] The German Aerospace Center is developing a global inventory of effective solar energy potentials, organized by country. E-mail communication with Dr. Wolfram Krewitt, German Aerospace Center.
[3] Photovoltaic (or PV) cells convert solar irradiance to direct current electricity. The average conversion rate for existing PV technology is about 14%.
[4] CSP refers to a family of technologies that concentrate the sun's insolation to produce

to generate more than 125 gigawatt hours (GWh) of electricity per year.[5] For instance, in the case of China, it is estimated that 1% (26,300 km^2) of its "wasteland" located in the northern and western regions, where solar radiation is among the highest in the country, can generate electricity equivalent to 1,300 GW – about double the country's total generation capacity projected for year 2020 (Hang et al, 2007).

Table 1.2 Regional estimates of energy and electricity demand compared with grid-connected solar potential

Regions	Estimated Technical Potential of Solar Energy[a]	Total Primary Energy Supply	Total Final Energy Usage	Final Electricity Usage
	Million Tonnes of Oil Equivalent (Mtoe)			
	1	**2**	**3**	**4**
Africa	23,215.7	605.4	193.8	39.3
Fmr. USSR	12,553.7	980.1	621.1	82.6
Australia & New Zealand	10,146.1	138.9	89.2	21.0
US & Canada	7,824.5	2,612.2	1,799.4	363.9
M. East	7,308.6	503.3	329.9	43.1
Central & South America	6,534.8	500.4	315.2	63.1
China[b]	4,987.1	1,735.2	902.3	174.8
India[b]	4,643.1	537.3	199.1	41.1
OECD Europe	1,633.7	1,875.7	1,359.1	254.4
Japan	86.0	530.5	350.9	84.6
Rest of World	8,340.4	1,915.2	1,048.0	187.0
Total	**80,738.9**	**11,433.8**	**6,892.8**	**1,291.8**

Data sources: Column 1 from de Vries B. J. M. et al. (2007); columns 2, 3 & 4 from IEA (2007 a & b)

[a] Estimates of regional technical potential is based on consideration of only grid-connected solar PV systems of 10 kW to many MW, and are presented here for the year 2000.

[b] Reported by de Vries et al. (2007) as "South Asia (incl. India)" and "East Asia (incl. China)."

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steam, which is used to generate electricity through a conventional power cycle using a steam turbine or Stirling engine.

[5] We assume that the efficiency of CSP is 8m^2/MWh/year, which is in the middle of the 4-12 m^2/MWh/year range offered by Muller-Steinhagen & Trieb (2004).

Similarly, in the United States, an area of 23,418 km^2, located in the sunnier southwestern part of the country, can match the present generating capacity of 1,067 GW (Mills and Morgan, 2008). Based on expected advances in the solar thermal technology coupled with the growing number of countries striving to meet greenhouse gas emission targets and power demand expectations, it is projected that the worldwide installed CSP capacity will reach 21.45 GW producing 54.6 TWh in 2020 (Aringhoff et al., 2003 cited in Philibert, 2005); 100 GW by 2030 and almost 600 GW by 2040 (Aringhoff et al., 2005: 6). It is estimated that 5% of the world's electricity needs could be served by 2040 even against the challenging backdrop of a doubling in the global electricity demand (Aringhoff et al., 2005).

1.3 A Characterization of Solar Energy Technologies

Solar energy has been used by mankind for thousands of years. For instance, 2000 years ago solar installations were built to extract salt from sea water (Hisolp, 1992; Brower, 1992). Ancient Greece used technology which is currently widely known as passive solar architecture for heating and cooling buildings. Today, harnessing the sun's energy includes a diverse set of technologies that range from simple sun drying of crops to direct generation of electricity using photovoltaic cells. Solar energy technologies can be divided into two broad categories: "solar thermal" applications that convert solar radiation to thermal energy, which can be directly used (e.g., solar hot water systems) or converted further into electricity (e.g., CSP); and applications that directly generate electricity from sunlight using the photovoltaic effect.[6]

In the broadest sense, "solar energy" can refer to any phenomenon that traces its origin to energy from the sun and can be harnessed as useable energy, directly or

[6] The photovoltaic effect is the conversion of radiant energy, contained in light quanta, into electrical energy when light falls upon a semiconductor material causing electron excitation and strongly enhancing conductivity. The movement of these excited electrons (i.e. electric current) is made possible by "doping" the semiconductor material to create a "p-n junction" and connecting this PV cell in a closed circuit. A "p-n junction" is formed when a p-type (lower electron density) and n-type (higher electron density) semiconductor are joined so that they acquire a common surface (Sorensen, 2000).

indirectly. In this respect, solar energy can even include phenomena such as wind and photosynthesis (Scheer, 2002). However, for our purposes, we limit use of the term "solar energy" to 'sources of energy that can be directly attributed to the light of the sun or the heat that sunlight generates' (Bradford, 2006: 90). As such, solar energy technologies can be arranged along the following *continuum*: 1) passive and active; 2) thermal and photovoltaic and 3) concentrating and non-concentrating.

Passive solar energy technology merely collects the energy without converting the heat or light into other forms. Thus, it is essentially an approach to building design and features that are conducive to this objective. It has been practiced for thousands of years and includes such considerations as site selection, placement of windows, dark walls and so forth, to maximize the collection of heat and light (Bradford, 2006; Chiras, 2002: 4-7).

In contrast, *active* solar *energy* technology refers to the harnessing of solar energy to store it or convert it for other applications and can be broadly classified as two groups, *viz. photovoltaic* and *solar thermal* (Bradford, 2006).

Table 1.3 Classification of Solar Energy Technologies

	Active Solar			Passive Solar[7]
	Photovoltaic (PV)	Solar Thermal		
		Electric	Non-Electric	
Centralized (> 200 kW)	Concentrating PV arrays (CPV) Utility-scale PV	Concentrating solar thermal (CSP)	District water heating	
Large-scale distributed (>20kW)	Commercial building PV		Commercial hot water systems	
Small-scale distributed (<20kW)	Small commercial & Residential building PV		Residential water heating systems	Heating & cooling
Off-grid applications	Stand alone systems for remote applications, solar home systems			Day - lighting

Source: Derived from Bradford (2006: 93), Figure 5.1.

[7] This report does not further investigate this market.

Solar photovoltaic (PV) is the "high-tech" among the active solar energy technologies. The earliest applications of solar PV, from the late 1950s, were used on space satellites to generate electricity. While this application remained an exclusive niche market that was largely insensitive to costs, it did help create a solar PV industry in the United States (Hoogwijk, 2004). Applications of the technology expanded following the oil-shocks of the 1970s. For almost fifteen years, from 1983 to 1999, the PV industry maintained an upward, but not spectacular, growth trend of about 15% per year in the shipments of photovoltaics (Turkenburg, 2000). By the early 1990s, off-grid applications such as solar home systems and village power systems accounted for about 20% of the market (based on power volume), while grid-connected systems accounted for about 11%. The rest of the market was comprised of remote stand-alone applications such as water pumping, communications, leisure, consumer products and so forth (see Figure 1.3, Trukenburg, 2000).

Commencing in the mid-1990s, a fundamental change in the market's composition became visible with regard to solar energy (see Figure 1.3). Between 1995 and 1998, for the first time, the market share of grid-connected systems eclipsed off-grid systems, when it grew to 23% of the PV installations (Trukenburg, 2000). Since that time the grid-connected PV capacity has dominated the market, by sustained dramatic growth rates. In 2006, 2007 and 2008 this market sustained dramatic increases in cumulative installed capacity, growing from about 5.1GW in 2006, reaching 7.8 GW in 2007 and crossing 13 GW by the end of 2008 (REN21, 2008, 2009).[8]

Single crystal and polycrystalline PV modules:

- PV modules are an assembly of individual PV cells, which have been interconnected
- PV cells are wafers of single crystal or polycrystalline silicon feedstock that are processed

Thin-film PV modules:

- PV modules do not involve wafers, instead made by deposition of a "thin-film" of photovoltaic material on suitable substrate
- Photovoltaic materials used include, amorphous silicon, copper indium diselenide and cadmium telluride

[8] See section 1.4.1.1 for some of the policy initiatives that were instrumental in driving this grid-connected PV market. Also see Section 4, specially the discussion of the policy

This market is dominated by crystalline silicon-based PV cells, which accounted for about 82% of the cell production in 2009 (Marketbuzz, 2010). The remainder of the market consists of thin-film technologies that use cells made by directly depositing a photovoltaic layer on a supporting substrate. Thin-film cells are made out of a range of different semi-conductor materials, including amorphous silicon, cadmium-telluride and copper indium gallium diselenide. While thin-film technologies have yet realized only lower technological efficiencies than silicon based cells, they are cheaper and more versatile than crystalline silicon based counterparts. In 2007, 2008 and 2009 cell production using thin-film demonstrated strong growth of over 100%, 123% and 88% respectively, to reach 1.68 GW in 2009 (Marketbuzz, 2008, 2010; Jager-Waldau, 2007).

Efforts are underway to commercialize improvements to existing technologies that drastically enhance the efficiency of crystalline silicon based PV cells (see e.g. Barnett et al., 2006)[9] and to develop new technologies that utilize other light harnessing processes based on dye-sensitized substrates and applications of nanotechnology (Gratzel, 2006).

Solar thermal applications include two distinct technological streams. The first stream, referred to as "solar thermal non-electric" includes such applications as agricultural drying, solar water heaters, solar air heaters, solar cooling systems and solar cookers (e.g. Weiss et al., 2007). Solar water and air heaters can meet most of the residential demand for hot water and warm rooms in winter since these can be served with a temperature range of 40-60°C (ESTIF, 2007). These small-scale solar thermal applications account for almost 100% of the Chinese and around 90 % of the European solar thermal non-electric market (ESTIF, 2007 and Weiss et al., 2008).

The second stream of solar thermal technology, referred to as "solar thermal-electric" includes technologies that utilize the sun's heat to produce steam and generate

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drivers in the grid-connected PV markets of Germany, California and New Jersey.

[9] This research being conducted at the University of Delaware has created solar cells in the lab that are 42% efficient, while commercially available solar cells that are in the range of 14 – 18%.

electricity. Widely referred to as CSP technologies, they include at least four models utilizing the same basic concepts of concentrating and collecting the sun's heat energy; *viz.* Parabolic Trough, Fresnel Mirror, Power Towers and Solar Dish Collectors (see footnote 4, also see Muller-Steinhagen and Trieb, 2004; Taggart, 2008a and b; Wolff et al., 2008).

A total of nine Solar Electric Generating Stations (SEGS) plants utilizing CSP technology were built between 1984 and 1991 in the California Mojave desert. The SEGS plants started with an initial 14 MW plant, followed by six plants of 30 MW each and reaching a capacity of 80 MWe in the last two units built between 1989 and 1991. In total, they continue to provide 354 MW of reliable capacity, which can be dispatched to the Southern California grid (Mehos and Kearney, 2007; Aringhoff et al., 2005; Taggart 2008a). Following this initial activity the CSP markets remained largely stagnant until as recently as 2004, when investment in new commercial-scale plants resumed (Aringhoff et al., 2005; REN21, 2008).[10] Since that time overall installed capacity has grown to over 679 MW worldwide, with United States and Spain accounting for 63% and 32%, respectively, of this operating capacity. In terms of projects under construction Spain accounted for 89% of this market activity that is reported to be 2GW (Tores et al., 2009). Worldwide, new projects are under contract in Arizona, California, Florida, Nevada, and New Mexico in the United States and under development in Abu Dhabi, Algeria, Egypt, Israel, Italy, Portugal, Spain, and Morocco (REN21, 2009).

The final category in our continuum of solar energy technologies is *concentrating vs. non-concentrating* technologies (Bradford, 2006). The CSP technologies just discussed are a family of concentrating solar energy technologies that use mirrors or lenses to focus sunlight and thus increase the intensity of light in the focus area. In addition to CSP the principle of concentrating solar energy is applied to PV as well by using a dish collector to concentrate sunlight on a smaller cell area (e.g., Wolff et al., 2008).

[10] See section 1.5.1 for more illustrations CSP projects in various stages of development.

The non-concentrating technologies, simply use the available intensity of solar irradiance for subsequent applications, whether PV or solar thermal (Bradford, 2006). The common applications of non-concentrating technologies include all the passive solar applications, the stand-alone PV panels, the rooftop solar water heaters, solar air heaters and so forth.

1.4 Photovoltaics

The world market for solar photovoltaic technology grew from 1,744 MW of annual installations in 2006 to 2,826 MW in 2007 and reached 5, 950 MW in 2008, for a cumulative worldwide installed PV capacity of over 16 GW (both grid-connected and off-grid applications) at the end of 2008 (Marketbuzz, 2008, REN21, 2009). In 2009 the annual market for PV is reported as 6.43 GW (Marketbuzz, 2010) suggesting a cumulative installed capacity estimate of about 22 GW. For comparison, in 1985 the demand for annual solar installation was 21 MW (Solarbuzz, 2008). While the present capacity is a milestone for solar PV, it represents only about 0.51% of the total global installed power generation capacity of about 4 TW estimated in 2006.

Over the long term, the dominant and sustained PV markets that have fueled this growth have primarily been Europe, lead by Germany, followed by Japan and the United States. Countries such as Spain in 2007 (480%) and 2008 (285%), South Korea in 2008, Italy in 2008 and 2009, and the Czech republic in 2009 have experienced spurts of growth that have catapulted them to the group of leading PV markets and contributing, in the process, to the overall worldwide cumulative capacity (Marketbuzz, 2008, 2010). Thus, in 2009 Germany, the Czech republic and Italy accounted for 4.75GW of new installations, while the United States and Japan accounted for about 500MW each (Marketbuzz, 2010).

The net result of these dramatic growth rates is captured in the exponential growth of cumulative PV installations over the past 15 years, as seen in Figure 1.2. A handful of

countries dominate the market for PV, but a number of significant markets exist outside this bloc. These include countries such as India, China, Australia, Canada and France.

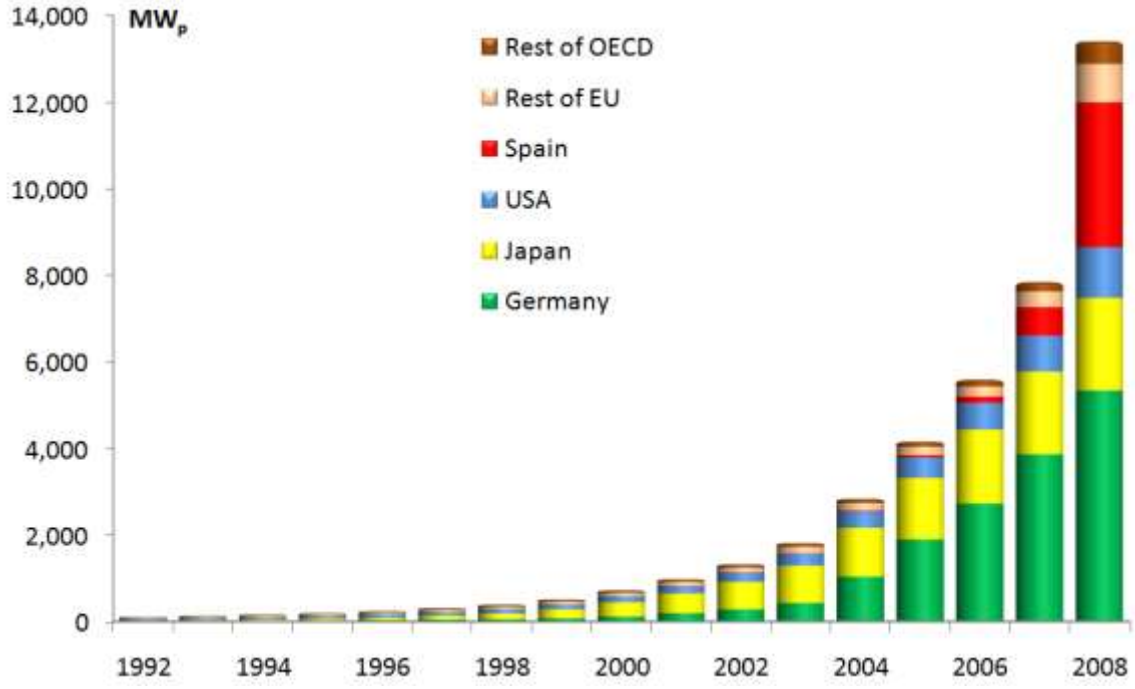

Figure 1.2 Cumulative PV Installations by Location in IEA-PVPS Countries 1992-2008
Data source: IEA-PVPS (2009)

1.4.1 Grid-connected PV

As noted above, the driving force in the ongoing commercialization of solar PV has been the emergence of the grid-connected solar PV market. Almost non-existent a decade ago, this application now accounts for the significant share of installed PV capacity worldwide, even as off-grid applications continue to grow at a relatively slower rate (REN21, 2008). Between the years 2002 and 2008, grid-connected PV reached an estimated cumulative installed capacity of 13 GW out of a total installed solar PV capacity (which includes off-grid) of 16 GW at the end of 2008 (REN21, 2009). The grid-connected PV applications can be further classified as 'grid-connected distributed PV systems' and 'grid-connected centralized PV systems' as seen below.

1.4.1.1 Grid-connected Distributed PV Systems[11]

As seen in Figure 1.3, on-grid distributed systems presently dwarf the other applications of solar PV. A favorable policy environment has underwritten the rapid growth in this application. Among the pioneers in this regard are Germany and Japan. For instance, Germany's Electricity Feed Law, introduced in 1991 and the Japan's 'Residential PV System Dissemination Programme' which commenced in 1994, along with its R&D programs, set the stage by providing support for grid-connected PV applications in these countries. At the end of 2008, Germany had 5.3 GW of grid-connected power, as compared to 40 MW of off-grid PV capacity. Similarly, at the same time Japan had over 2 GW of grid-connected PV capacity (almost fully distributed with 9 MW of centralized), as compared to about 90 MW of off-grid (IEA-PVPS, 2009). Indeed, considering the cumulative installed PV capacity across all the IEA-PVPS countries, grid-connected PV accounted for over 12.6 GW out of a total installed PV capacity of 13.4 GW in 2008 (IEA-PVPS, 2009).

1.4.1.2 Grid-connected Centralized PV Systems

A rapidly growing sector in the past two years within the PV market is the so-called large-scale solar photovoltaic applications that are over 200 kW and operate as centralized power plants. The leading markets for these applications include Germany, United States and Spain with over 500, 370 and 750 plants, respectively, as of December 2008 (Lenardic, 2008). While some of the early systems in this sector can be traced back to the early 1980s, this application did not exhibit significant growth for much of the 1990s, indeed it witnessed the opposite (PVRES, 2007). For instance, between 1995 and 1999 annual additions to installed capacity declined from 5.3 MW to 2.4 MW (PVRES, 2007). However, since the turn of the century, annual installations have grown from 4.8 MW in 2000 to just under 1000 MW as of December 2008; for a total cumulative capacity of over 3.6 GW from about 1,900 large-scale solar PV plants put into operation in 2008 and earlier (Lenardic, 2008). Given the rapid rate of growth it is acknowledge

[11] Distributed systems are not identified by whether they are connected to the grid or not. Instead, the key differentiation of such systems is that "they are located near or on customer premises." As such they are "distributed" the network and are close to the loads (Byrne et al. 2005b: 2).

that publicly available information is likely to be outdated (PVRES, 2007, Lenardic, 2008).

Some of the largest such plants are located in Spain and Germany. They include the 60 MW Olmedilla and 50 MW Puertollano plants commissioned in Spain in 2008 and the 54MW and 53MW Strabkirchen and Turnow Perilack plants in Germanay commissioned in 2009. Following in close order are the 46 MW Moura plant in Protugal and the 45 and 42 MW Kothen and Finsterwalde plants in Germany, that have come online since 2009. The average power plant is 1.8 MWp (PVRES, 2010, Lenadric, 2008). Such centralized systems have very recently appeared on the horizon of the PV landscape in countries such as India. In a year, between March 2009 and March 2010, the state of Karnataka in South India, installed two centralized PV plants of 3 MW each (Pillai, 2010). Such installations changed, almost overnight, the long reported *national* grid-connected PV capacity of 2 MW for India.

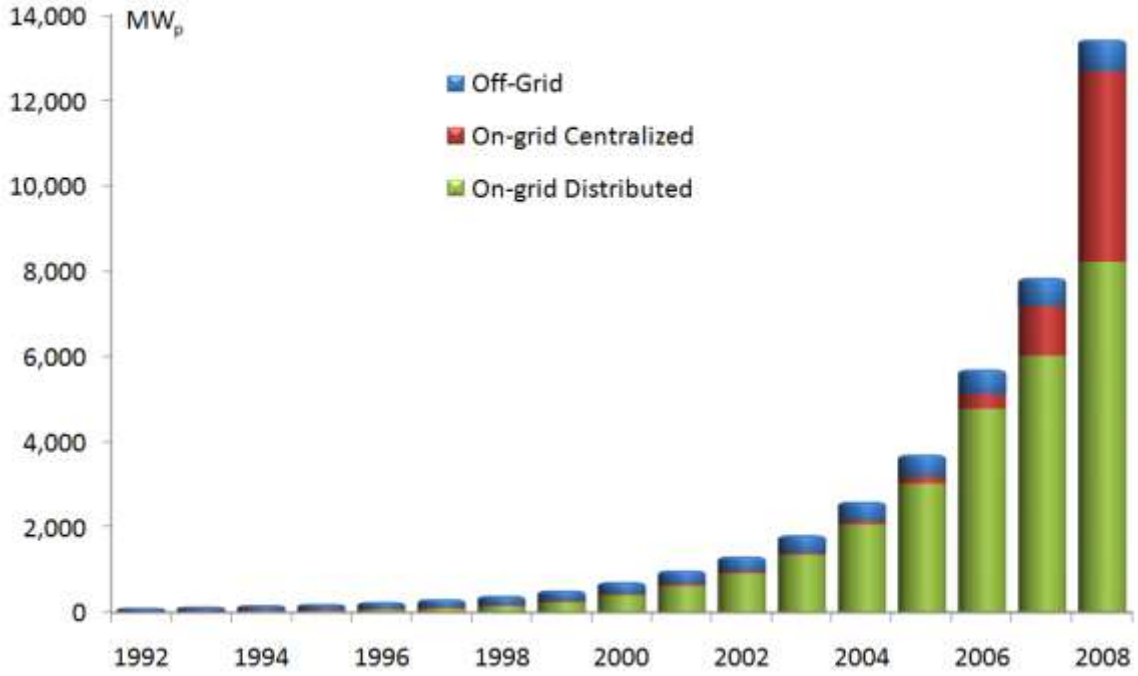

Figure 1.3: Cumulative PV Installations by Category in IEA-PVPS Countries 1992-2008.
Data source: IEA-PVPS reports covering 1992-2008

1.4.2 Off-grid PV Systems

The market for off-grid PV systems dates back to the 1970s' attempt to commercialize solar energy. As seen in Figure 1.3, this sector of the PV market has been eclipsed in terms of cumulative installed capacity. In 2008, cumulative worldwide off-grid installations are estimated to have reached 3 GW as compared to 13 GW for grid-connected (REN21, 2009). However, the accuracy of such estimates is all the more difficult to establish given the range and diversity of applications involved (Jager-Waldau, 2009; REN21, 2009)

Overall, industrialized countries, such as those in the IEA-PVPS list are predominantly skewed toward grid-connected applications with only about 5% (~710 MW) of the cumulative capacity by 2008 being off-grid projects (IEA-PVPS, 2007).

In contrast, countries like India and China and large number of developing country markets are presently dominated by the off-grid systems, although this appears to be rapidly changing as discussed above. For instance, in India, until recently, out of the total installed capacity of about 122 MW, grid-connected PV accounted for only 2 MW (Akshay Urja, 2008). In China, half of the country's installed solar PV capacity of 80 MW is found in off-grid applications, with the remainder distributed between applications in communication, industry and consumer products (Martinot and Li, 2007). The Chinese market for installed off-grid PV is growing at about 5-10 MW per year (Martinot and Li, 2007). The dominant applications for off-grid PV in countries like India, China, Bangladesh and Thailand, among others, are solar water pumps, small solar home systems (e.g., 40Wp) and street lighting (REN21, 2008).

The differing trend seen in industrialized and developing country markets vis-à-vis off-grid PV applications and distributed grid-connected PV systems could be accounted for by at least two factors. First, as seen in Section 4 of this report, there is and has been a difference between these groups in the prioritization of solar photovoltaic technologies and available policy incentives for their promotion. For instance, while Germany, California, New Jersey and Japan have aggressively promoted policies to incentivize

grid-connect distributed PV systems, developing countries have sought to use PV technology to meet the energy needs of vast rural and peri-urban populations who have limited or no access to commercial energy and often live in areas without a grid. In this context the off-grid systems have proven to be more applicable and affordable. Second, the average size of a distributed grid-connected PV system is about 3kW, whereas the size of the off-grid PV Solar Home Systems, used in developing countries is often less than 100W. Thus, the financial incentives required to promote these systems are very different and developing countries have adopted the policy of waiting for costs to come down and are only beginning to make significant policy commitments such as incentivizing higher capacity, distributed grid-connected or centralized PV.

1.4.3 Production of PV Cells

In 2009 PV cell production is estimated to have reached over 9 GW, including about 1.6 GW of thin-film capacity (Marketbuzz, 2010). If the capacity expansion that has been announced or is underway is realized, worldwide production levels could reach 38GW by the end of 2010, of which 10GW are expected to be thin-film (Jaeger-Waldau, 2009).

In this rapidly evolving industry, the long-time market leader in terms of PV cell production, Japan, was displaced by China in 2007 (Marketbuzz, 2008). While Japanese producers accounted for 26%, Chinese manufacturers grew from 20% in 2006 to 35% of the global market in 2007 (Marketbuzz, 2008). Companies such as Suntech Power, which reached a production level of 550 MW in 2008, drive China's explosive growth. In 2008, Chinese cell production accounted for 2.4 GW, followed by Europe at 1.9 GW and Japan and Taiwan at 1.2 and 0.8 GW, respectively (Jager-Waldau, 2009).

Other countries like India, Malaysia and South Korea are trying to replicate the example of China and Taiwan by attracting investment in the solar energy sector (Jager-Waldau, 2007). For instance, in 2008 India announced a number of state and national policies to support manufacturing PV in special economic zones. These policies include

a capital investment subsidy of 20% and have led to new PV manufacturing plans or proposals totaling $18 billion (REN21, 2009).

After years of lagging as the less preferred solar technology, thin-film production first crossed the 100 MW mark in 2005. In the years since, production has increased at a higher rate than the overall industry. It accounted for 6% in 2005, 10% in 2007, 12-14% in 2008 and 18% in 2009. Further, the utilization rate of thin-film production capacity at 60% is marginally higher than the industry average (crystalline and thin-film) of 54% (Jager-Waldau, 2009).

The United States accounts for two-third of the global thin-film production (Sawin, 2008)[12]. Various other countries are making commitments to this market over the coming years. Sharp, the Japanese corporation recently started production at 160 MW facility that is one-third the 480 MW it had proposed prior to the financial crisis. (RECharge, 2010). In India, Moser Baer India has commenced production at its 40 MW thin-film facility (Moser Baer, 2010). In China, Suntech Power is building its first 50 MW production line (Suntech, 2010). Figure 1.4, captures the recent growth of region wise PV module production by technology.

Since 2003 global PV production increased almost 10-fold at an annual rate in the range of 40% to 80%. In comparison thin-film, which started from a very low level, grew at an average of 90%. Massive capacity expansions are underway in the industry or have been announced. If all of the announced expansion plans are realized the worldwide production capacity for solar cells would exceed 38GW at the end of 2010. Of this, thin-film can reach 10GW at the end of 2010 (Jager-Waldau, 2009).

[12] Includes amorphous silicon and "other" non-silicon based thin-film based cell production (see IEA-PVPS 2007)

Table 1.4 Top 20 Global PV Cell Producers in 2006 and Their Past Production (in MW), (with 2007 update)

		2000	2002	2004	2006	2007*
1	Sharp (Japan)	50.4	123.0	324.0	434.0	363.0
2	Q-cells (Germany)		8.0	75.0	253.1	389.2
3	Kyocera (Japan)		60.0	105.0	180.0	207.0
4	Suntech (China)			28.0	157.5	540.0
5	Sanyo (Japan)	17.0	35.0	65.0	155.0	155.0
6	Mitsubishi (Japan)	12.0	24.0	75.0	111.0	150.0
7	Motech (Taiwan)		8.0	35.0	110.0	240.0
8	Schott Solar (Germany)	10.0	24.5	53.0	83.0	130.0
8	Schott Solar (USA)	4.0	5.0	10.0	13.0	
9	Deutsche Solar/Shell Solar (Germany)	3.3	9.0	38.0	51.0	
9	Solarworld CA/Shell Solar (USA)	28.0	46.5	62.0	35.0	
10	BP Solar (Australia)	5.8	8.4	34.0	33.4	
10	BP Solar (USA)	20.5	31.0	14.2	25.6	228.0
10	BP Solar (India)	6.5	13.1	14.1	14.4	
10	BP Solar (Germany)	9.2	16.7	23.5	12.3	
11	Sunpower (Philippines)				62.7	100.0
12	Isofoton (Spain)	9.5	27.4	53.3	61.0	150.0
13	First Solar (USA)			6.0	60.0	307.0
14	CEEG Nanjing (China)				60.0	
15	Ersol (Germany)		9.0	16.0	40.0	
16	Baoding Yingli (China)				35.0	142.5
17	E-Ton (Taiwan)			5.0	32.5	210.0
18	Kaneka (Japan)	5	7.5	20.0	30.0	
19	Sunways (Germany)		4.5	11.0	30.0	
20	United States OVONICS (USA)	3.0	4.0	14.0	28.0	
	Total Top 20	**184.2**	**464.6**	**1081.1**	**2107.5**	
	Total Global (76)	276.8	547.1	1193.5	2520.8	

Data source: Maycock & Bradford (2007);
* 2007 data are based on companies' press releases and news reports.

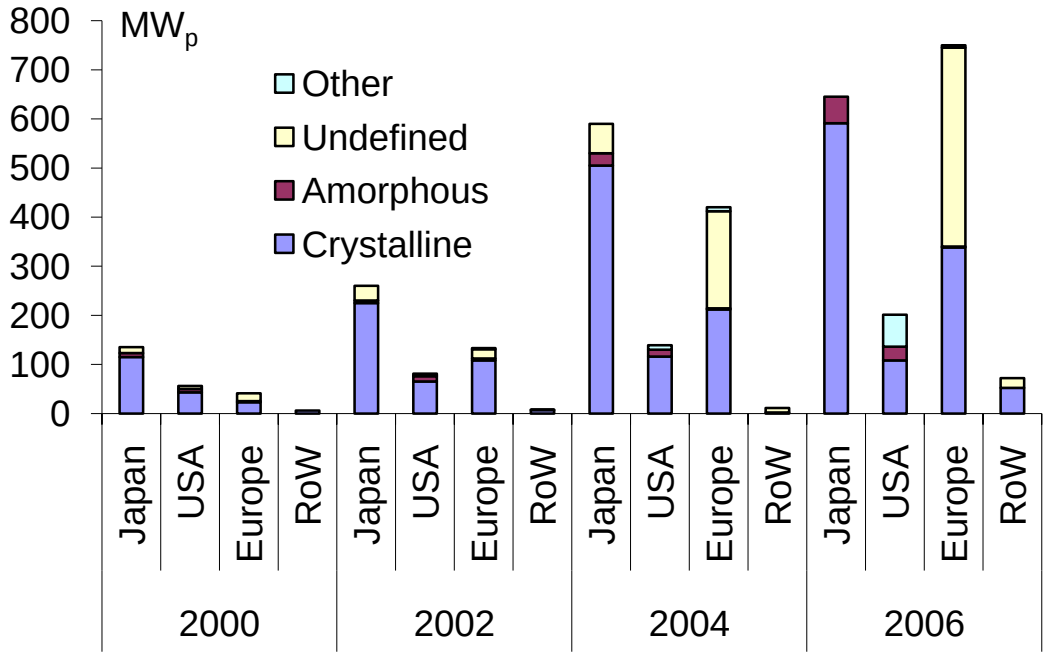

Figure 1.4 Global PV Module Production
Data source: IEA-PVPS Reports, 2001-2007; For the year 2000, IEA-PVPS figures combine categories "Undefined" & "Other" and report under single head: "Other/Unknown;" "Other" refers to non-silicon based modules such as Cadmium Indium Diselenide (CIS), Cadmium Telluride (CdTe) and others; "Undefined" indicates that technology type was not clarified.

1.5 Solar Thermal

As seen in Table 1.2, solar thermal installations are the bigger share in terms of solar energy being harnessed. This trend is primarily driven by solar hot water systems that are increasingly becoming common across the 'developed' and 'developing' markets. It is estimated that global heat demand across all sectors of the economy is 40-50% of the final energy demand (IEA, 2007). The solar thermal non-electric technologies currently on the market are efficient, highly reliable and ideally suited to provide solar energy solutions for meeting this vast demand (ESTIF, 2007: 6).

According to Aringhoff et al. (2005) suitable sites for installing solar thermal collectors should receive at least 2,000 kWh of sunlight radiation per square meter

annually, whilst best site locations receive more than 2,800 kWh/m^2/year. Further the ideal sites are in regions with low levels of atmospheric humidity, dust and fumes such as the steppes, bush, savannas, semi-deserts and true deserts, which are usually, located within less than 40 degrees of latitude North or South. Therefore, the most promising areas of the world for solar thermal include the South-Western United States, Central and South America, North and Southern Africa, the Mediterranean countries of Europe, the Near and Middle East, Iran and the desert plains of India, Pakistan, the former Soviet Union, China and Australia (Aringhoff et al., 2005).

1.5.1 Solar Thermal Electric

The market evolution for CSP technologies is distinguished by a long static period that lasted from 1984 until the early 1990s. In contrast recent years have seen a spurt of activity that is marking the revival of the CSP market (Wolff et al., 2008). While many regions of the world, such as for instance, South West United States, Spain, Algeria, Morocco, South Africa, Israel, India and China, provide suitable conditions for the deployment of CSP, recent market activity has occurred in South West United States and Spain, both of which are supported by favorable policies investment tax credits and feed-in tariffs, respectively (Wolff et al., 2008). In 2006-2007 the three CSP plants that were completed included a 64 MW parabolic trough plant in Nevada and a 1 MW trough plant in Arizona in the United States, and an 11 MW central receiver plant in Spain (REN21, 2008). In 2008, two new CSP plants came on line, which included a 50MW plant (Andasol-1) in Spain and a 5 MW demonstration project in California (REN21, 2009)

There are currently many projects around the world either under construction, in planning stages, or undergoing feasibility studies. As of mid-2009 and counting only the "major solar thermal and CSP plants operating and under construction" Richter et al. (2009) found a total operation capacity of 560 MW, while 984 MW were under construction and nearly 7.5 GW were announced. While this list is dominated by Spain and the United States, other markets for CSP included Israel, Morocco, Algeria, Egypt, South Africa, China, India, among others (Richter et al., 2009). For instance, India's National Thermal Power Corporation (NTPC), a state owned electric utility has

envisaged about 111 MW of solar thermal by 2014, as part of its strategy to enter utility scale solar power generation (PM News Bureau, 2010).

1.5.2 Solar Thermal Non-Electric

In 2008 the global solar hot water capacity had reached 145 gigawatts-thermal (GWth), and the leading markets included China, Israel, Japan, Spain, Germany, USA and Mexico. By far the dominant market for this application is China, which accounted for 75% of the global capacity addition was China where the volume of added capacity realized in 2008 was 14 GWth (20 million square meters). China also retained its leadership position in this application of solar energy by accounting for 70% of total existing global capacity. Europe was the next biggest market. Germany at 1.5 GWth added in 2008 along with Spain and the rest of Europe adding about 0.5GWth accounted for about 2 GWth. Among the developing economies, Brazil, India, Mexico, Tunisia and Mexico also saw notable growth in solar hot water installations (REN21, 2009). Notwithstanding these gains, this sector remains a market with vast untapped potential. For instance, the potential for solar water heating systems in India is estimated to be 140 million square meters, but only 4.3 million square meters (about 3%) have been utilized (Akshay Urja, 2008).

The use of solar thermal non-electric technologies varies greatly in scale as well as type of technology preferred. The widely documented technologies include glazed flat-plate collectors, evacuated tube collectors and unglazed collectors that use water as the energy carrier, as well as glazed and unglazed air collectors. For instance, glazed flat-plate and evacuated tube water collectors dominate the markets in China, Taiwan, Japan and Europe. While China and Taiwan dominate the market in terms of size, Europe has the most sophisticated market when variety of applications is considered. It includes systems for hot water preparation, plants for space heating of single- and multi-family houses and hotels, large-scale plants for district heating and industrial applications (Weiss et al. 2009).

In Austria, Germany, Switzerland and the Netherlands solar thermal applications other than preparing hot water in single-family houses is 20% and higher. It is estimated that about 130 large-scale plants (greater than 500 square meters and 350 kWth) are in operation in Europe with a cumulative capacity of 140 MWth. The biggest among these include solar assisted district heating applications located in Denmark with 13 MWth (18,300 square meters) and Sweden with 7 MWth (10,000 square meters). The biggest reported solar thermal system for providing industrial process heat was installed in 2007 in China. This 9 MWth (13,000 square meters) plant generates heat for textile operations (Weiss et al., 2009).

Separately, unglazed water collectors employed for applications such as heating swimming pools dominate the North American (numbers cited above from REN21, (2009) exclude this unglazed swimming pool application). Other markets for unglazed collectors include South Africa, Canada, Germany, Mexico, The Netherlands, Sweden, Switzerland, Belgium and Austria. But these countries all had values below 0.1 GWth of new installed unglazed collectors in 2007.

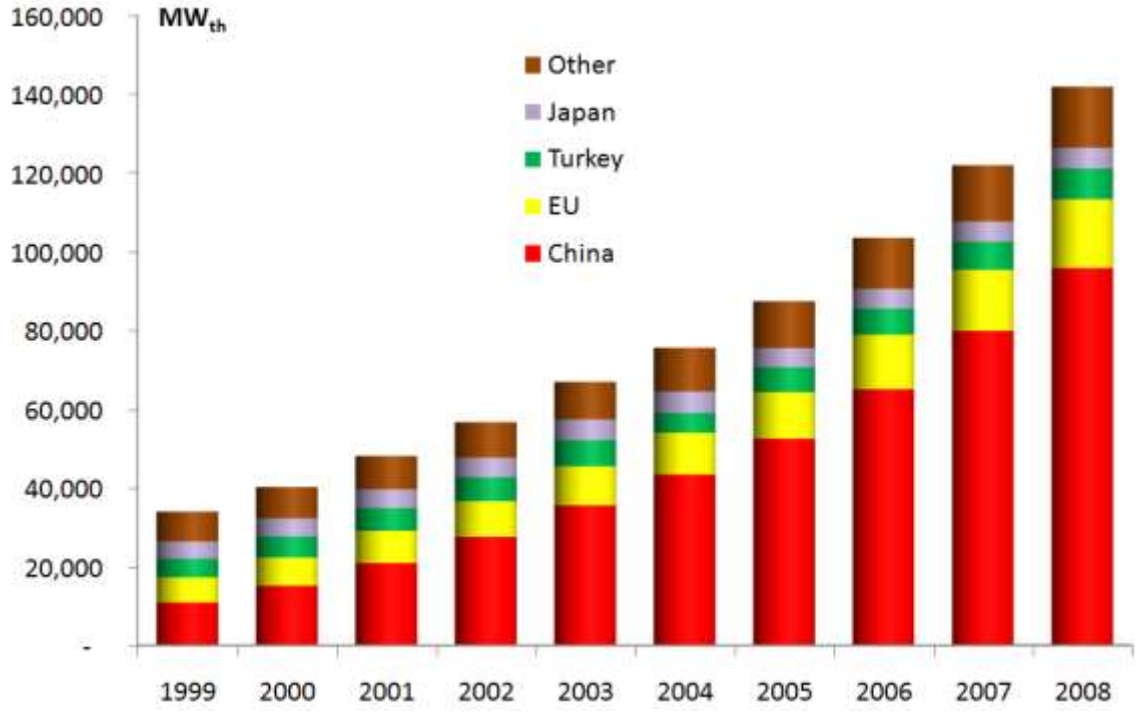

Figure 1.5 Installed Capacity of Small-Scale Solar Thermal Systems
Data Source: Weiss et al. (2005, 2006, 2007, 2008 and 2009)

Based on data from 49 countries (representing about 85-90% of worldwide market and about 4 billion people) the total area of installed solar collectors increased from 159 million square meters at the end of 2005 to 182.5 million square meter in 2006 to 209.7 million square meters at the end of 2007. This corresponded to an increase in the installed capacity from 111.0 GWth in 2005 to 146.8 GWth in 2007. It is estimated that the total capacity in operation grew to 165 GWth during 2008 and corresponded to a collector area of 236 million square meters (Weiss et al., 2008; 2009). The installed capacity for 2007 was composed of 46.4 GWth glazed flat-plate collectors, 74.1 GWth of evacuated tube collectors, over 25 GWth of unglazed collectors and a cumulative glazed and unglazed air collector capacity of about 1.2 GWth (Weiss et al., 2009).

Along with the application of solar energy for water and space heating on a decentralized level, its application for air conditioning and cooling are also gaining popularity especially in some European countries like Austria, Germany and Sweden. Currently, Europe has at least 40 systems in service for air conditioning of buildings (25 of them in Germany alone) with a combined collector area of approximately 17,000 square meters with total capacity of 4.4 MWth (REN21, 2007 in IEA, 2007).

Overall, in terms of solar thermal non-electric's contribution to meeting energy needs, it is second only to wind among the renewable energy resources (not counting biomass and hydropower). Some analysts have argued that this aspect needs greater attention in energy policy deliberations (Weiss et al., 2009).

2. A COMPARATIVE ANALYSIS OF SOLAR AND NON-SOLAR ENERGY COSTS

2.1 Introduction

There are a wide variety of solar energy technologies and they compete in different energy markets, notably centralized power supply, grid-connected distributed power generation and off-grid or stand-alone applications. In each of these market segments, the price of applicable solar energy technologies can be compared with the prices of conventional and other renewable energy technologies.

For instance, concentrating solar power (CSP) competes with various technologies seeking to serve the centralized grid, which represents a wholesale market. On the other hand, small-scale solar thermal applications, such as solar hot water and space heating, along with photovoltaics, are modular and largely customer sited technologies. They are categorized within the broader category of distributed energy resources (DER)[13] and compete with a number other technologies in retail energy markets. The DERs offer many advantages: they can reduce peak loads, enhance system reliability, reduce the need to buy power in wholesale markets during peak hours when prices are high, and enhance energy security and boost local economies (Byrne et al., 2005b).

The traditional approach for comparing the cost of generating electricity from different technologies relies on the "levelized cost" method. The levelized cost of electricity, or LCOE, represents the break-even cost at which 'all expenses,'[14] needed to

[13] DERs are essentially 'small power generation and storage applications, usually located at or very near customer loads' (Denny and Dismukes, 2002). Broadly, DERs include technologies and applications, which can be categorized into grid-connected applications, known as 'distributed generation' (DG) and a separate category known as stand-alone systems, which includes electric as well as non-electric applications (IEA 2002, Byrne et al., 2005b).

[14] These include 'initial expenses' such as design, licensing and installation; 'operating expenses, maintenance expenses, taxes and decommissioning expenses' (Kammen and Pacca, 2004).

generate electricity are recouped over the life of the plant while also providing a sufficient return to investors (Falk et al., 2008; NEA/IEA, 2005).

The main components included in LCOE calculations are the levelized costs of capital, operation and maintenance (O&M) and fuel. Generally LCOE is estimated using formulae presented in equations such as the following (derived from Stoft, 2002)[15]:

$$LCOE = \frac{IC}{cf} + OMC + FC \quad \ldots\ldots\ldots\ldots\ldots..(1)$$

$$\text{where, } IC = \frac{(r * OC)}{1 - 1/(1+r)^T} * \frac{1}{8760} \quad \ldots\ldots. (2)$$

IC = "Investment costs," *OC* = "overnight costs;" *OMC* = "operation and maintenance costs;" *FC* = "fuel costs;" *cf* = "capacity factor," *r*= "discount rate" and *T* = "plant life time in years."

In recent years the costs of fossil and nuclear fuels have increased significantly (see Figure 2.1). Based on data from the U.S. Energy Information Administration, for the ten-year period, 1998-2007, the wholesale price of residual fuel oil (No. 5 & 6 distillates) has increased by over 248% ($0.39/gallon to $1.38/gallon; 2007 dollars).[16] Similarly, the cost of natural gas supplied to electricity generators has increased by 139% (from $3.05/mcf to $7.3/mcf; 2007 dollars). In the case of Uranium Oxide (U_3O_8) imported to the United States, the cost has increased by 112% ($15.44 to $32.78; 2007 dollars) for the same time frame. While the least volatile, coal prices have also witnessed an increases of about 11%.[17] However, due to the financial crises, the world oil price has dropped to lower than one-third of its peak occurred in 2008. The drop on fuel prices and downward pressure on material prices resulted from financial crises could lower fuel and O&M

[15] This formula assumes a zero escalation rate for O&M costs and fuel costs. For a more comprehensive formula, see Roth & Ambs (2004).
[16] In the case of No. 2 distillate, also used for electricity generation, the corresponding increase in wholesale cost is 457%, ($0.69 to $3.84; 2008 dollars).
[17] Cost information is derived from data presented by EIA.

costs in the short-term. Yet, the long-term trends remain unclear.

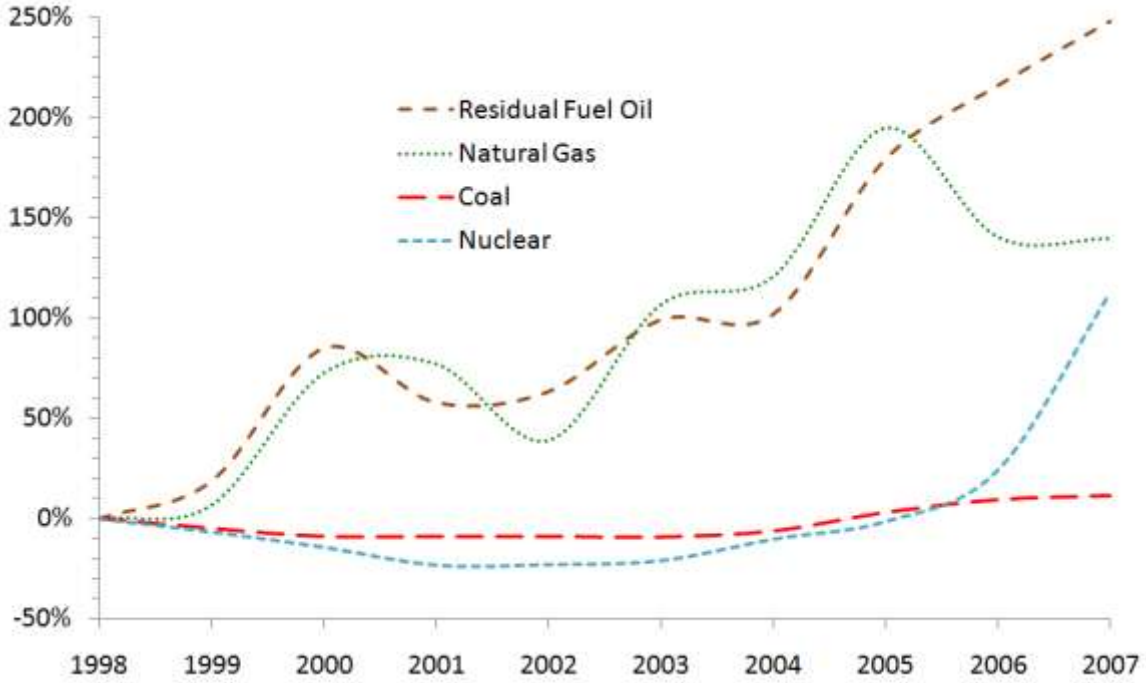

Figure 2.1 Percentage of Fuel Price Change from 1988 to 2007
Data Sources: (EIA 2008a, 2008b, 2008c, 2008d)

These cost trends have in turn been reflected in the cost of electricity. For instance, in the United States, increases in fuel prices and purchased power costs, accounted for over 95% of the cost increases experienced by utilities between 2000 and 2005 (Falk et al., 2008). Fuel cost escalation can have a significant impact on LCOE.

With the recent rise of the deregulated electricity industry and efforts to internalize the energy industry's externalities, computing electricity costs has become more complex. LCOE frequently incorporate risk premiums for investors who now have to produce and sell electricity in a non-regulated market and require hedges to balance fuel and commodity price fluctuations. LCOE also often count direct and indirect subsidies to provide an informed comparison between various technological choices and many include social and environmental externalities (Kammen and Pacca, 2004).

2.2 Cost Comparison for Centralized Power Generation Technologies

Below we summarize the overnight and LCOE costs of emerging renewable technologies, which are typically, utility scale such as CSP and wind and compared them to more traditional forms of power generation based on coal, natural gas and nuclear energy. The reported costs of power plants of both conventional and renewable electric technologies vary significantly across countries and regions (NEA/IEA, 2005). For instance, the overnight cost of a coal fired power plant is $1,290/kW in India, while a coal plant costs $2,250/kW in Romania. Likewise, a combined cycle natural gas power plants costs $1,140/kW in Romania but $1,410/kW in US (ESMAP/WB, 2008). Table 2.1 provides the range of costs of various centralized power generation technologies reported in literature (NEA/IEA, 2005; Lazard, 2009; IEA, 2008; ESMAP/WB, 2008).

Table 2.1 Overnight Costs of Central Station Technologies (2009 $/kW)

	NEA/IEA			**ESMAP/WB**			**Lazard**			**IEA**		
	Low	High	Ave.	Low	High	Ave.	Low	High	Ave.	Low	High	Ave.
Coal	849	2773	1550	1303	2757	1995	2800	5925	4363	1414	2020	1717
Nuclear	1270	2966	1996				6325	8375	7350	1100	3466	2284
NG	430	1527	758	1424	1151	1252	950	1175	1063	606	758	682
Wind	1153	1931	1534	1646	1778	1700	1900	2500	2200	1236	1724	1481
CSP		3279	3279				4500	6300	5400	9090	10100	9595

Data Sources: (NEA/IEA, 2005; Lazard, 2009; IEA, 2008a; ESMAP/WB 2008) Note that the average costs in NEA/IEA and ESMAP/WB columns are weighted average.

2.2.1 Coal

Worldwide, coal fired power plants account for over 40% of electricity generation (NEA/IEA, 2007). In the United States and China, which together account for over 37% of the world's electricity generation, coal based generation accounts for 50% (2,154 TWh, 2005) and 80% (1,972 TWh, 2005), respectively. India is the third largest producer of electricity from coal with more than one half of the country's electricity supplied by coal plants (480 TWh in 2005). In 2005, Japan (309TWh) and Germany

(305TWh) ranked 4th and 5th in the list of countries generating electricity from coal (IEA, 2007, 2007a).

As noted above, the LCOE is a function of several variables, including capacity factor. Worldwide coal fired power plants usually operate as base load units and have a very high capacity factor. For instance, the NEA/IEA (2005) in its analysis uses 85% for its LCOE calculations for electricity from coal based generators in OECD countries. The ratio used to report the performance of coal and lignite based power plants in India is "plant load factor" (PLF).[18] The highest PLF of 77.03% was achieved in 2006-07 (CEA, 2007). In China, the capacity factor of coal fired power plants was 56% in 2006 (NBSC, 2007; China Power, 2007).

A questionnaire survey of 27 coal based power plants in OECD countries found that the average net thermal efficiency was about 40%. Among these plants the lowest thermal efficiency of 29% was reported for a pulverized coal unit in Romania, while the highest thermal efficiency of 51% was reported for an integrated gasification combined cycle coal plant in Germany (NEA/IEA, 2005).

Based on our investigation, the overnight costs of coal fired power plants constructed between 1958 and 2005, ranged from $849 to $5,925/kW (2009 dollars) (Vergara, 1990; Reynolds, 1983; NEA, 1986; NEA/IEA, 1989; 1992; 1998; 2005; ESMAP/WB, 2008; Lazard, 2009; Falk et al., 2008). The range of $800 to $2300/kW based on a questionnaire evaluation of 27 coal-fired power plants in OECD countries also lies within these limits (NEA/IEA, 2005).

The LCOE from coal based power plants estimated by Lazard (2009) was found in the range of $0.078/kWh - $0.144/kWh, assuming an 85% capacity factor, a 20-year

[18] The "plant load factor" is the ratio of total electricity generated in a given time to the product of the maximum load and hours. As such it is slightly different from the more commonly reported "capacity factor"—a ratio of total electricity generated in a given time to the products of the hours and installed capacity.

plant life, a fuel cost range of $0.022 - $0.030/kWh, and an O&M cost range of $0.005 - $0.010/kWh. The corresponding range of overnight costs was $2,800 - $5,925/kW.[19]

2.2.2 Natural Gas

Worldwide, natural gas fired power plants account for about 20% of electricity generation (IEA, 2007). In the United States which accounts for over 23% of the world's electricity generation, natural gas based generation accounts for about 20% (833TWh, 2005). In Russia and Japan, the second and third largest producers of electricity from natural gas, it contributed 48.5% (439TWh) and about 21% (231TWh), respectively, in 2005. The United Kingdom (153TWh) and Italy (149TWh) rank 4th and 5th in the list of countries generating electricity from natural gas (IEA, 2007a; IEA, 2007b). Large developing economies such as China and India rely on natural gas to a lesser extent, where it accounts for 2.1% and about 12%, respectively (CEA, 2005).

Natural gas power plants based on combined cycle gas turbine (CCGT) technology usually operate as base load units and thus have high capacity factors. The NEA/IEA (2005) in its calculations of an LCOE for gas based generators in OECD countries uses 85%. However, capacity factor varies between countries. Lazard's analysis has used a range of capacity factors from 40% to 85% (Lazard, 2009).

A survey of 23 gas fired generators in IEA countries found that the average net thermal efficiency was over 54%. The highest thermal efficiency of 60% was reported for two combined cycle gas turbine plants from Germany and Netherlands. The lowest efficiency in this survey, 40%, was reported for a combustion turbine plant in the United States (NEA/IEA, 2005). In comparison to coal fired power plants the overnight construction costs of natural gas plants are smaller and range from $426/kW to $1,512/kW (see Table 3.11 in NEA/IEA, 2005; Table 3.4 in ESMAP/WB 2008; Lazard, 2009; Falk et al., 2008).

[19] The Lazard (2008) analysis assumes 60%debt at 7% interest rate, and 40% equity at 12% cost. These parameters are applied to the LCOEs for all technologies reported in its analysis.

The estimate for LCOE from gas-fired combined cycle power plants is in the range of $0.069/kWh to $0.096/kWh (Lazard 2009). The analysis assumed a capacity factor range of 40% to 85%, a 20-year plant life, an O&M costs range of $0.004 - $0.005/kWh, and a fuel cost range of $0.054 - $0.058/kWh. The range of overnight construction cost assumed in their analysis was between $950 - $1,175/kW (Lazard 2009).

2.2.3 Nuclear Power

Nuclear power accounted for about 15% of worldwide electricity generation in 2005 (IEA 2007a). The top five countries in terms of gross electricity generation from nuclear power include the United States (811 TWh), France (452 TWh), Japan (305 TWh), Germany (163 TWh) and Russia (149 TWh). They accounted for about 68% of global nuclear power generation (2,768TWh) in 2005. In terms of nuclear power's contribution to domestic electricity generation, the top five countries include France (79%), Ukraine (48%), Sweden (46%), Korea (38%) and Japan (28%) (IEA, 2007b).

Nuclear power plants typically serve as base load units and are assumed to have a capacity factor of about 85% - 90% (NEA/IEA, 2005; Lazard, 2009). But this level of performance is found to vary widely. For instance, performance evaluations of nuclear power plants outside the OECD region, in China, India and Pakistan, between 1989 and 1996, revealed average national capacity factors of 71%, 46% and 34%, respectively (Rothwell, 1998).

Compared to natural gas and coal fired generators, nuclear power plants have the lowest average net thermal efficiency of about 34%. Based on a survey of thirteen nuclear power reactors in the IEA countries, the lowest thermal efficiency of about 30%, was reported from reactors in the Czech Republic, Slovak Republic and Romania, while the highest, 37%, was reported for a reactor in Finland.

Based on our investigation, the overnight cost of specific nuclear power plants built in different years varies from around $1,270 to $8,375/kW (2009 dollars) (NEA/IEA, 2005; EIA, 2005; ESMAP/WB, 2008; Lazard, 2009; Falk et al., 2008).

The LCOE of nuclear plants ranges from $0.107 to $0.138/kWh with an assumed 90% capacity factor, a 20-year plant life, an O&M cost of $0.002/kWh, and a fuel cost of $0.005/kWh (Lazard, 2009)[20]. The range of overnight construction cost was assumed to be between $6,325 - $8,375/kW (Lazard, 2009).

2.2.4 Wind

Worldwide, the installed capacity of wind power is about 93.85 GW, led by Europe which accounts for 60.9% (57.1 GW), followed by North America 19.9% (18.7 GW) and Asia including China and India, contributing about 16.8% (15.8 GW) (GWEC, 2007).

With the rapid development of wind power technology, construction costs have been increasing modestly and it is expected that this trend will continue for some time. Based on our investigation, the overnight cost of wind plants built in different countries and years varies from around $1,153 to $2,500/kW (2009 dollars) (NEA/IEA, 2005; EIA, 2008; ESMAP/WB, 2008; Lazard, 2009). Bolinger and Wiser (2009) suggest that the overnight cost is likely to remain about $2/kW for several years.

The O&M costs for wind power plants vary between different countries and in some cases even within the same region. O&M costs have also begun to increase recently (Bolinger and Wiser 2009).

Given the intermittent nature or wind, the operation of wind turbines can have relatively lower capacity factors. The reported capacity factor of wind power plants range between 17% and 38 % for onshore plants with turbine lifetimes of about 20 years (NEA/IEA, 2005). This inherent characteristic of wind energy puts an upward pressure on LCOEs.

[20] In the case of nuclear power, Lazard (2008) does not report high and low values of O&M and fuel costs.

The LCOE from wind is calculated with the assumed capacity factor range of 28% to 36%, a 20-year plant life, and an O&M costs range of $0.013 - $0.020/kWh (Lazard, 2009). The analysis reports an LCOE for wind in the range of $0.057/kWh to $0.113/kWh for wind. The overnight costs of wind power plants ranged between $1,900 – 2,500/kW (Lazard, 2009).

2.2.5 Concentrating Solar Power (CSP)

The global capacity of installed CSP reached 457 MW in 2007. However, CSP capacity is expected to double every 16 months over the next five years and worldwide installed CSP capacity is projected to reach 6,400 MW in 2012 (14 times the current capacity -- see Dorn, 2008). The United States and Spain are at the forefront of global solar thermal power development with a combined total of over 5,600 MW (over 90% of the global market). New capacity expected to come online by 2012 will be sufficient to meet electrical demands of more than 1.7 million homes (Dorn, 2008).

Outside the United States and Spain, regulatory incentives in France, Greece, Italy, and Portugal are expected to stimulate the installation of 3,200 MW of CSP capacity by 2020. Meanwhile, China anticipates building 1,000 MW in the same time period. Other countries developing CSP include Australia, Algeria, Egypt, India, Iran, Israel, Jordan, Mexico, Morocco, South Africa, and the United Arab Emirates (Aringhoff et al., 2005; Dorn, 2008).

The literature on the overnight construction costs of CSP (using parabolic trough technology[21]) reveals a wide range ($4,500/kW - $6,300/kW) and the reported average overnight cost of CSP is around $4,323/kW (NEA/IEA, 2005; Aringhoff et al., 2005; Lazard, 2009). The technical lifetime for power plant varies from 20 years in the Czech Republic to 40 years in the US (NEA/IEA, 2005).

The capacity factors of CSPs are assumed to fall in the range of 26% to 38%, a plant life of 20-year is expected, and O&M costs may range from $0.021 - $0.029/kWh

[21] See Section 1, Sub Sections 1.3 and 1.5 for more details.

(Lazard, 2009). Based on these assumptions the LCOE from CSP is in the range of $0.129/kWh to $0.206/kWh, with corresponding overnight construction costs of $4,500 – 6,300/kW (Lazard, 2009).

2.3 Cost Comparison for Distributed Power Generation Technologies

Distributed generation (DG) refers to the production of electric power at the consumer's site and the supply of that power directly to the on-site consumers (NEA/IEA, 2005: 69). Solar PV technology carries characteristics suitable for DG because of its on-site "installability" and modularity for easy capacity additions.

DG enjoys special advantages such as the following: it avoids transmission costs, reduces distribution costs and avoids line losses. DG technologies like PV carry very short gestation periods of development and, in this respect can reduce the risk valuation of their investment (Byrne et al., 2005b). DG applications enhance the reliability of electricity service when transmission and distribution (T&D) congestion occurs at specific locations and during specific times. By optimizing the location of generating systems and their operation, DG can ease constraints on local transmission and distribution systems (Weinberg et al., 1991; Byrne et al., 2005b).

DG can also protect consumers from power outages. For example, voltage surges of a mere millisecond can cause 'brownouts,' causing potentially large losses to consumers whose operations require high quality power supply. DG carries the potential to significantly reduce market uncertainty accompanying bulk power generation. Because of their modular nature and smaller scale (as opposed to bulk power generation), DG "reduces the risk of over shooting demand, longer construction periods, and technological obsolescence" (Dunn, 2000 quoted in Byrne et al., 2005b: 14).

One of the main advantages of DG is its capacity to reduce peak load as the peak generation time of PV systems often closely matches with peak loads for a typical day that in turn delays or eliminates the need for investment in power generation,

transmission, and distribution (Byrne et al., 2005b). For large-volume customers, notably in the commercial and industrial sectors who pay demand charges as well as energy charges, peak shaving can sizably reduce electricity expenditure during periods when variable rates are often highest and maximize their return on investment.

DG can enhance energy security and thereby improve local economies by utilizing local resources for and providing jobs to local people, rather than relying on external resources and labor. Most of the economic value generated by DG stays in local the economy in the form of increased jobs and income.

2.3.1 PV

As discussed in section 1, there has been exponential growth in the installation of PV systems. Worldwide, the total installed capacity of solar PV, at the end of 2007, was 10.5 GW, with the dominant markets being Germany (~40% of total PV installations), Japan (~ 20 %), the United States and Spain (each have about 6% of total PV installations) (see Figure 1.2).

The global market share of PV is predominantly for grid-connected systems with only about 4% (~63 MW) of the installed capacity during 2006 being off-grid projects (IEA-PVPS, 2007). However, countries like India and China and a large number of developing country markets are dominated by the off-grid systems. As mentioned in the previous section, for instance, in India, with a total installed capacity of about 122 MW, grid-connected PV accounted for only 2 MW (Akshay Urja, 2008). In China, one-half of the country's installed solar PV capacity of 80 MW is found in off-grid applications, with the remainder distributed between applications in communication, industry and consumer products (Martinot and Li, 2007). The Chinese market for installed off-grid PV is growing at about 5-10 MW per year (Martinot and Li, 2007). The dominant applications for off-grid PV in countries like India, China, Bangladesh and Thailand, among others, are solar water pumps, small solar home systems (e.g., 40Wp) and street lighting (REN21, 2008).

Along with exponential growth in the cumulative installation of PV, there have been significant gains in the economics of the technology. Our estimates suggest that the percentage reduction in cost of PV over the last two decades has been over 80% (see Figure 2.17). The cost of high power band solar modules has reduced from about $27,000/kW in 1982 to about $4,000/kW in 2006 while the installed cost of PV system declined from $16,000/kW to $8,000/kW between 1992 and 2006 (IEA-PVPS, 2007; Solarbuzz, 2006).

The productive life of PV modules is generally taken to be in the range of 20-25 years. In the case of PV systems, the absence of any moving parts drastically reduces the O&M costs. However, some components of the balance of a system (BOS) require replacement at shorter intervals. For instance, batteries usually have a life of about 8 years while inverter life is about 10 years. As such, these components would have to be changed during the life of a PV module. This creates a slight upward pressure on the overall cost of PV system.

The capacity factor of PV systems depends on the quality and quantity of solar insolation and thus, varies on a global and regional basis. For instance, estimates from *PV Planner*© (2006)[22] suggest that PV systems installed in Hamburg, Germany have a capacity factor of about 9% while a similar system installed in the Kutch region of India, has a capacity factor of 20%. The range of the overnight costs of PV is $4,800 to $7,100/kW (van Alphen et al., 2007; CBO, 2003; Lazard, 2009; ESMAP/WB, 2008).

For LCOE calculations of distributed PV systems, Lazard (2009) assumed a capacity in the range of 20% to 26% and a plant life of 20 years. The assumed range of O&M costs is $0.011- $0.014/kwh for both crystalline and thin-film solar PV. The range of LCOE from PV obtained from this analysis is $0.160 - $0.196/kWh for crystalline solar PV and $0.131 - $0.182/kWh thin-film solar PV. The overnight construction costs

[22] See Byrne at al. (2006a) on this software program developed at the Center for Energy and Environmental Policy, University of Delaware.

range between $3,250 - $4,000/kW for thin-film and $4,500 – 5,000/kW for crystalline solar PV (Lazard, 2009).

2.3.2 Fuel Cells

Unlike most conventional technologies that derive shaft-power by burning fuels, fuel cells generate electricity when hydrogen and oxygen are combined. While oxygen is taken from the air, hydrogen could come from a variety of sources, among which steam reformation of natural gas appears to be the most common (Byrne et al., 2006b). Fuel cells are being widely explored for automotive applications but are also increasingly being considered as a viable source for electricity generation. Fuel cells also enjoy the advantage of converting fuels to electricity at very high efficiencies (as much as 95%) compared to conventional technologies (IEA, 2002; Lazard, 2009). The LCOE for fuel cells, assuming capacity factor of 95%, a plant life of 20 years, O&M costs of $0.023/kWh, and overnight cost of $3,800/kW was found in the range of $0.111 - $0.119/kWh (Lazard, 2009).

2.3.3 Geothermal Heat Pumps

Heat from the earth, or geothermal energy can be and already is accessed by drilling shallow water or steam. Geothermal energy is an enormous, underused heat and power resource that is clean (emits little or no greenhouse gases), reliable (average system availability of 95%), and local (DOE, 2009). The most common geothermal technology requires a shallow well and heat pump. The technology is ideally suited as a distributed generation option at a user's site.

The LCOE for distributed geothermal applications is in the range of $0.058 - $0.093/kWh, assuming an average capacity factor of 75%, a plant life of 20 years, an average O&M costs of $0.0275/kWh, and an overnight construction cost in the range of $3,425 - $4,575/kW (Lazard, 2009).

2.4 Comparison of the LCOEs for Distributed and Central Station Renewable Energy Technologies

LCOE calculations depend upon the assumptions made by the analyst. Therefore, a proper comparison depends upon a single, common set of assumptions being used. Only a few studies offered such methodological consistency and one of the most respected analyses is that by Lazard, an investment bank. Figure 2.2 summarizes the LCOE estimates for key technologies relevant for this review. The figure distinguishes between technologies which compete in wholesale markets to supply power to utilities (i.e., central station RETs) and the technologies which compete in retail markets to provide energy to end users (i.e., renewable DGs).

The comparison is based on U.S. policies and capital and labor costs, and cannot be applied to other countries without adjustments for differences in these factors. Nonetheless, the comparison is instructive. It shows that the principal solar technology for central station applications is becoming competitive with conventional electricity sources, while wind technologies are setting the wholesale clearing price in some cases. DG solar applications are also approaching parity with their competitors for end-user applications, with geothermal application offering attractive opportunities to end users. Of course, the use of all RETs is dependent upon resource availability and the load profiles involved.

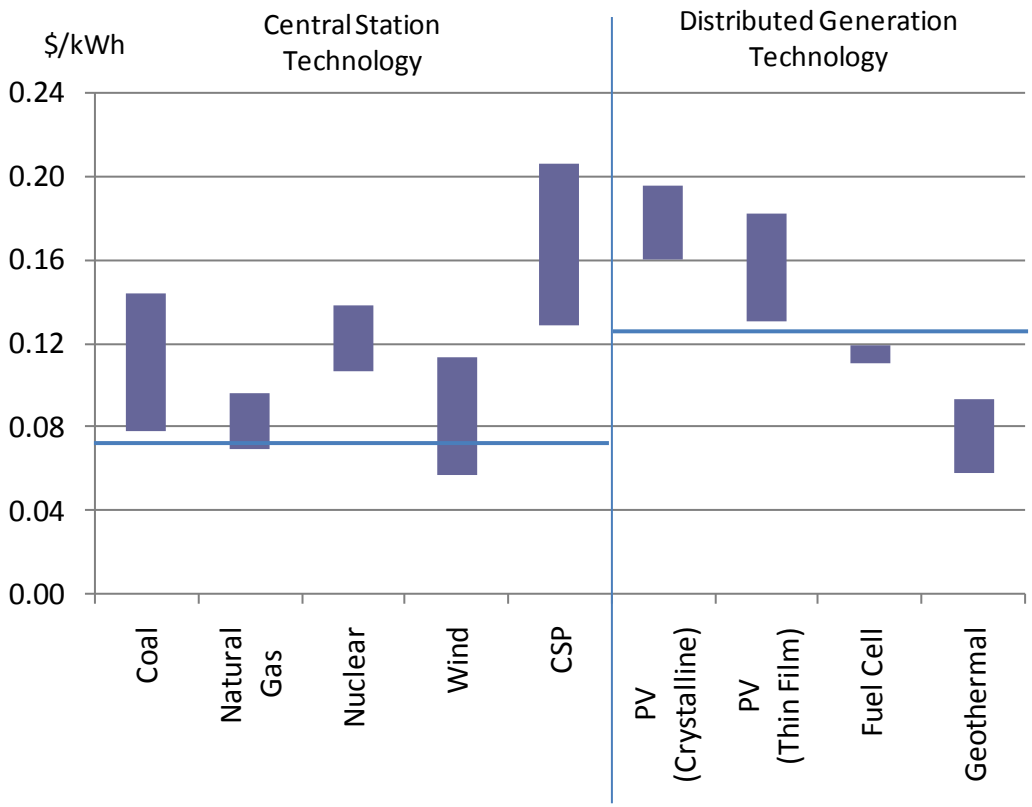

Figure 2.2 Range of LCOEs for Electricity Generation Technologies
Data Source: (Lazard, 2009; Lushetsky, 2008; IEA, 2009)

2.5 Experience Curves

In this section, we have reviewed experience curve analyses of cost trends for various renewable energy technologies. We also introduce our own calculations of learning rates and probable grid parity milestones for RETs, and especially solar technologies.

The concept of experience or learning curves was first used in the aircraft industry by T. P. Wright in 1936 with the idea that improvements in labor-hours needed to manufacture an airplane could be described mathematically (Wright, 1936). Since then, the analytical technique has become a handy tool for policy makers to assess trends in the cost competitiveness of technologies given the cumulative application of the technology (Reis, 1991; IEA, 2000; Colpier and Deborh, 2002; Neij, 2008).

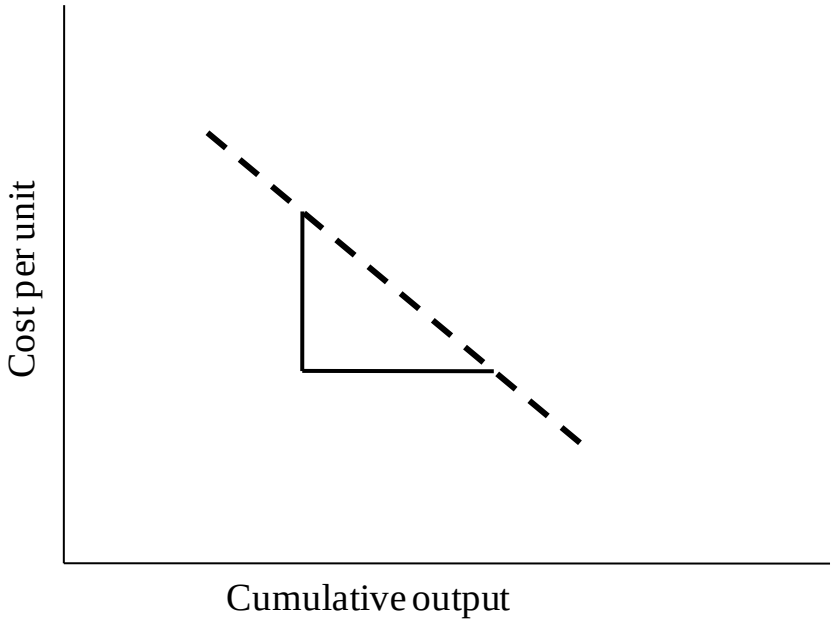

Figure 2.3 Experience Curve on Log Scales

The International Energy Agency (IEA, 2000: 9) offers the following definition: "An experience curve is a long-range strategic rather than short-term tactical concept. It represents the combined effect of a large number of factors…it cannot be use reliably for operating controls or short-term decision making. But in the formulation of a competitive strategy, the experience curve is a powerful instrument, indeed."

According to Neij, experience curves offer a means of analyzing past cost developments in order to project future costs. The approach does this by estimating cost as a function of cumulative production on a logarithmic scale (Neij, 2008). The graphical representation of an experience curve on double-logarithmic scales (i.e. logarithmic scale on cost as well as on cumulative output) is shown in Figure 2.3. The resulting trend line is linear making it easy to identify the cost effect of production experience as the slope remains constant. Anywhere along the log-log line, an increase by a fixed amount of cumulative output gives a consistent percentage reduction in cost per unit. It shows that changes in cost are proportional to the relative or percentage change in cumulative output. This representation suggests a steady, continuous improvement in performance but underlines that these improvements should always be seen relative to previous performance (IEA, 2000).

2.5.1 Experience Curves of Renewable Electric Technologies

It is now evident that conventional electricity generation technologies (e.g., coal and natural gas) no longer demonstrate significant declining trends in costs (Neij, 2008). However, as seen in Figure 2.4, our analysis finds that renewable energy technologies demonstrate strong declining trends in cost. Indeed, from the perspective of a sustainable energy future, PV technology demonstrates the strongest potential for cost declines.

The cost of solar PV has been declining rapidly in the past compared not only to conventional technologies like coal and nuclear but also to renewable technologies like wind. The "learning rate"[23] of CSP is about 9%, and for wind is about 13%. PV has the highest learning rate of about 20% falling well within the recorded range in the research literature (e.g. see Nemet, 2007; Beinhocker et al., 2008) from 15% to 25%. These learning rates compare favorably with those of conventional technologies such as coal and natural gas, which are in the range of 3% - 4% (Neij, 2008).

[23] There are two important metrics devised to reflect the information contained in an experience curve and apply it for evaluative purposes viz. "progress ratio" and "learning rate." The progress ratio is that proportion of original price, which results from a doubling of the cumulative volume. Thus, if the cost per unit reduces to 0.75 of the original price by doubling the cumulative output, then the progress ratio of such a technology is 75%. The learning rate for a particular technology is derived from the progress ratio by subtracting it from 1 or 100%. Thus, if the progress ratio is 0.75, the corresponding learning rate for the technology is 0.25 (or 25%).

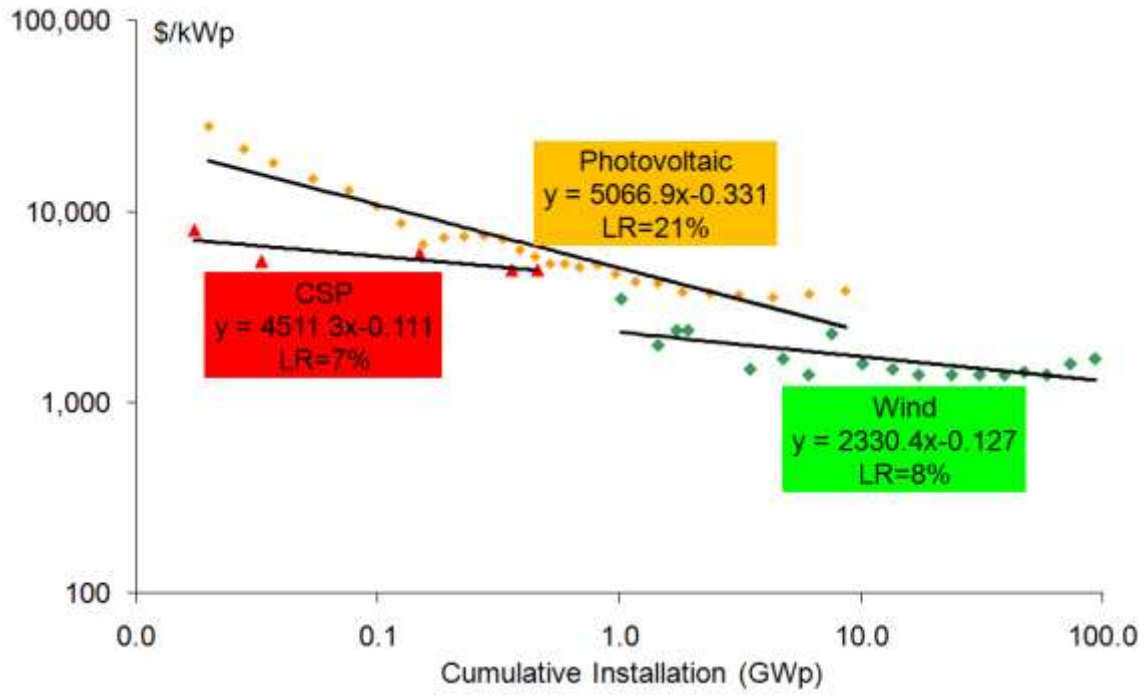

Figure 2.4 Experience Curves of Renewable Electric Technologies
Data Sources: Earth Policy Institute,2009; DOE, 2008; Stoddard et al., 2007; Charls et al., 2005; Winter, 1991

2.5.2. Insights into Short-Term Cost Trends in Solar PV

Recent industry assessments of the cost trends in the solar PV industry (e.g., O'Rourke et al., 2009) are particularly revealing and underscore the likelihood of future cost decline as projected by the learning curves above. PV remains a 'young' industry and technology with substantial room for efficiency improvements. The industry-wide "shake-up" engendered by the current global financial crisis appears to be a key driver for an even more competitively priced and therefore affordable expansion of PV applications (O'Rourke et al. 2009).

The eventual cost of a PV system is the cumulative expression of numerous factors, which can broadly be divided into "module costs" and "system costs." The module costs are in turn comprised of a number of components and processes, which are each subject to techno-economic efficiency gains. These include: a) the cost of

crystalline silicon (used in over 85% of PV modules and by far the biggest component of the module's cost); b) the cost of slicing "wafering" the silicon; c) the cost of processing the PV cell; d) the cost of integrating the module; and e) the industry's acceptable gross margin. Similarly, the "system costs" include: a) the balance of system components viz. mounting hardware, cables etc.; b) the inverter; c) transaction costs, viz. cost of permits, warranty reserves etc.; d) labor costs; e) the industry's acceptable gross margin.

2.5.2.1. Trends in Module Costs

With regard to module costs, the biggest component by far is the cost of polysilicon. In recent years the exponential growth of the young PV industry led to a commensurate growth in the cost of polysilicon. A commodity that historically sold at around $35/kg, supplying the mature demand pattern of the semiconductor industry, surpassed $250/kg in spot market prices in 2008. The resulting expansion in production capacity combined with the contraction in demand in light of the global financial crisis is now expected to promote dramatic price reductions in the near future. Analysts expect long-term polysilicon contract prices to settle at around $70- $80/kg. In effect, at $250/kg and a polysilicon usage efficiency of 7 grams per/Wp, the cost of silicon for one Wp would be $1.75. At a long-term cost of $70- $80/kg, the comparable prices will range from $0.49 - $0.56/Wp (O'Rourke et al. 2009).

Another series of costs concern "wafering," "cell processing" and "module integration" - all of which are expected to decline moderately over the near term. Analysts presently use a cost of $0.45/Wp, $0.35/Wp and $0.45/Wp, respectively for these components (O'Rourke 2009). It is apparent that these steps in the manufacture of PV modules still have considerable room for technological innovation and resultant cost reductions, as suggested by the learning curve in Figure 2.4. For instance, a recently announced innovation in the wafering of crystalline silicon blocks using proton beams claims a new benchmark of 2-4 g of Si/Wp - a significant improvement in silicon utilization over the traditional wire-saw method and the existing standard of about 7 g/Wp (Solar-PV-Management 2008). Innovations such as this have the potential to increase the number of wafers/kg of silicon and thereby reduce costs. However the exact

cost differentials between various innovations and present best practice are uncertain at this time.

Module integration is a component that has demonstrated considerable variation in cost – largely because it is subject to choices made by individual manufacturers with regard to equipment, automation, geography and other factors. While industry analysts have found a range of about $0.35/Wp to $1.00/Wp, most predict a value of $0.45/Wp for their calculations (O'Rourke et al., 2009).

Cell processing has experienced constant technological innovation, which has led to sustained cost reductions. Of all the stages of assembling a PV system, this step appears now to be the central focus of considerable technological research and development with a constant rise in conversion efficiencies. While the first generation of PV cells built in the 1950s were about 4% efficient, today commercially available cells are over 18% efficient (Sunpower, 2008). In addition, an overview of the state of the art in PV cell development finds that cells in the range of 40% efficiency have been tested in laboratories, while the next generation of 50% efficiency is expected (Barnett et al., 2007). The cost differentials between the new technology and current best practice needs to be factored into pricing, but efficiency increments such as these lead to improved energy outputs with lower material input demands.

2.5.2.2. Trends in Other System Costs

As a rule of thumb, remaining components of system costs account for about 45% of the total installed cost of a PV system. As such, just as there are efficiency-driven gains with regard to, for example assembling a module, there are also efficiency gains to be had with regard to installing a full system. However, unlike module costs, most components of other system cost such as "balance of system" costs "transaction costs" and "labor costs" demonstrate considerable cost variation. A predictable component of the system cost is the inverter. Next to the module, the inverter is the costliest component in the installed system. Industry analysts have found a range of$ 0.70/Wp to $0.30/Wp

depending on the system size; with bigger systems having a lower inverter cost (O'Rourke et al., 2009).

Currently, it appears that about 25% of module costs and about 35% of system costs are accounted for by gross margin requirements. The movement in this component of the cost matrix is influenced by various factors. Competition between different suppliers is certainly part of the equation. In addition, the chosen business model can impact gross margin. For instance, a fully integrated business model – from silicon ingots to system installation – would allow the "stacking" of margins and thereby enable value extraction from the gross margins of "module costs" and "systems costs" to be addressed individually. Industry analysts predict fully integrated business models to offer lower prices while retaining higher gross margins.

2.5.3 Aggregate Impacts

Considering the potential for cost extraction remaining in the various components of the value chain discussed above, industry analysts present favorable cost projections for the near future. With regard to "module costs" for crystalline silicon modules analysts expect the Average Supply Price (ASP) to drop from the present estimate of $4.00/Wp to under $3.00/Wp by the end of 2009; under $2.50/Wp in 2010 and approach $2.00/Wp by 2011. Remaining installed system costs such as labor, inverter and balance of system components, and other miscellaneous costs could decline from the present level of $3.20/Wp to $2.39/Wp over the next two to three years. Thus overall, installed cost for crystalline systems in efficient markets could decline from the current level of $7.20/Wp to $4.39/Wp by 2011 (O'Rourke et al., 2009).

2.6 Conclusion

The PV industry is young and there remains considerable scope for efficiency improvements in the technology, methodologies and business models. As discussed above, all of these are dynamic and currently moving in the direction predicted by the learning curve presented in Figure 2.4. By contrast, all indications for conventional

energy technologies such as fossil fuels or nuclear are that they have exhausted the possibilities for efficiency improvements in the technologies and business models.

Notwithstanding the impressive learning rates of solar technologies, there is much that can be done to hasten wider adoption. There are additional barriers that can be helpfully redressed to encourage further and wider growth of the market for these technologies. The next section addresses these matters.

3. DEVELOPMENT OF SOLAR ENERGY TECHNOLOGIES AND EXISTING BARRIERS

3.1 History of Development of Solar Energy Technologies

Solar energy technologies have a long history and can be divided into, what are today, at least three distinct markets viz. solar thermal heating, solar thermal electric and most recently, photovoltaics. In addition to its historic utilization, the modern applications of solar thermal energy commenced in the late nineteenth century. Between 1860 and the First World War, a range of technologies, able to generate steam by capturing the sun's heat and powerful enough to run engines and irrigation pumps, were invented (Smith, 1995). However, given the dominance of fossil fuels that defined the twentieth century, these technologies did not achieve commercial viability. Nevertheless, the fundamental principles of solar thermal conversion have been revived and improved in recent decades, to produce technologies and create markets for what have been discussed in this report as CSP applications.

The second major attempt to commercialize solar energy was triggered by the oil-shocks of the 1970s. This period witnessed the revival of interest in not only solar thermal electric applications such as CSP, but also solar thermal heating applications in the form of solar air and water heaters and cookers. As discussed in section 1, the first large-scale CSP power projects were built in California during this period and are in operation even today (Taggart, 2008; 2008a; 2008b; 2008c).

In addition to the solar thermal applications, the new entrant into the market triggered during this period was solar photovoltaic technology. Photovoltaic cells were invented at Bell Labs in 1954 and the earliest applications of PV, in the late 1950's, were onboard space satellites to generate electricity (Hoogwijk, 2004). The years immediately following the oil-shock saw much interest in the development and commercialization of solar energy technologies and PV applications, such as off-grid applications, expanded rapidly. However, this incipient solar energy industry of the 1970 and early 80s, collapsed with the Regan administration's removal of tax credits for solar energy in 1986,

and a sharp decline in oil prices, which prevailed over the last two decades of the twentieth century (Bradford, 2006).

The third and ongoing effort to commercialize solar energy has been underway since the end of the twentieth century. Indeed, the world remains dominated by fossil fuels, which account for over 79% of global final energy consumption, and are supplemented by renewables such as traditional biomass and large hydro, which along with nuclear supply about 13%, 3% and 3% respectively. The remaining current market share of about 2.4% of total global final energy consumption, for new renewable energy technologies, is the result of a sustained dramatic growth trend over the past decade (REN21, 2008).

In the next section we review the recent history of the diffusion of photovoltaic technology and compare it with other semiconductor based technologies such as personal computers and cellular phones whose diffusion is often considered exemplary.

3.2 Diffusion Trends of Photovoltaics Compared to other Semiconductor and Electronics Technologies

Our interest in this section is on solar energy technology, and specifically the diffusion of photovoltaics in comparison to other recent and comparable technological innovations such as personal computers and cellular phones. In this context it has been widely observed that most stable phenomena exhibit growth that is confined by some limit. The limit could be the size of the potential market, as in the case of technological innovations, or an ecosystem's carrying capacity, as in the case of animal and plant populations. The graphical representation of this type of growth has been found to resemble a 'S-shaped curve' (Meyer et al., 1999).

The diffusion of innovations, i.e. growth in the market for innovations, such as photovoltaics (Byrne et al., 2004; 2005a) computers or cellular phones have also been found to represent an S-shaped curve. A comparison of diffusion patterns for photovoltaics with those of personal computers and cellular phones (as seen Figures 3.1-

3.3) reveals that all three technologies show comparable patterns of diffusion (Byrne et al, 2005a). Indeed, the diffusion of photovoltaics is in the midst of an accelerating exponential growth phase, which contrasts with the slowing trend in the diffusion of personal computers and cellular phones. However, as discussed in section 1 a small number of markets such as Germany, Spain, United States and Japan have largely driven this rapid growth in photovoltaics.

Given the vast potential to harness solar energy,[24] and the overall demand for energy, the potential for diffusion solar energy in various markets (e.g. rural, urban, industrialized, and less-industrialized) and energy infrastructure formats (e.g. off-grid, distributed grid-connected, and centralized), is vast, provided favorable policy environment is created. In this regard the next section turns to a discussion of the barriers that appear to inhibit the diffusion of solar energy technologies.

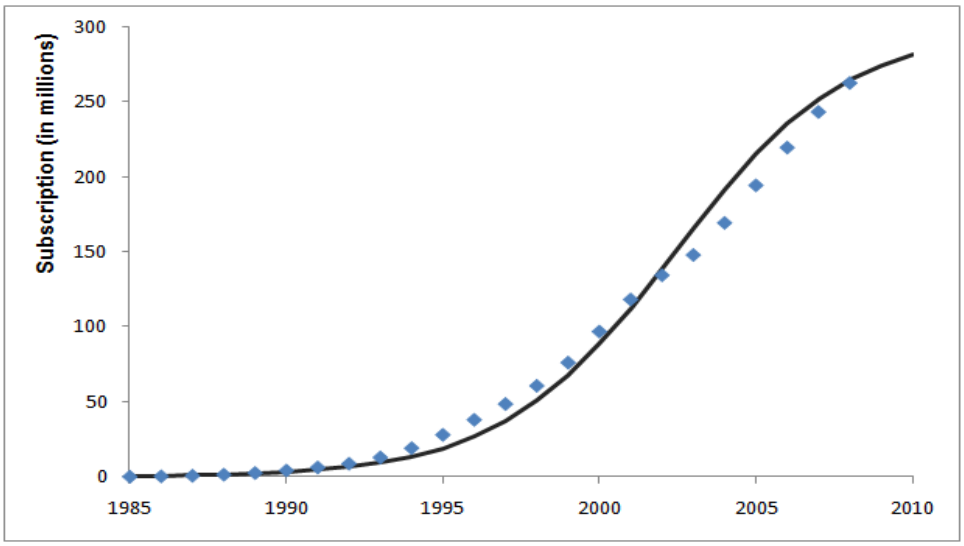

Figure 3.1 Resulting logistic curve for actual numbers of annual cellular phone subscriptions in the U.S. during 1985-2007
Data Source: CTIA, 2008

[24] See discussion in Section 1

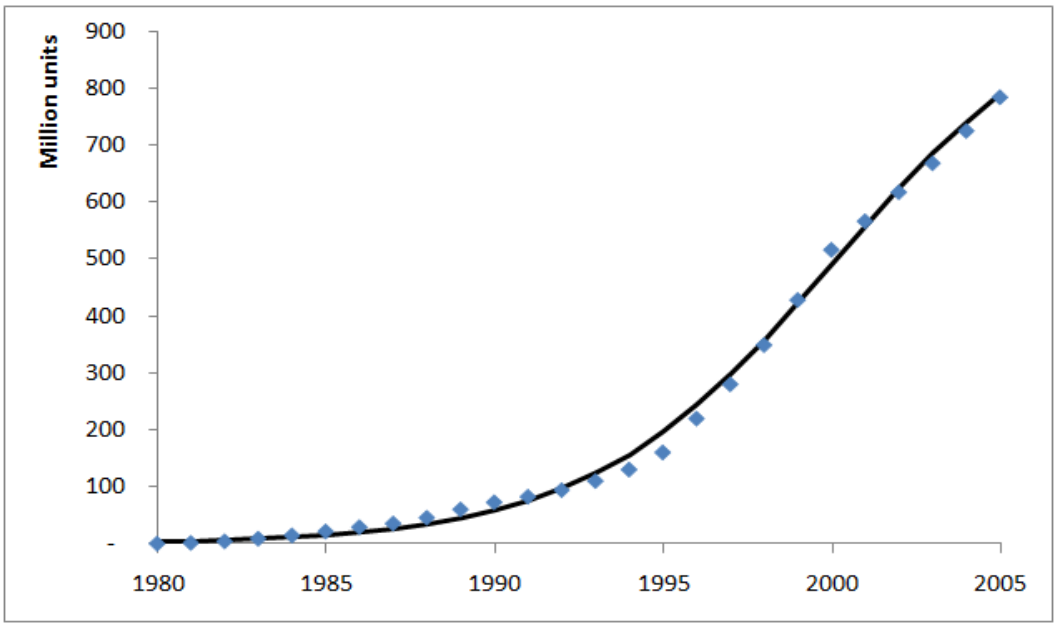

Figure 3.2 Resulting logistic curve for actual numbers of annual PCs in use in the world during 1980-2005
Data Source: Reimer, 2008

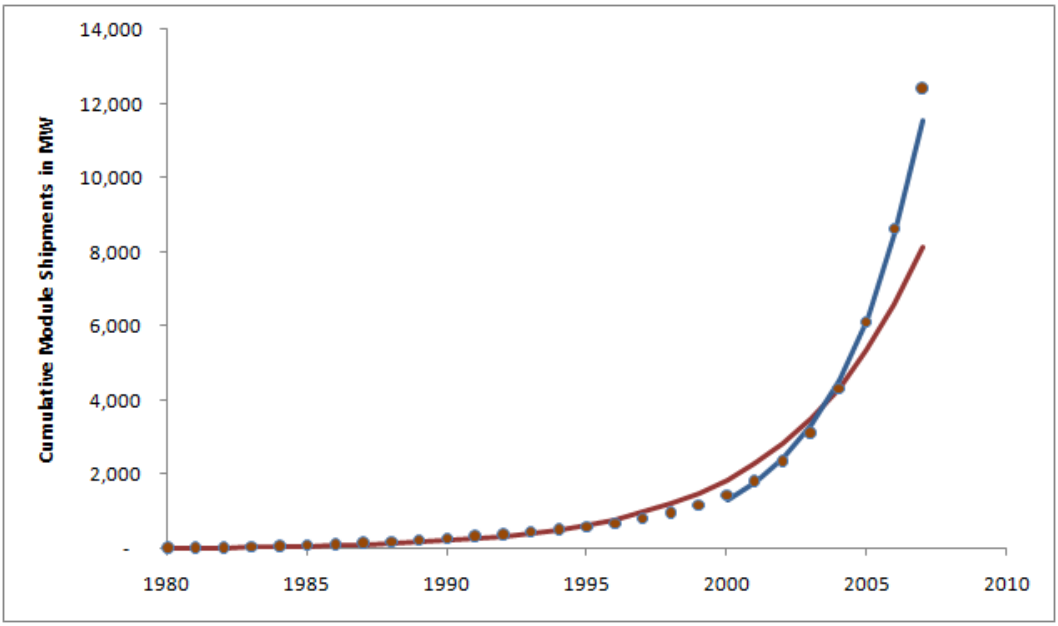

Figure 3.3 Resulting logistic curve for actual numbers of cumulative PV module shipments in the world during 1980-2007
Data Source: Dorn, 2007

3.3 Barriers to the Development and Utilization of Solar Energy Technologies

Notwithstanding the recent impressive performance of photovoltaics in comparison to other technologies, there is much that can be done to hasten the adoption of this beneficial suite of renewable energy technologies. The literature identified a range of so-called "barriers" that tend to weaken the adoption of solar energy technologies for electricity generation and thermal purposes. These barriers are classified broadly as technical, economic, and institutional.

3.3.1Technical Barriers (PV)

- The efficiency constraint is one of the main barriers to widespread use. The thin-film and crystalline-silicon modules have efficiency ranges of 7% to 10% and 12% to 18% respectively. Even as PV technologies with significantly higher efficiencies are underdevelopment (Barnett et al, 2007), the present efficiency ranges constitute a barrier.
- Lack of adequate manufacturing infrastructure to increase throughput and yield. The manufacturing rate of PV components is low, but it is expected to grow rapidly.
- Strong demand for PV in 2004 and 2005 outpaced the supply and partly stalled the growth of solar sector (PI, 2006). However, the resulting surge in production combined with the present financial crisis has created an industry wide "shake-up" (O'Rourke et al., 2009).
- The performance limitations of balance of system (BOS) components, such as batteries, inverters and other power-conditioning equipment are another area with considerable room for improvement (Rickerson et al., 2007; Beck & Martinot, 2004, O'Rourke et al., 2009).
- Lack of clarity regarding technical limits of exporting power to the grid and network grid protection requirements for PV systems to safely export power (Rickerson et al., 2007).
- In the case of stand-alone PV systems, storage is an important concern as is the shorter battery life compared to that of the module. Further, safe disposal of batteries becomes difficult in the absence of a structured disposal/recycling process.

- Lack of an adequately sized work force with desired technical skills to meet manufacturing, installation, maintenance, inspection and evaluation demands.
- Lack of proper information about the utilization of solar electric systems, especially PV, has been seen in many developing countries. For instance, incorrect charging techniques such as polarity reversal were seen as frequent problems that damaged the junction boxes of the PV panel. Irregular use of the systems results in damage to controls and wiring. Such damages could be attributed to about 60% of systems visited by Green (2004) in Thailand. It was observed that cracks in the glass of the PV module, water intrusion during rainy season, dust and algal growth accumulating along the lower section of the panels also constituted some of the major problems of PV systems (Green, 2004).
- When the PV systems are promoted, especially from government sponsored programs, very little care is given to the potential load of the prospective user's household. People have been found to install more bulbs than the specified number. In addition, in many cases it was found that the replacement for a fused CFL bulb was a cheaper incandescent one. This resulted in faster drainage of the battery. It has also been observed that in an effort to 'overcharge' the battery, the charge controller is bypassed. Such practices reduce the battery life a require investment in a new battery (Ahiataku-Togobo, 2003).

3.3.2 Technical Barrier (Solar thermal)

- Many critical technical problems with regard to solar thermal technologies for electricity generation have already been fixed, yet there remain few important issues that constitute barriers to their widespread application.
- In the case of parabolic trough systems, one of the most proven solar power technologies (Herrmann et al., 2004), the upper process temperature is limited by the heat carrying capacity of the thermal oil used for heat transfer. Thermal loss from heat storage in such system remains an important technical challenge in solar thermal technologies.
- In case of central receiver systems the promising technologies such as the molten salt-in-tube receiver technology and the volumetric air receiver technology, both with

energy storage system needs more experience to be put for large-scale application (Becker et al., 2000).

- With regard to solar thermal application for space and water heating, thermal losses from heat storage is an important challenge. It was observed that the losses were up to five times greater than originally expected (IEA, 2006a). In addition many of solar thermal designs are put to market without assessing appropriateness of people's needs and without proper education related to its efficient use. Lack of trained manpower to install and maintain such systems has also been a persistent concern.
- Another barrier to solar air and water heating applications especially in industrialized countries of Europe and North America is the lack of integration with household appliances (IEA, 2006a).

3.3.3 Economic Barriers (PV)

- While PV has zero "fuel" cost, low O&M costs and is competitive on a life-cycle cost basis, the high initial upfront cost and unavailability of easy and consistent financing options forms a prime barrier (Beck & Martinot, 2004; Chaki, 2008).
- Cost comparisons for PV are made against established conventional technologies that benefit from direct and indirect subsidies,[25] accumulated industry experience, economies of scale and uncounted externality costs. PV thus faces an "uneven playing field," even as its energy security, social, environmental and health benefits are not internalized in cost calculations (Jacobson & Johnson, 2000).
- Unusually high risks are assessed in determinations by finance institutions because of their lack of experience with PV projects (Goldman et al., 2005).
- Bias against distributed technology platforms among conventional energy agencies and utilities (Margolis & Zuboy, 2006). Thus, in less wealthy countries, limited sources of investment finance are directed towards conventional energy technologies.
- The cost of the module may decline but may not be matched by a proportional decline in BOS costs (Rickerson et al., 2007).

[25] It is estimated by agencies like the World Bank and IEA that global subsidy for fossil fuels fall in the range of $100 - $200 billion (Beck & Martinot, 2004).

- In the case of BIPV, its adoption can be hindered by gaps in technical and financial data needed for accurate project planning and implementation.
- In some countries, power tariffs are subsidized for certain sectors of the economy (e.g. agriculture) and/or certain income groups. As such the use of PV to serve these market segments is at a disadvantage (IEA, 2002a).

3.3.4 Economic Barriers (Solar Thermal)

- High upfront and maintenance costs constitute significant barriers. This is particularly relevant for poorer potential customers in the developing countries.
- The lengthy payback periods and small revenue stream also raises creditworthiness risks of such systems (REN21, 2008).
- Cost comparisons are often made against established conventional technologies that benefit from direct and indirect subsidies, accumulated industry experience, economies of scale and uncounted externality costs.
- In the case of solar space and water heating applications, lack of integration with typical building materials, designs, codes, and standards make their widespread application difficult. Also the lack of inadequate installation and service infrastructure increases the cost of solar thermal systems.
- The bias against distributed energy technology platforms among conventional energy agencies and utilities
- In the case of solar thermal applications, diffusion can be hindered by gaps in technical and financial data needed for accurate planning and implementation of projects.

3.3.5 Institutional Barriers

A critical reason for many of the barriers discussed below is the novelty of the technology. As such solar energy still has to operate and compete on the terms of an energy infrastructure designed around the conventional energy technologies. In addition to the technical and economic barriers discussed above, solar energy technology is also faced with what are broadly referred to as “institutional barriers.”

- Information about solar energy: The 'path to PV' has been described as 'difficult' (Dayton, 2002). While, technology 'innovators' are willing to take on the additional inconvenience of 'figuring things out,' the large chunk of the adopters are often unlikely to take the effort. Gathering information about PV systems, deciding the appropriate system configuration and navigating the fiscal and market mechanisms in place to assist customers are seen as barriers by potential adopters.
- Interconnection: Some investigations have found that interconnection of PV systems has to overcome 'cumbersome and inappropriate' interconnection requirements such as insurance, metering and billing issues (Florida Solar Energy Center, 2000).
- Legislative failures: A controversial USEPA decision of January 2008, not to grant a waiver to California allowing it to legislate state rules curbing greenhouse gas emissions from cars and trucks, illustrates legislative challenges involved in shifting the terms in favor of renewable energy technologies.
- Workforce training: Inadequate numbers of sufficiently trained people to prepare, install and maintain solar energy systems is a common barrier. Without a concerted effort to institutionalize the process of training, the diffusion of new technologies is often hampered. A comparison of the trajectory of nuclear power and renewable energy in India is illustrative. From its earliest days as an independent nation, India invested in training of nuclear physicists and engineers, while correspondingly ignoring this requirement in the case of renewable technologies. Thus, while the country has for decades produced scientists and engineers capable of contributing to various aspects of the atomic energy program, curricula to train scientists and engineers in renewable technologies is only getting underway (Banerjee, 2005).
- Inertia of capital markets: An important requirement for transforming the energy system is the capital to invest in renewable energy technologies, which at present tend to have higher initial investment costs but negligible O&M, zero fuel costs and various positive externalities. In this context innovative legislation and financing mechanisms could help institutionalize a changed scheme for project evaluation that can capture socially beneficial attributes of renewable energy technologies. For instance, consider the recent piece of legislation passed by the state of Delaware, USA, creating a Sustainable Energy Utility. This legislation uses the market to

monetize energy savings from conservation, efficiency and attributes of customer sited renewable energy technologies, as a means to provide energy services and realize a renewable energy future (SEU, 2007).

- Underdeveloped organizational and political power of new entrants: The established energy technologies are well represented through long standing trade associations and industry groups. The new technologies are often at a disadvantage given the scattered efforts to advocate on their behalf.
- Procedural problems: the need to secure financing from multiple sources and approvals and coordination from several agencies (for instance in India, the Ministry of New and Renewable Energy (MNRE), the Planning Commission, Ministry of Agriculture and Rural Development) results in duplication, overlap, and lack of co-ordination in the implementation of solar energy programs. In addition, a bureaucratic structure with target oriented approach leads to rigidity in instruction and centralization, which eventually hinders the growth of solar technologies (Radulovic, 2005).
- The fragileness of solar development partnerships: many PV projects are based on development partnerships and with the early departure of a partner the revenue required to complete, operate and maintain the system may falter. Often, this is seen when the need arises to replace batteries and other system components, which have a shorter life than the PV module and therefore need some funding even after the initial setup (see Ahiataku-Togobo, 2003).

4. A REVIEW OF POLICY FRAMEWORKS TO SUPPORT SOLAR ENERGY DEVELOPMENT

4.1 Introduction

As has been described elsewhere in this study, many solar energy technologies are not yet cost-competitive with commodity energy at the wholesale or retail levels. As a result, governments around the world have supported solar energy development through a broad range of monetary, fiscal and regulatory instruments that include, tax incentives (e.g. credits and exemptions), preferential interest rates, direct incentives (e.g. performance-based incentives, rebates, and grants), loan programs (including microcredit finance mechanisms), construction mandates, renewable portfolio standards, voluntary green power programs, net metering, interconnection standards and "demonstration" or pilot projects. A number of different studies and policy documents have detailed these different policy types (Aitken, 2003; Geller, 2003; Goldman Sachs, 2007; Haas, 2002; MNRE, 2006; Uddin & Taplin, 2008).

Some policy analysts tend to infer particular policy types (e.g. feed-in-tariff, Renewable Portfolio Standard) are the primary drivers for certain solar energy markets. What is often overlooked in this view is that it is the *implementation* of relevant policies and their *sustained* support over time that explains the success of efforts to commercialize solar energy observed in different markets (see, e.g. Herig & Gouchoe, 2008b; Weiss et al., 2006; Osborn et al. 2005; IEA 2008). To wit, the lessons to be learnt are not primarily about whether to adopt, say a particular FIT rate or particular RPS obligation (which is actually decided by the regulatory and market structure of different regions) but how the chosen mechanism(s) has been *sustained* in an *orderly* manner that is *substantial* enough to influence the market; *predictable* and *credible* so as to give confidence to investors, while also exerting downward pressure on the price of solar energy (Osborn et al., 2005).

Toward this end, this report is organized around case studies of the policy approach being used to support various solar energy markets internationally. This section considers leading markets such as Germany, Spain and the United States and prominent

developing country markets such as India and China. Also discussed are markets such as Philippines and Bangladesh distinguished by aggressive efforts to commercialize solar energy. The short case studies are organized according to market and technology type: photovoltaics, solar thermal heating, and solar thermal electric. Several illustrative policy case studies for each technology type will be presented, and lessons learned are summarized. These case studies provide an opportunity to discuss how different policies interact and combine to drive markets.

4.2 Germany

4.2.1 Photovoltaics

***Market summary*:** As discussed above, Germany is currently the world's largest PV market, with over 430,000 solar installations nationwide totaling over 3,800 MW of capacity. After growing by 850 MW in 2006, the German market expanded by an additional 1,100 MW in 2007 (BSW, 2008).

Policy structure: The primary driver for German market growth has been the feed-in tariff. The German feed-in tariff has several key components:

- *Guaranteed interconnection*: The term "feed-in" derives from the fact that the German law guarantees all renewable energy generators priority access to the grid, and requires utilities to interconnect all eligible generators. It is notable that utilities purchase 100% of a grid-connected PV system's output, regardless of whether the system is customer-sited or not. This approach differs from countries such as the United States, where many states permit onsite generators to offset their own retail load through net metering (c.f. Section 4.6)
- *A long-term, technology-differentiated fixed price payment*: Each renewable energy technology type is eligible for a 20-year fixed-price payment for every kilowatt-hour of electricity generated. The payments are technology-specific, such that each renewable *energy* technology type receives a payment based on its generation cost, plus a reasonable profit. The feed-in tariff is further subdivided by project size, with larger projects receiving a lower feed-in tariff rate in order to account for economies

of scale, and by project type, with freestanding systems receiving a low feed-in tariff, and building integrated systems (Sösemann, 2007). The current feed-in tariff rates are contained in the table below:

Size	€/kWh
< 30 kW rooftop	0.47
<100 kW rooftop	0.45
>100 kW rooftop	0.44
Free-standing	0.35

Through 2007, there was *also* a €0.05/kWh bonus for building-integrated systems installed on *building* façades, but this adder was removed this year in the latest round of feed-in tariff amendments (Podewils, 2008).

- *A declining incentive schedule*: The German feed-in tariff declines every year by a set percentage such that a generator locking into a 20-year fixed-price payment in 2008 would receive a *lower* 20-year payment than a generator locking into a rate in 2007. The 2004 Renewable Energy Law set the rates of decline at 6.5% annually for free-standing systems and 5% annually for rooftop and façade-mounted systems. The decline rates are reviewed every two years. In the most recent review, the German government changed the PV digression schedule such that feed-in tariffs for rooftop systems 100 kW and below will decline 8 percent in 2009 and 2010, and 9 percent in 2011. For ground-mounted systems, and rooftop systems over 100 kW, the feed-in tariff will decline by 10 percent in 2009 and 2010, and 9 percent in 2011 (Siemer, 2008).

The current PV tariff is not combined with other federal incentives. From 1999 to 2003, the feed-in tariff established by a 2000 law was coupled with a government-supported low-interest (~1.91%) loan program called the 100,000 Solar Roofs Program (Stubenrauch, 2003). The program expired in 2003 and was not replaced.

The current feed-in tariff has been in place since 2004. The 2004 law replaced a 2000 law that included a form of PV-specific feed-in tariffs that were not as generous and not as differentiated by size and application. Prior to 2000, the German feed-in tariff law

was set at 85% of the retail electricity rate, with the same incentive available to all renewable generators regardless of technology type (Rickerson and Twele, 2002). The original concept for a feed-in tariff based on PV generation costs was developed by a municipal utility in the German town of Aachen in 1993. The Aachen model originally awarded generators a 20-year contract of 2 Deutsch Marks per kilowatt-hour, or approximately $1.34/kWh (Solarenergie-Förderverein, 1994). The concept spread to other municipal utilities in Germany before a similar model was adopted by federal legislation in 2000.

Success: Germany's program has been highly successful at driving PV market growth, and the feed-in tariff is widely credited with creating a level of security that has enabled residential, as well as commercial, investors to participate in the market. The feed-in tariff also places an emphasis on renewable energy production and performance, rather than investment cost.

PV feed-in tariffs inspired by the German example have been adopted in many other countries, including, most recently, Switzerland and Israel. In Asia, Korea has established a feed-in tariff for PV, which has thus far resulted in over 100 MW of PV capacity (Hirshman, 2008; Yoon et al., 2007). Although each of these countries has a feed-in tariff, it is difficult to generalize about their structure, effectiveness, and interactions with other domestic policies since feed-in tariff design varies widely from country to country (Grace et al., 2008; Klein et al., 2007).

Limitations:

- *Cost:* The German PV *feed*-in tariff has increasingly faced criticism as being too expensive and is currently under pressure from conservative politicians that hope to cap it or speed its rate of decline (Frondel et al., 2008; Podewils, 2007). It is important to note, however, that the German government has justified the expense of the feed-in tariff not through cost-benefit analyses alone, but in economic development terms as well. As a German government publication observed, "…in view of the fact that…foreign markets for photovoltaic are already likely to be very

large…further domestic promotion should then be provided from the point of view not of energy policy, but of safeguarding export markets and industrial policy." In 2007, the German PV industry employed 42,600 people, and sold 43% of its domestically-produced PV systems abroad, for a total of €2.47 billion in export sales (BSW, 2008)

- *Perception:* Related to cost, another limitation of the German feed-in tariff is its *perceived* high level of compensation. The German feed-in tariff is the primary incentive that German investors rely on to achieve their target return on investment. In other countries such as the United States, PV is supported by multiple policies at multiple levels of government, including, for example, federal tax incentives, state tax incentives, state rebates, renewable energy credits, and net metering. The result is that US PV generators are compensated in some markets at levels above those of the German feed-in tariff (Bradford, 2008), but this fact is obscured by the policy mix, and thus less vulnerable to criticism.
- *Lack of upfront financing:* The German feed-in tariff depends heavily on lending, since there is no upfront incentive to help cover the capital cost of a project. This can be a difficult model to follow in markets that do not have well-established lenders willing to support PV.

4.3 United States

4.3.1 Photovoltaics

Market summary*:* The US is the third largest PV market in the world, but it remains highly regionalized. It is estimated that between 150 and 160 MW of grid-connected capacity was added in 2007, but 88% of this was concentrated in the top 4 state markets, and 96% was concentrated in the top 10 state markets (Hering, 2008c). The federal government primarily supports PV development through the use of a 30% investment tax credit, and a 5-year accelerated depreciation schedule for commercial entities. The federal incentives are insufficient to drive market growth on their own, however, and the leading US markets are those that have supplemented federal incentives with their own programs. All but three states have at least some form of either

government- or utility-sponsored PV incentive, including direct incentives, tax credits, tax exemptions, net metering, and loan programs (Herig and Gouchoe, 2008a). These incentives vary widely in their magnitude, and effectiveness, and a few states have emerged as clear market leaders. The two largest markets in the US have been California and New Jersey. Eleven other states and Washington, DC, have also recently created solar-specific requirements within their RPS laws, but most of these requirements were established during the last two years, and it remains to be seen how they will perform (DSIRE, 2008). This section focuses on the California and New Jersey markets.

California

Policy Structure: California was the first state to implement a buy-down program for PV in the US. The original incentive was structured to decline in five blocks, such that the first block of was set at $3 per watt, and the fifth block was set at $1/watt (Bolinger and Wiser, 2003). The buy-down program, and its subsequent iterations (e.g. the Emerging Renewables Program (ERP) for small systems, and the Self-Generation Incentive Program (SGIP) for large-systems) drove rapid market growth in California during its first several years of operation.

Program evaluation of the buy-down program revealed, however, that installed systems were producing between a quarter and a third less energy than was projected (Regional Energy Research Inc., 2000). This revelation, combined with the fact that the ERP and SGIP programs were oversubscribed, led California to launch a pilot program based on performance-based incentives (PBIs), rather than upfront payments (Brasil et al., 2005).

When Governor Schwarzenegger launched the California Solar Initiative (CSI) in 2006, the program drew on the experience of both the buy-down programs and the performance-based incentive programs (California Public Utilities Commission, 2006). The goal of the $3.3 billion CSI program is to support the development of 3,000 MW of PV in California by 2017 using both rebates and performance-based incentives. Systems 100 kW and smaller are eligible for an Expected Performance-Based Buy-Down (EPBB)

which awards rebates based on projected system performance, taking tilt, location, orientation, and other factors into account. The better the system is projected to perform, the higher the buy-down it receives. Buy-down levels start at $2.50 for private sector system hosts in 2007 and $3.25 for public sector and non-profit organizations (who cannot take advantage of the federal tax credit. The buy-down decline when certain blocks of capacity are reached.

Systems over 100 kW are eligible for a five-year, performance-based kilowatt which declines in steps similar to the EPBBs. Step 1 included incentives of $0.39/kWh for private sector organizations, and $0.50/kWh for non-profit and public sector organizations. In addition to the CSI incentives, California projects are also eligible to take advantage of federal tax benefits, and state net metering regulations. System hosts also maintain the rights to sell RECs from their solar systems, although there is no solar-specific REC market in California[26] as there is in New Jersey.

***Success**:* As a result of its early and sustained commitment to solar power, California continues to have the largest PV market in the US, with over 60% of installed capacity in 2007. California successfully demonstrated the use of upfront, capacity-based incentives through its buy-down programs. California also has led attempts to shift away from capacity-based payments to performance-based payments that are fixed, rather than variable as they are in renewable energy credit markets.

***Limitations**:* Although the California Solar Initiative has set an ambitious goal, early experiences with the program indicate that it may have some trouble achieving its targets without programmatic adjustments. The residential market appears to be moving slower than expected as a result of higher installed costs and the new lower incentive. The non-residential market has experienced the opposite problem. A large proportion (11% of the 10-year program's funds) were reserved by potential projects within the first

[26] It was reported at the end of October 2008 that the California Public Utilities Commission is drafting decisions that would allow the use of Tradable Renewable Energy Credits that could be used to comply with the state's renewable energy mandates. http://www.platts.com/Electric%20Power/News/6002787.xml?S=printer&

six months of the CSI. As a result, the incentives decreased from Step 1 to Step 4, representing a 33% reduction in incentive levels (Harris and Moynahan, 2007). The CSI declines were built into the program to encourage PV costs to decline, but it is difficult to match incentive schedules to experience curves (Alsema et al., 2004), and the CSI incentives declined far faster than the 7% annually projected by the program (Go Solar California, 2008). As a result, it remains to be seen whether incentive levels will be too low to sustain market growth this year and next, and whether the market will be able to force installed costs low enough to supply attractive systems to customers (Hering, 2008b).

New Jersey

Policy Structure: The New Jersey policy framework is currently in a state of flux. In 2004, New Jersey became the first state in the nation to create a solar "carve-out" in an RPS based on tradable renewable energy credits. The New Jersey RPS required that 6.8% of the electricity sold in the state be renewable by 2008, of which 0.16%, or approximately 90 MW, was to derive from PV. This created a stand-alone market for solar renewable energy credits (SRECs), whose market price was capped through the use of an "alternative compliance payment" (ACP) of $300/MWh. In addition to selling RECs and claiming federal tax incentives, New Jersey PV systems up to 2 MW in size can also net meter. Finally, PV systems of any size were eligible for a rebate from the state of up to $5.50/watt – one of the most generous rebates in the country (Kling, 2004). In combination, these policies drove extremely rapid growth, and propelled New Jersey to the second largest PV market in the US after California.

In 2006, New Jersey revised its RPS to require 22.12% of its electricity to come from renewables by 2020, including 2.12%, or approximately 1,500 MW, of PV. The New Jersey Board of Public Utilities calculated that it would cost $500 million annually to reach the goal if the rebate program were to continue (Winka, 2006). As a result, New Jersey launched a regulatory proceeding to explore ways to transition to a "market based" system in which rebates were removed in favor a market based entirely on RECs. The transition was vigorously debated, and the BPU ultimately decided to transition to a

system wherein systems 10 kW and smaller would qualify for rebates, and systems larger than 10 kW would have to compete in a tradable SREC market. Unlike the original SREC market, however, the ACP was raised to $711/MWh to take into account the fact that larger systems could no longer take advantage of rebates (New Jersey Board of Public Utilities, 2008). The ACP is set to decline by 3% each year, though it is anticipated that RECs will trade at $100 below the ACP amount.

Success*:* New Jersey was successful as an innovator for solar policy. It was the first state to establish a 2 MW net metering rule, a standard which a number of states have since emulated.[27] It was also the first state to establish a solar-only RPS carve-out based on a short-term tradable renewable energy credit market. This is also a practice that other states have since adopted.[28] New Jersey also was successful in developing a policy mix that combined a broad range of federal and state incentives to drive rapid market growth. Finally, New Jersey's revised RPS target is an indicator that the state is committed to solar market growth over the long-term.

Limitations: Despite initial successes and ambitious targets, the New Jersey market has stalled in the wake of its market transition proceedings. By shifting away from rebates for larger projects, New Jersey removed an important element of securitization from its renewable energy credit market. Without rebates, developers and investors are more exposed to the volatility inherent in the tradable credit markets. Some industry analysts have reported that lenders discount future New Jersey REC revenues by up to 100% because of their perceived risk, greatly diminishing, or eliminating, their value to project developers (O'Brien and Rawlings, 2006).

In order to address REC market volatility, the BPU has launched a new regulatory proceeding to explore securitization measures to remove some of the volatility from the REC market, but recent reports indicate that this new proceeding has created additional

[27] e.g. Delaware, Maryland, New York, Massachusetts, and Florida
[28] e.g. Delaware, Maryland, Pennsylvania, Washington, DC, and New Hampshire

uncertainty about the market's future structure and could further slow growth (Hering, 2008a).

A key lesson from the New Jersey market is that financial risk plays an important role in capital intensive renewable energy markets such as PV. The risks associated with uncertain incentive revenues (e.g. from RECs) and uncertain future policy structures have emerged as important barriers to the state's solar market development (Summit Blue Consulting and Rocky Mountain Institute, 2007; 2008).

4.3.2 Solar Thermal Electric

Market Summary: The United States was the birthplace of solar thermal electric systems, with the installation of 354 MW of parabolic trough systems built in the California deserts in the 1980s. Although solar thermal electric is primarily limited in the to the Southwest, it has been conservatively estimated that up to 7,000 gigawatts of solar thermal capacity could be installed in that region (Mehos and Kearney, 2006). The solar thermal electric market seems poised for rapid growth.

Policy summary: When the initial 354 MW of parabolic troughs were constructed, they benefitted from the combination of federal tax credits, favorable utility power purchase agreements, and property tax exemptions from the State of California. Although property tax exemptions may not be a significant incentive for residential PV systems, property taxes can equate to millions of dollars for large-scale, ground-mounted solar thermal electric projects. In 1990, outgoing California Governor Deukmejian vetoed the property tax exemption during his last two hours in office. The veto led to the bankruptcy of the solar thermal developer, Luz Limited International, and brought a halt to solar thermal development in the US. During the last several years, however, the passage of renewable portfolio standard (RPS) laws in the Southwestern states, namely Arizona, Nevada, and California, has created an opportunity for new solar thermal electric installations.

Unlike RPS laws such as New Jersey's, which are based on short-term renewable energy credit markets, utilities in the Southwest typically procure renewable energy through competitive bidding and negotiated, bilateral contracts, or ownership of their own renewable generating assets. In 2006, Arizona Public Service (APS) installed the first solar thermal electric system in the US since 1991. The one megawatt Saguaro Project was funded by the 30% federal tax credit (Canada et al., 2005). APS owns and operates the system and counts system output towards the state renewable portfolio standard of 15% by 2020 (and toward the requirement that 30% of the standard derive from distributed renewable generators) (NREL, 2008). APS is also currently supporting the construction of a 280 MW Solana parabolic trough plant, which is scheduled to come online in 2011(Taggart, 2008c). In 2007, the 64 MW Nevada Solar One parabolic trough solar system came online in Boulder City, Nevada. Similar to the Saguaro Plant, Solar One benefited from a 30% federal tax credit and from a state RPS that has a tier for distributed generation. Nevada's RPS mandates that 20% of state electricity come from renewable resource by 2015. Of that, 5% must come from solar power. In order to satisfy its RPS requirements, Nevada Power has signed a power purchase agreement with Nevada Solar One, rather than owning the project outright (NREL, 2008).

A third project that is benefitting from Southwestern RPS policies is a 500 MW concentrating solar dish project based in the Imperial Valley in California. The output of the plant is contracted to be purchased under a 20-year agreement with San Diego Gas & Electric (SDG&E). The output of the system will be used to comply with California's renewable portfolio standard requirement that 20% of state electricity be supplied from renewable sources by 2010. The project is somewhat controversial because the technology is not yet proven on such a large-scale, and it remains to be seen whether construction will begin in 2009 as scheduled (Taggart, 2008a).

Success: The combination of an excellent solar resource, the 30% federal tax credit, and RPS policies in the Southwest United States have resulted in a rebirth of solar thermal electric generation. In two of the three states exploring solar thermal electric, the

existence of a solar- or distributed generation-specific RPS tier has also played a role in successful project development.

Limitations: It is unclear whether current power purchase agreements will move forward without the 30% federal tax credit (which is set to expire at the end of 2008). Moreover, the focus on competitive tendering in states such as California can serve as a barrier to sustainable market growth. A reliance on price competition for fuel-free, capital intensive renewable energy systems such as solar can lead to unrealistic bidding. In California, there have been concerns that utilities are counting projects towards compliance that will never be constructed (Wiser et al., 2005), and a recent study concluded that, at a minimum, large-scale competitive processes can expect a 20%-30% contract failure rate (Wiser et al., 2006).

4.4 Spain

4.4.1 Solar Thermal Heating

Market Summary: The Spanish solar water heating market is not the largest in the world in terms of total installed capacity, or in terms of capacity per capita. These distinctions belong to China and Cyprus, respectively (W. Weiss et al., 2007). Spain's recent policy development, however, is rapidly emerging as a model being adopted by other countries. After strong initial growth in the 1970s, the Spanish solar water heating market stagnated during the 1980s. After a slow return to growth in the late 1990s, the market is poised for rapid growth as a result of a highly successful municipal policy, which has diffused to the national level.

Policy Summary: In 2000, the Spanish federal government launched a program to provide grants of between €240.40/m^2 and €310.35/ m^2 to solar thermal systems. In 2003, Spain also established a low-interest loan program, under which system owners could access 7-year loans with interest rates at 2%-3.5% below commercial rates. These federal policies were supplemented by additional incentives at the regional level (Institut Català d'Energia, 2003). While the subsidy and loan programs were successful in Spain, one of

the most significant policy drivers for the Spanish solar thermal market has been the solar water-heating obligation.

Israel has had a solar water heating obligation for new construction in place since the 1980s, but it did not diffuse to other countries immediately. In the late 1990s, the City of Berlin proposed to create a similar solar water heating mandate, but was unsuccessful in its attempt. The Spanish city of Barcelona, however, adapted the proposed Berlin mandate, and passed an ordinance in July, 1999 requiring that all new construction or major renovation projects be built with solar water heating (Schaefer, 2006). The original ordinance, which targeted only certain building subsets, such as residential buildings, hotels, and gymnasiums, required that at least 60% of the hot water load be supplied by solar energy. The "Barcelona model" was adopted by 11 other Spanish cities by 2004 (Pujol, 2004), including Madrid, and in 2006, Spain passed a national law requiring solar water heating on new construction and major renovations (ESTIF, 2007).

Success: The Barcelona ordinance was extremely successful in expanding the local market. The ordinance increased Barcelona's installed capacity from 1,560 m^2 in 2000 to 31,050 m^2, or 27 MW_{th}, by 2005 (Hack, 2006). The rapid diffusion of the Barcelona model to other municipalities, then to the region, and ultimately the nation has laid the foundation for rapid market growth on a much broader scale. Based on the strength of policies such as the local and regional ordinances, the Spanish market grew by 150 MW_{th} in 2007 (ESTIF, 2008). The national ordinance did not come into effect until 2008, and the Spanish government projects that between 1,050 and 1,750 MW_{th} of new capacity will be installed nationwide by 2010 as a result of the ordinances (ESTIF, 2007). In addition to its rapid diffusion across Spain, the Barcelona model has since been adopted by four other European countries, and the European Commission (2008) has included renewable energy building obligations in its latest proposal for a Renewable Directive to the European Union.

Limitations: The solar ordinances, if structured to require compliance, create automatic markets for solar water heating. They do not, however, automatically create the

workforce and infrastructure necessary to install, commission, and maintain the solar water heating systems. The lag in expertise can create problems with quality control, especially since the obligation can create a disconnect between the obliged (e.g. the builder) and the benefactor (the owner/tenant). Another limitation with the obligations is that they could face strong resistance from the conventional building industry. In Barcelona, this was partially addressed by obligating only certain subsets of buildings under the initial ordinance, before obligating all building types under a revised ordinance several years later (Hack, 2006).

4.4.2 Solar Thermal Electric

Market summary: By the end of 2007, there was a 10 MW power tower operating near Seville, Spain (Taggart, 2008b). As a result of Spain's aggressive feed-in tariff, however, there were 270 MW of additional solar thermal electric plants under development in Spain as of March, 2008, with industry analysts projecting a potential total of 2,000 MW by 2025 (Geyer, 2008).

Policy Summary: Spain was the first country in Europe to introduce a feed-in tariff specifically for solar thermal electric systems in 2002. The original feed-in tariff was not high enough to encourage investment, however, and the tariff was amended in 2004 and again in 2007 (Klein et al., 2007). Under the current law, developers can choose between either a 25-year fixed price payment, which is currently set at €0.269/kWh ($0.357/kWh), or a fixed premium of €0.254/kWh ($0.337/kWh) that rides on top of the spot market price. For the fixed premium option, there is also a price floor for the combined rate (spot market price + premium) of €0.254/kWh (0.337/kWh), and a price ceiling of €0.344/kWh ($0.457/kWh) to ensure investor security and cap policy costs (Held et al., 2007). This structure is fundamentally different from the German tariff, which only offers a fixed price option. In Spain, most developers forgo the fixed price option in favor of the fixed premium option, since the fixed premium option is more lucrative (del Río and Gual, 2007).

Another important difference between the Spanish and German feed-in tariffs is the cap. The German feed-in tariffs have no cap on them, and the primary market limiter is the digression schedule. In Spain, by contrast, the solar thermal feed-in tariff initially had a cap of 200 MW. In the 2007 amendment, this cap was expanded to 500 MW.

Success: The Spanish solar thermal feed-in tariff has touched off a solar thermal development race in Spain, and inspired the entry of a broad range of new market players into the solar thermal industry. The Spanish solar thermal feed-ins are also high enough to allow developers to include molten storage systems in order to maximize daily system output.

A number of other countries have also recently followed Spain's lead and introduced feed-in tariffs that specifically target solar thermal electric projects. In Europe, these include France, Germany, Greece, and Portugal. Outside of Europe, Algeria and Israel have also instituted feed-in tariffs for solar thermal electric, and project development in both countries is ongoing (Geyer, 2008).

Limitations: The concerns with the Spanish feed-in tariff are similar to those expressed about the German feed-in tariff above. An additional concern with the Spanish feed-in tariff is the cap. Although the amendment of 2007 fairly increased the cap from 200 MW to 500 MW without significant market disruption, the review of the cap on the PV side of the market has no been as smooth. Current uncertainties as to feed-in tariff levels and the capacity limits that will be contained in future regulations have "paralyzed" the PV market (Rutschmann, 2008), and similar issues could arise as the solar thermal electric market nears the 500 MW mark in the future.

4.5 Lessons Learned

This section has provided an overview of different solar energy policies used by some of the leading international solar technology markets. From these case studies, it is

clear that there is no one policy panacea that fits all situations and policy objectives, and that different countries may require different policy solutions.

4.5.1 Photovoltaics

The international policy landscape for photovoltaics is currently the most complex of the three solar technology types, with a broad range of different policy types driving growth in the key markets. The PV markets are also in a period of transition as policy makers in attempt to reduce policy costs while sustaining PV market momentum. In Germany, this transition will involve a sharper decrease in the feed-in tariff level, whereas in California and New Jersey, the transitions have involved significant shifts in incentive structure.

Another key concern in addition to policy cost is system performance. In both US markets, the transition has been away from upfront incentives and toward performance-based incentives. Several analysts have argued that different technologies in different stages of the product cycle may require different types of incentives. Importantly, however, both New Jersey and California have deemed it necessary to preserve upfront incentives for small-scale generators.

A final concern is risk. The feed-in tariffs in countries such as Spain and Germany have been cited as creating investor security and lowering policy costs (Commission of the European Communities, 2005). In the United States, a key difference between California and New Jersey's performance-based policies, however, is that California's is a fixed-price performance-based incentive, whereas New Jersey's is based on a short-term REC market. The risks inherent in this market, and the steps that New Jersey takes to address it will have important implications for US solar policy making, given the leadership role that New Jersey has played up to this point.

4.5.2 Solar Thermal Heating

As exemplified by the Spanish experience to date, solar water policy is very different than PV policy. There is also no central "heat" utility as there are electrical utilities, and it is difficult to create thermal feed-in tariffs or renewable portfolio

standards. Moreover, it is more difficult to measure and verify solar water heating performance, and so performance-based incentives are harder to enact. Perhaps most significantly, however, solar water heating is much cheaper than PV. For this reason, solar water heating policies involve simpler incentives (e.g. upfront grants and loan programs), or no incentives at all. In China, the world's largest solar water heating, solar systems are frequently competitive with conventional energy alternatives and require no incentives – although parts of the country are moving towards solar water heating obligations similar to Spain's (Li and Runqing, 2005; Martinot and Li, 2007).

4.5.3 Solar Thermal Electric

Similar to the PV markets, the recent renaissance of solar thermal electric is being driven by feed-in tariffs in Europe and a mix of tax policy and renewable portfolio standards in the United States. Unlike PV, however, solar thermal electric is closer to competition with wholesale, rather than retail, electricity rates. Since the reintroduction of solar thermal electric is fairly new, there are fewer specific policies that target it and, as a result, fewer discernable policy trends.

4.6 India

4.6.1 Photovoltaics

Market Summary: As discussed in section 1, India currently has over 122 MW of solar photovoltaic installations. Of this, grid-interactive PV is reported to account for about 10MW, which includes PV power plants, streetlights and other grid-interactive sources (MNRE, 2008). The vast majority, about 110 MW, is composed of a number of stand-alone applications such as PV street lighting, home lighting systems, lanterns and pumps (MNRE, 2006, Akshay Urja, 2008). As of this year, a little under 700,000 PV lanterns, over 400,000 PV home lighting systems, about 55,000 PV street lighting systems and over 7,000 PV pumps have been installed (MNRE, 2008).

Nevertheless, there is a vast unmet demand for electricity services across the country, which is exacerbated in remote rural areas, many of which are unlikely to get

access to grid electricity in the near future. For instance, only 44% of rural households are electrified despite 80% of villages being officially electrified (Sharma, 2007).

Policy Structure: India's renewable energy program is one of the oldest in the world, with a dedicated institutional infrastructure—the predecessors to today's Ministry of New and Renewable Energy (MNRE) – established in 1981. The primary policy driver during the early years was capital subsidies funded either through donor and/or government funds.

Commencing in the mid-1990s efforts to encourage the commercialization of renewable energy in the country have been undertaken. Emerging from the early emphasis on subsidies as the predominant policy approach, efforts to encourage the deployment of photovoltaics has expanded to include a mix of subsidies, fiscal incentives, preferential tariffs, market mechanisms and legislation (MNRE, 2006). For instance, in 2004-05 the subsidy for the solar photovoltaic program varied between was 50% and as high as 90% for so-called 'special category states and islands.' Similarly, subsidys for solar photovoltaic water pumping was Rs. 100/Wp and as much as Rs. 135/W in the special category states (Banerjee, 2005).

The primary reliance on subsidies has come under criticism because it incentivized capacity and not necessarily production (Sharma, 2007). In response to these changes, government policy for PV in India has recently been revised.

The 11th Five-Year Plan proposal (2007-2012) for new and renewable energy the Government of India has sought to "rationalize" its strategies for the development and deployment of these sources. Thus, going forward, the market for photovoltaics in India is likely to be shaped by the following priorities (MNRE, 2006). These include:

a) The need recognized by the Integrated Energy Policy Report (2006) to 'maximally develop domestic supply options as well as the need to diversify energy sources,'

b) The recommendations of the Planning Commission to 'rationalize development and deployment strategy' for renewable energy sources and to adopt a sector-based approach instead of the 'individual technology' approach adopted until recently, and

c) The demand for electricity services that can be economically (e.g. solar home lighting in remote villages) met only by photovoltaics.

Thus, the overall position adopted toward photovoltaics has been to remove direct subsidies, arguing that the technology needs to be promoted when technology improves and the levelized cost of electricity becomes competitive (MNRE, 2006). Certain exceptions have been made to accommodate remote villages and hamlets, which are unlikely to be electrified via the grid in the near future. Thus, the PV markets have been categorized into the following segments and related policy proposals for the 11th Plan Period (2007-2012):

- **Grid interactive solar power projects:**

(PV or CSP) will be supported as demonstration projects with the objective of developing and demonstrating the technical performance of solar energy in this market as well as achieving reductions in the cost of solar power generation in the country.

Toward this end the Ministry will support a maximum capacity of 50 MW during the 11th Plan Period. It will provide a generation based incentive of Rs. 12/kWh for photovoltaics (Rs. 10/kWh for solar thermal power) for 10 years. In addition a subsidy of Rs. 30,000/KWp – 50,000 /KWp is proposed. Any developer will be allowed a maximum aggregate capacity of 5MW.

- **Remote village solar lighting program:**

The program is aimed at providing lighting service through solar PV home lighting systems in remote villages where other efforts at electrification are not feasible. This

program proposes a single light solar PV system and estimates that about 9,000 villages and remote hamlets will be covered.

This program is primarily subsidy driven with 90% of the system cost underwritten by the government. In the case of below poverty line (BPL) families 100% of the system cost will be underwritten by the state (MNRE, 2006).

- **Retailing of solar energy products:**

The ongoing efforts to promote solar photovoltaic systems through the market route will continue. Toward this end innovative program to retail solar energy products is underway. The government has supported the establishment of over 220 'Akshay Urja Shops' and proposed to increase this number to 2,000 during the 11th plan. Entrepreneurs will be assisted with soft loans, a recurring grant and turnover incentive for the first two years of the shop's operation. A subsidy of Rs. 240,000 is available per shop in addition to the provision for interest-subsidized loans.

- **Shifting cash markets to credit**

In 2003 UN along with the Shell Foundation worked with two leading banks in India, *viz.* Canara Bank and Syndicate Bank to develop renewable energy financing portfolios. This project helped the banks put in place an interest rate subsidy, marketing support and vendor qualification process. Using the wide network of branches of these banks the interest subsidies were made available in over 2,000 branch offices in the two states of Kerala and Karnataka. Within two and half years, the programs had financed nearly 16,000 solar home systems and the subsidies were gradually being phased out. Whereas in 2003 all sales of PV home systems were on a cash and carry basis, by 2006 50% of sales were financed (Usher and Touhami, 2006).

4.6.2 Solar Thermal Heating

Market summary: Over the past two decades the deployment of solar thermal applications has reached over 630,000 solar cookers and over 4.3 million sq. mts. of solar water heating collector area (MNRE, 2008). While significant, they pale in comparison to the overall potential (and potential market) for solar thermal installations. The total potential for collector area in the country is estimated to be 140 million sq. mts. (Akshay Urja, 2008).

Policy structure: As in the case of PV, the policy structure for solar thermal heating has also recently undergone a revision with an emphasis on rationalization. These applications have also been supported thus far with significant subsidy support. Up until 2004, solar cookers received a 50% subsidy on total cost (Banerjee, 2005). And until the mid-1990s solar water heating systems had a capital subsidy of up to 30%. Efforts to rationalize the capital subsidies for solar hot water systems has led to the extension of the interest subsidy approach to this market too.

The Ministry of New and Renewable Energy underwrote the interest subsidys on loans for all segments of the solar hot water system market. This favorable interest regime (e.g. In 2005 Canara Bank in Karnataka state offered loans at 2%, 3% and 5% for individuals, institutions and commercial entities respectively) has had dramatic effects. For instance, in Karnataka, the availability of finance enabled the creation of a viable market and the number of manufacturers increased from six to 60 in 2005 alone (Hande, 2006).

- **Grid-connected Village Renewable Energy Program**

In addition to the efforts to commercialize solar energy such as interest subsidies, direct capital subsidies are still used. Under this program, solar thermal for cooking, hot water, and drying applications are targeted but at a significantly reduced subsidy level compared to the 10th plan (2002-2007). A maximum subsidy level of 25% of total system cost is proposed (enhanced to a maximum of 33% for special category states).

Solar hot water systems, will get a subsidy of Rs. 1,500/sq. mt.; solar cooking and drying applications will get a subsidy of Rs. 1,250/sq. mt. and concentrating solar cookers will get a subsidy of Rs. 2,500/sq. mt.

- **Solar thermal for urban, commercial and industrial applications**

Flat plate solar hot water systems: Over the past few years solar hot water systems have become increasingly popular. As against a target of 500,000 sq. mts. for the 10th Five Year Plan (2002-2007) a total of 850,000 sq. mts. were installed by 2006 (MNRE, 2006). In support of this trend the government proposes to continue a subsidy of about 15% of system cost and the target by the end of the 11th Plan (2012) is 9.5 million sq. mts. The pre-subsidy systems cost is around Rs. 7,500/sq. mts. and can reportedly conserve up to 1,000 kWh/sq. mt. /year, depending on the location and use – offering an attractive payback period of 2.5 years in favorable conditions (MNRE, 2006).

Solar air heating/drying systems: A large number of industries, such as for instance, processing of tea leaves, coffee beans, fruits, vegetables, spices, leather, chemicals, rubber, paper and pharmaceuticals require low-temperature hot air in the rage of 50-80°C. Solar thermal systems not only offer the potential for significant energy savings, but are also reported to improve product quality. By 2006 about 10,000 sq. mts of flat plate collector area for solar drying applications had been installed in about 50 facilities across the country. Under the 11th plan the government seeks to enhance this to 0.25 million sq. mts and offers a subsidy of 25% of total system cost (MNRE, 2006).

Solar concentrating systems: Solar concentrating systems using parabolic as well as Scheffler dishes are being used to generate steam and heat air and oil for applications that requires temperatures over 80°C. For instance, the world's largest solar concentrating system capable of cooking for 15,000 people/day is in operation at Tirupati, in south India, which hosts a revered deity and millions of pilgrims a year. In total there are about 16 solar concentrating systems in operation, accounting for an

aggregate area of 5,000 sq. mts. Under the 11th plan the government will provide a subsidy of 25% of total costs and seeks to enhance this to a total of 0.25 million sq. mts.

4.6.3 Solar Thermal Electric

Market summary: With abundant solar resources, many parts of India offer significant technical potential to harness solar thermal electricity. The first solar thermal power project was proposed as far back as 1988 in Mathania, Rajasthan. A proposal for a 140 MW solar hybrid plant (with 40MW of solar thermal) was presented with financing with a mix of grants from the GEF, loans and private investment (Lahmeyer, 2003). An evaluation of the project by the World Bank concluded that the project was not economically viable even with grant support from the GEF (World Bank, 2004).

Policy structure: The experience of the Mathania project has influenced the current policy structure toward solar thermal power in the India. The MNRE (2006: 12) urges a "cautious approach toward the deployment of grid-interactive solar projects at this juncture in view of the very high unit cost of generation of solar electricity apart from technological and commercial reasons"

- **Grid interactive solar power projects**

Given the need for caution the 11th plan proposes solar thermal projects as demonstration projects. As noted above under photovoltaics, the 11th Plan makes provision for supporting up to 50MW of solar projects, which includes both photovoltaic and CSP in the 2007-2012 period. The production-based subsidy offered by the ministry is up to Rs. 10/kWh, which will be supplemented by the prevalent rate structure for conventional electricity to offer a combined feed-in-tariff of about Rs. 15/kWh for up to 10 years (MNRE, 2006).

Success: The successes of the renewable energy program in India are significant. While having reached a significant target of over 120MW of solar PV, it has also evolved

from a primarily capital subsidy driven endeavor to one that is increasingly shaped by commercial considerations. The recent government policy of "rationalization" has sought to remove the government from picking technologies and instead focusing its efforts on overall priorities of providing energy services and encouraging new and renewables energy sources; even while maintaining a stake in presently economically infeasible technologies, such as centralized solar power, by supporting demonstration projects. This is witnessed in the growing role of private finance and fiscal policy drivers in the overall financing mix for solar power. Capital subsidies have been ratcheted down substantially, except in exceptional cases such as 'remote villages and hamlets.'

Limitations: The scope for improvement remains vast. The primary limitations for solar energy, and renewables more broadly, can be categorized as follows (Banerjee, 2005):

- *High Initial Costs* – The fundamental challenge for renewables remains the challenge innovatively addressing high initial costs, when evaluated within an energy paradigm and infrastructure that is predisposed to low initial cost and high (a part of which is often excluded) life-cycle costs. This challenge is universal at the present time and India is no exception.

- *Sub-critical R&D support* – The renewable energy systems installed in India are often based on imported designs and technology and as such there is a mismatch with local requirements. Research and development efforts within the country to design and develop renewable energy technologies appropriate for local needs remains 'sub-critical.' For instance, between 1992 and 2000 the actual investment in R&D declined in real terms (Banrejee, 2005).

- *Capacity Building* – There is a need to create and develop the institutional infrastructure in terms of educational curricula and research facilities to realize the full potential of renewable energy technologies. Toward this end curricula are being developed in some of the premier engineering schools of the country, but need to be disseminated more widely (Banerjee, 2005).

4.7 China

4.7.1 Photovoltaics

Market summary: Total installation of solar PV systems reached 100 MWp in 2007 (PMO, 2008). Of that, rural electrification accounts for 41.25%, communication and industrial application takes up to 33.75%, PV commodities 20%, building integrated photovoltaics (BIPV) 4.75%, and PV power station 0.25% (PMO, 2008).

Rural electrification is still the single largest component of Chinese PV market, although its share has reduced from 51% in 2003 to 41.25% in 2006 (Wang, 2003; PMO, 2008). Market share of PV commodities and grid-connected PV systems have increased by 11% and 1% respectively, in the same time period (Wang, 2003; PMO, 2008). Distributed solar PV system is the majority of the Chinese PV market. Of all the installed PV systems, only 5% are on-grid and 95% are distributed systems.

The potential market for household system is 1,400MWp -- 3,000MWp. Before 2010, the PV market focus is on small-scale, dispersed and stand-alone PV stations and household system as well as small and medium-sized building-integrated grid-connected PV systems. According to official estimates, after 2010 the PV market in China will begin to change from stand-alone systems to grid-connected systems, including very-large scale PV stations in the Gobi desert and city roof plan.

On the other hand, domestic production of PV systems has gone through an incredible process, growing at 191.3% annually from 2002 to 2007 (PMO, 2008). Output in 2007 was 1,088 MWp, even as China surpassed Japan to become the largest producer of PV systems (PMO, 2008). In 2007, only 2% of the total production was installed in China (PMO, 2008).

Solar PV is expected to play an increasing role in energy supply. According to the Medium and Long Term Development Regulation for Renewable Energy (NDRC, 2007), the total installed solar PV in China will increase to 300 MWp in 2010 and 1,800 MWp

by 2020. Future market share of solar PV in China will change dramatically. Before 2010, solar PV will continue its role to provide energy needs of 1 million unelectrified households in remote areas. In economically developed regions, BIPV is expected to increase. In terms of market share, rural electrification will drop from 50% in 2010 to 17% in 2020, while BIPV will increase from 17% to 56%, and on-grid PV grow from 7% to 11% during the same duration (NDRC, 2007). With the further driving down of cost and improvement of technology, the International Energy Agency (2008) estimated that in 2030, installed PV capacity in China will reach 9,000 MWp.

Policy structure: The rapid development of the PV industry and market in this decade is mainly due to government support, implemented through a number of rural electrification programs, for solar PV or PV/Wind hybrid system to provide electricity for unelectrified villages in China. On the other hand, China has formulated national laws and policies to guide the development of solar PV industry and encourage domestic PV market expansion. Programs for rural electrification were the major driving force for solar PV market expansion in China in late 1990s and early 2000s. Most of the PV projects were government sponsored with international aide or within the framework of government programs at national or local levels. Selected programs are described as follows:

- **Brightness Program Pilot Project**

This pilot project was launched by the Chinese Government in 2000. The Brightness Program plans to provide electricity to 23 million people in remote areas by 2010 using wind, solar PV, wind/PV hybrid and wind/PV/diesel hybrid systems to provide an average capacity of 100 W per capita, for a total installed capacity of 2,300 MW. Inner Mongolia, Gansu and Tibet were selected as pilot provinces. SDPC (renamed as NDRC in 2003) allocated RMB 40 million grant for the projects and installed an execution system. About 5,500 wind/PV hybrid home systems and one village system were installed in Inner Mongolia by end of 2003. And about 10,000 solar home systems and three PV mini-grid village systems were installed in Gansu by end of 2002. Six PV village systems around 6 kW were installed in Tibet by end of 2001 (Ma, 2004).

- **Township Electrification Program**

In 2002, SDPC launched an ambitious renewable energy-based rural electrification program known as Song Dian Dao Xiang, literally "Sending Electricity to Townships." The objective of this program is to supply power to more than 700 unelectrified towns, using small hydro, PV, wind or PV/wind hybrid systems. By 2005, 268 small hydro stations and 721 PV, PV/wind hybrid systems were installed, providing basic energy needs to 300 thousand households, or 1.3 million people (PMO, 2008). The overall investment was RMB 2.7 billion and 15.3 MWp of PV systems were installed during program.

- **China Renewable Energy Development Project (REDP)**

This project (2002 ~ 2008) was supported by a GEF grant, a World Bank loan and Chinese governmental co-financing. The aim of the project is to use PV and wind to supply clean, renewable energy to dispersed rural households and institutions. A direct subsidy of US$1.5 per Wp would be provided to PV companies to assist them to market, sell and maintain 10 MWp of PV systems in Qinghai, Gansu, Inner Mongolia, Xinjiang, Tibet and Sichuan. Technology improvement support was also provided to strengthen institutional capabilities for PV quality assurance and project management.

- **Other Programs**

A number of other rural electrification programs were launched in China. Together, they greatly influenced the development of a PV market in the country. A summary of some of these programs is provided in Table 4.1.

Table 4.1 Summary of Major Programs in China

Project	Sponsor	Approach	Time line	Achievement
PV Plan for Ali, Tibet	GOC (60 million RMB)	Establishment of village level PV station, PV pumps, and Promotion of SHS	2000 -	190 kWp PV systems installed; 10,000 people in Ali electried
New Energy Project	GOC 0.2 billion RMB	Subsidy for household renewable energy systems in rural Inner Mongolia	2001 -	
Silkroad Brightness Program	The Netherlands (15 million Euro); GOC (10 million Euro)	Subsidy for solar home systems in Xinjiang	2002 - 2006	78 thousand households, or 300 thousand people electrified
Solar PV Program in West China	Germany (KFW) (26 million Euro); GOC (77 million RMB)	Establishment of Village Power Station (mainly focus on school and clinic) and Training of staff in Xinjiang, Yunnan, Qinghai and Gansu	2003 - 2005	Electrified hundreds of villages in 4 provinces
Renewable Energy in Rural China	Germany (GTZ) 4.6 million Euro	Technical support and Training in Qinghai, Yunnan, Tibet and Gansu	2003 -	
Solar PV Program	Canada (CIDA) 3.43 million Canadian $	Power station demonstration and training in Inner Mongolia	2003 - 2005	
NEDO Program	Japan (NEDO) 38.53 million RMB	Capacity building and Establishment of PV power station in numerous provinces	1998 - 2002	Most power stations were built for schools and clinics in rural areas; public awareness

Renewable Energy Policy

In January 2006, China issued the Renewable Energy Law to encourage renewable energy development. It mandates utility companies to purchase “in full amounts” renewable energy generated electricity within their domains and provide related technical support. According to the law, power grid operators should purchase this electricity at a

price that includes production cost plus a reasonable profit. The extra cost incurred by the utility will be shared throughout the overall power grid (GOC, 2005). The State Electricity Regulatory Commission issued an order in 2007 requiring utility companies to give priority to renewable energy electricity, and provide grid-connecting services (this cost will be included in the price and then distributed in the whole electricity grid).

Success: China's solar PV market depends largely upon policy. In the past years, rural electrification programs have greatly influenced PV market. Primarily aimed at meeting basic energy needs for people who do not have access to conventional electricity grids, these programs use solar PV, along with/or wind, as a means for energy delivery. Implementation of these programs has resulted in increased installed capacity of PV systems, as well as capacity building for personnel who operate and maintain these systems. As a result, millions of people are now using solar PV electricity. Furthermore, more than 100 on-grid PV stations are built, with capacity ranging from kW level to MW level.

In 2001 the actual sale of PV systems was 4.5 MWp and cumulative installation reached over 20 MWp. By the end of 2003 this figure had grown to 55 MWp. An increasing part of the PV products were exported as well. At the same time, production cost of solar PV is continuously decreasing. The price per Wp dropped from 400 RMB in 1976 to about 20-30 RMB in 2003 (REDP, 2004).

The Renewable Energy Law has had a positive influence on the solar PV market. For example, 20 MWp were installed in 2007 (PMO, 2008). This data includes establishment of on-grid PV stations financed by companies and local governments.

Limitations: Despite of the fact that rural electrification programs have promoted solar PV market in China and trained technicians for system operation and maintenance (O&M), O&M is still a big challenge for existing solar PV systems and for future expansion of solar PV market. As mentioned, most of these PV systems are installed in remote areas. When a system fails, it is extremely difficult to find technical support.

Additionally, remote PV stations and household systems are primarily funded by Chinese government and international donors. And because the life span of components is shorter than that of PV cells, replacement of components presents a special challenge for rural end users, as the cost could be expensive. Although the Renewable Energy Law required the maintenance fee of off-grid PV stations to be shared throughout the national electric grid, details of this mechanism are still being finalized.

Grid-connected PV systems are a very small proportion of the market. Most grid-connected PV systems are demonstration projects run on test basis. None of them are operating under the pricing principle of "production cost plus reasonable profit," nor being built through a completely commercial process by the developers. Considering the safety of electric grids, most of the grid-connected PV systems are not allowed to transmit electricity to the high voltage grids (10kV), but only for consumption at the low voltage (380V/220V) side (PMO, 2008).

China became the largest PV producer of PV in 2007. However, the growth of the domestic market is far less than the production capacity. The annual installation of about 20 MWp in 2007 was only 1.84% of the production (1,088 MWp) in that year (PMO, 2008). This phenomenon could be explained by the low labor cost in China, and lack of effective policy incentives for solar PV marketing domestically, meaning that the support for solar PV installation from the government is not enough and the input is not sufficient.

4.7.2 Solar Thermal Heating

Market Summary*:* China is now the largest producer and consumer of solar water heaters (SWH) in the world, with a high possession and market growth rate. Currently China has installed 75 million square meters of solar water heaters, about half of the world's total (Weiss et al., 2007). SWH are mainly used for residential use. Nowadays, the best market of SWH is in the province of Jiangsu, Zhejiang, Shangdong and Yunnan, where most of the manufacturers are located.

SWH technology in China is already cost effective. The goal of China is to raise total installed area to 150 million square meters by 2010 (including 50 million m^2 in rural area) and reach 300 million square meters by 2020 (NDRC, 2008).

Policy Summary: Solar water heater technology is mature and commercially competitive in China. According to Hua (2005), in warm regions a typical solar water heater comprises two square meters of solar collectors, a 180-liter storage tank and an open circulation system and would cost 1,500 RMB. A similar configuration in colder regions of the country would cost about 2,200 ~ 3,000 RMB. However, with 20 years of development, SWH accounts for only 11.2% of the water heater industry. Market for SWH is largely spontaneous, but still, there are some policies that contribute to the development.

The Renewable Energy Law encourages installation and use of solar thermal systems. It requires the government to formulate policies that guide the integration of solar water heaters and buildings; real estate developers to provide provisions for solar energy utilization; and residents in existing buildings to install qualified solar energy systems if it does not affect the building quality and safety (GOC, 2005). The 11th Five-Year Plan for Renewable Energy (NDRC, 2008) stated the necessity of policy formulation to mandate integration of buildings and solar water heaters. In regions with high solar radiation, hot water intensive public buildings (such as schools and hospitals) and commercial buildings (such as hotels and restaurants) should be gradually mandated for SWH installation. New buildings should reserve spaces for future SWH installation and piping (NDRC, 2008). It also requires further research, development and demonstration. Relevant standards and certification have been established. At provincial and local levels, the government has issued various policies for SWH promotion, for instance, Jiangsu, Gansu and Shenzhen require buildings less than 12 floors to be quipped with solar water heaters, and in some areas, a certain amount of subsidy is provided to buyers of solar water heaters (Hu, 2006 & 2008).

The Program of Improvement and Expansion of Solar Water Heating Technology in China ran from 2003 to 2006, with United Nations funding and Chinese government co-financing. A set of technology standards and building codes has been promulgated, as well as a guidebook and design model for integrating solar water heaters into buildings. As a result of the project, in the last two years, 100,000 square meters of floor area of demonstration buildings have been constructed in Beijing, Shanghai, Yunnan, Anhui, Shangdong and Tianjin (Office of National Coordination Committee on Climate Change, 2005).

Success: Solar water heaters are market competitive in China. Instead of focusing on subsidies and reducing costs, governmental policies are aiming at capacity building in the solar water heater industry, including setting up technological standards, testing centers and guidance for future development.

Limitations: Although China is the largest market in the world, SWH ownership per capita is still low. In province such as Guangdong, which has excellent solar energy resource, SWH ownership is less than 5%. Barriers to SWH market expansion lie in the fact that real estate management companies are reluctant to allow SWH installation in the communities. Though several demonstration projects have been completed and the necessity is stated in national policies, it is a challenge to develop a detailed implementation plan that integrate SWH into the buildings, while guaranteeing safety and avoid atheistic problems. Further, numerous cities have adopted the policy of mandating SWH installation. While the experience and effect remains to be examined; a national policy is desired as well.

4.8 Philippines

Market Summary: Lacking in traditional energy reserves, the Philippines largely depends upon imported coal and oil. Philippines is located close to the equator, therefore has an excellent supply of solar radiation. According to a study conducted by the Department of Energy in the Philippines, the country has an annual average potential of

5.1 kWh/m^2/day (The Philippine Department of Energy, 2008). Further, the country is an archipelago of more than 7,000 islands. Presently solar PV is seen mainly as a niche product to generate electricity for isolated communities in small islands since it would be too expensive to get the electricity grid through transmission towers or underwater cables. Based on the 2001 inventory of solar technologies, a total of 5,120 solar systems have been installed, which include: (i) 4,619 solar photovoltaic (PV) systems; (ii) 433 solar water heaters; and (iii) 68 solar dryer systems (The Philippine Department of Energy, 2008).

Policy Structure: Based on current projections of the Department of Energy (DOE), renewable energy is foreseen to provide up to 40% of the country's primary energy requirements over the ten-year period beginning in 2003. Biomass, micro-hydro, solar and wind will remain the largest contributors to the total share of renewable energy in the energy mix with an average share of 27.5 percent.

As an aggressive move to promote renewable energy development and use, the DOE has identified long-term goals, namely, to (i) increase renewable energy based capacity by 100% by 2013; and (ii) increase non-power contribution of renewable energy to the energy mix by 10 million barrels of fuel oil equivalent (MMBFOE) in the next ten years (The Philippine Department of Energy, 2008). The DOE will push for the installation of up to 548 MW from RE sources by 2013. Of this total, 417 MW will come from wind-based power while the remaining 131 MW will be sourced from solar, ocean and biomass.

According to the DOE, contribution of wind, solar and biomass sources for non-power applications will comprise a large portion of total demand for renewable energy in the next ten years. Demand for solar and wind energy sources is foreseen to grow with the implementation of the program to invigorate the market for solar water heaters and locally fabricated solar dryers and wind pumps (The Philippine Department of Energy, 2008).

- **Rural Electrification**

In the government's rural electrification efforts, renewable energy sources such as solar, micro-hydro, wind and biomass resources are seeing wide-scale use (The Philippine Department of Energy, 2008). The government aims at diversifying energy mix in favor of indigenous renewable energy resources. To promote wide-scale use of renewable energy and complementing the government's program on rural electrification, 30 islands are targeted to be energized using renewable energy hybrid power systems. In addition, 1,500 barangays are programmed to be electrified using renewable energy systems (The Philippine Department of Energy, 2008).

- **Priority endorsement of renewable energy for bilateral and multilateral financing**

The World Bank has launched a rural power project in the Philippines, aimed at installation of 135,000 solar systems; totaling 9 MW installed capacity. In addition, the International Finance Corporation finished a 1 MW grid-tied PV with hydro hybrid project in the Philippines (Prometheus Institute, 2007). Agencies such as USAID and Winrock International have also conducted solar projects in the Philippines.

- **Market-based incentives**

With the target to improve solar energy utilization and make the Philippines a manufacturing hub for PV cells to facilitate development of local manufacturing industry for renewable energy equipment and components, one important policy by the Philippine government is to encourage greater private sector investments and participation in renewable energy development through market-based incentives (The Philippine Department of Energy, 2008). There is the “sunset” or “fall-away” provision, to encourage investors to proceed with dispatch the implementation of renewable energy projects to avail of incentives (first 2,500 MW or 20 years), which is intended for renewable energy projects that are not yet commercially viable, e.g. solar and wind, to ensure benefit to end-users (Energy Utilization Management Bureau, 2008). In 2008, the senate passed Renewable Energy Act, which assures investors in wind, solar, ocean, run-

of-river hydropower and biomass premium rates in electricity generated from these clean sources through feed-in tariffs. Other incentives include duty-free importation of equipment, tax credit on domestic capital equipment and services, special realty tax rates, income tax holidays, net operating loss carry-over, accelerated depreciation and exemption from the universal charge and wheeling charges (WWF, 2008).

- **Renewable Portfolio Standards (RPS)**

Direct imposition on having a minimum amount of energy sources from renewables for all generators of electricity; RPS levels shall be set on a grid-to-grid basis (Energy Utilization Management Bureau, 2008).

Discussions: Primary challenges include large up-front investment needed for solar power and little PV support infrastructure (Trinidad, 2007). Policies and strategies are formulated to focus on renewable energy as a whole, not for solar specifically, while biomass, ocean and hydro account for a major share of renewable energy development. With the much higher cost, additional policies need to be adopted for further solar energy development, including cutting down of the high cost, promoting public awareness of benefits from solar energy use, providing sufficient financial incentives, and constructing a commercially viable market (The Philippine Department of Energy, 2008).

4.9 Bangladesh

Market Summary: Bangladesh is an energy market where there is substantial unmet demand for electricity. A majority (over 70%) of the population does not have access to electricity and the per capita electricity consumption in 2004 was about 154 kWh (UN 2007). The conventional electricity system is geared toward urban centers where demand has rapidly increased. The low-load rural areas are extremely underserved. Thus, fully recognizing the development and environmental benefits of solar PV, the Government's priority appears to be to serve the rural sector (IDCOL 2008). The present market for solar energy technologies includes primarily Solar Home Systems (SHS), while various solar thermal applications such as cookers, dryers, water

heaters and tunnel dryers for crops are in various stages of research, development and demonstration (Uddin & Taplin 2008). Presently, there are over 211,000 SHS with a total capacity of above 11 MW serving over 1 million customers (IDCOL 2008).

***Policy Structure*:** Government, donor and private sector efforts to promote renewable energy in Bangladesh has a reasonably long history, going back to the 1980's. This early approach was stymied by the fact that projects often ran out of steam after the pilot scheme was completed. There are a variety of policy frameworks that influence renewable energy development in Bangladesh (Uddin et al. 2006). These include the Private Sector Power Generation Policy (1996), which encouraged private sector participation in power generation; the National Policy Statement on Power Sector Reform (2000); the Remote Area Power Supply Systems Policy; and Guidelines for Small Power Plants in Private Sector 2001. However, the country is still in the process of developing a comprehensive Renewable Energy Policy, although drafts have been issues in both 2002 and 2008. The draft proposal addresses technology, regulatory, financing arrangements, tariff regulations, fiscal and other incentives for the implementation of renewable energy technologies.

The overriding objective of the policy direction for solar chosen by Bangladesh is to encourage private sector participation in the expansion of renewable energy with an emphasis on rural areas.

The draft policy offers financial incentives such as a 15-year corporate income tax exception for investors in renewable energy and an accelerated depreciation of 80% within the first year. It envisions the creation of an agency to access funding from a variety of sources, including private, public, donor and CDM and carbon markets (GOB 2008). However, on the question of grid-interconnection and guaranteed payments for renewable energy generators – policies responsible for the recent success of solar PV in markets such as Germany, New Jersey and California – the draft policy does not follow suit. This difference is policy structure might be reflective of divergent priorities for Bangladesh.

Thus, while grid-connected installations of PV are negligible in this country, the primary driver of the PV market in Bangladesh is the ambitious and rapid penetration of stand along SHS. A prominent success story in this regard is the microfinance driven, private owned SHSs installed under the Solar Energy Programme of the Infrastructure Development Company Limited (IDCOL) under the Rural Electrification and Renewable Energy Development Project (REREDP) (IDCOL 2008).

Between 2003 and 2008 the IDCOL Solar Energy Programme has facilitated the microcredit-financed installation of over 211,000 SHS. Having exceeded its expectations the program now has a target of 1 million systems by 2012. This model has been built on one of the key strengths of Bangladesh namely the microcredit banking system pioneered by Grameen Bank and now adopted by numerous organizations (IDCOL 2008). Further, this approach to developing the PV market in Bangladesh has sought expressly to involve local business entrepreneurs and member of local communities of both genders (Uddin & Taplin 2008).

4.10 Discussion

As discussed in Section 1 of this report, the previous decade has witnessed the strong growth of solar energy markets, notably, those for grid-connected solar PV and solar thermal water heating. This trend has been driven in large measure by the sustained implementation of an aggressive policy suite in Europe, some states of the United States and Japan and the emergence of cost competitive solar thermal water heaters in China and some other countries. A critical variable that influences the market for solar energy technologies is cost and as seen in Section 2 the cost trends across all the solar energy technologies evaluated by this report are downward, even while today's costs remain higher than comparable conventional energy sources. Nevertheless as discussed in Section 6 of this report, given the downward cost trends, the potential market for solar energy remains vast, if it is also supported by innovative and well-designed policy

approaches. The short case studies presented in this section highlight various policy approaches and challenges.

The dominant position of the German PV market is attributed largely to a policy framework (namely, feed-in-tariff) that guarantees attractive returns on investment along with the technical and regulatory requirements such as grid connectivity and power purchase commitment required to incentivize investments. The leading solar states in United States have combined federal and state incentives and rebates along with regulatory and market mechanisms such as renewable portfolio standards and renewable energy credits. In both cases however there is pressure to gradually transition to mechanisms or modifications that limit the fiscal burden of the policy. Thus, a prominent challenge for the leading solar energy markets, particularly those for PV, is to manage the transition to reduced policy costs while maintaining the significant momentum realized thus far.

An illustration of this challenge is the use of REC markets as a revenue stream for solar energy applications. While New Jersey has pioneered this approach, California is presently considering the introduction of a State REC market (CPUC 2008). However, managing financial risks associated with revenues streams derived from short-terms REC markets would require closer attention during this transition. In Germany, the increased political pressure to reduce policy costs is finding expression more rapid digression schedules for feed-in-tariffs.

The sensitivity to policy costs is more significant in developing country markets such as India, China, Philippines and Bangladesh. Thus, a common approach toward renewable energy technologies, seen in developing countries, is to "rationalize development and deployment strategy" (MNRE 2006) of renewable energy technologies. Thus for instance, while India plans to install 15,000 MW of grid-connected renewable energy under the current five-year plan (2007-2012), this market expansion will likely be driven by wind, micro-hydro and biomass. The scope for solar-PV and solar thermal electric is limited to demonstration projects totaling 50 MW to be supported primarily by

a feed-in-tariff approach. The five-year plan recognizes that solar PV is an option if the prices come down to levels comparable to micro-hydro. The approach to the renewable energy mix in China, Philippines and Bangladesh represents similar priorities of rationalizing the policy costs.

On the other hand solar PV is recognized as serving a niche market that is very important in developing countries – electrification of rural and peri-urban areas that do not yet have access to the electric grid. There are vigorous efforts to expand the market for Solar Home Systems (SHS) as a means toward rural electrification. The earlier approach to this market was primarily subsidy driven either via government funds or through international donors. While subsides and these funding sources still remain an important, there has been an expansion of low interest rate credit markets for purchase of SHS. The successful efforts of Bangladesh discussed above are exemplary in this regard.

A solar energy technology that is by and large cost competitive with conventional fuels is solar thermal hot water systems. As seen in the case of China solar water heaters have become technologically mature and commercially competitive. Given that the market is largely spontaneous the government's policy approach to further expand this market includes mandates to help further integrate the technology with existing building stock and new building construction. The success of mandates has also been underscored by the rapid expansion of solar thermal hot water systems in countries such as Spain. Also emphasized are efforts for further research, development and demonstration of the technology.

Finally, the solar thermal electric market has reemerged in recent years and has been driven primarily by feed-in-tariff approach popular in Europe and rebates and tax incentives in the United States, where it is also supported by Renewable Portfolio Standards. Thus far, solar thermal electric has not found much success in developing country contexts. Unlike Solar PV, solar thermal electric is limited to utility scale applications and as such is often out of consideration in the traditional utility generation market, due to current prices, and the niche rural electrification market, due to scale and

price. Thus developing country governments have adopted a cautious policy approach to this market focusing more on pilot scale projects, as with grid-connected solar PV.

Overall, in industrialized countries, the policy landscape for solar energy technologies is marked by significant success stories where sustained and substantial policies have been in place to guarantee return on investment and mitigate technical and institutional barriers such as grid interconnection and administrative hurdles. Among developing countries the policy approach is driven by a commitment to renewable energy markets but cautioned by efforts to rationalize policy costs at the same time. For the moment, this approach offers only limited support for solar PV and solar thermal electric markets, while solar thermal hot water markets are growing rapidly. This is likely to change dramatically by decrease in technology costs and elimination of various technical and institutional barriers.

5. CARBON FINANCE MECHANISM AND SOLAR ENERGY DEVELOPMENT

5.1 Overview

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) has introduced three "flexibility mechanisms" to help reduce greenhouse gas (GHG) emissions, *viz.* International Emission Trading (IET), Joint Implementation (JI), and Clean Development Mechanism (CDM). These mechanisms were designed to help industrialized country parties (also, known as Annex I) to achieve their emission reduction target at a lower cost.

In order to facilitate GHG reductions through these Kyoto mechanisms, international or regional financial agencies and governments have set up various carbon funds that focus on different technologies and regions. Examples are Certified Emission Reduction Unit Procurement Tender (CERUPT, now closed since January 1 2008) by the Netherlands government, the Prototype Carbon Fund (PCF), Community Development Carbon Fund (CDCF), Umbrella Carbon Facility (UCF) and other funds established by the World Bank, and the Asia Pacific Carbon Fund (APCF) administered by Asian Development Bank (ADB).

These carbon finance mechanisms are project-based, intending to provide financing for project activities that will cut off carbon emissions, in which renewable energy is an important component. Due to the abundance and prevalence of resources, solar energy is widely regarded as an ideal candidate for these mechanisms. In fact, solar energy, along with other renewable energy technologies, was favorably endorsed under these mechanisms, particularly the CDM. For example, the ADB administered APCF identifies solar power as one of its target projects, as it provides energy security benefits as well as certified emission reductions (CER) (ADB, 2006). China has prioritized renewable energy and energy efficiency as key areas for CDM project development, and provided financial incentives (Office of National Coordination Committee on Climate Change, 2008).

However, the role of Kyoto Mechanisms to develop solar energy has remained relatively small as compared to other renewable energy projects, such as wind. For

example, no solar project has been considered for validation and registration under JI until now despite the fact that 33 other projects have been already registered and 160 projects are at the stage of validation (UNEP Risoe, 2009). No solar project was identified for CERUPT and APCF (SenterNoverm, 2008; ADB, 2008). For the carbon finance mechanisms administered by the World Bank (2009), only two solar projects were found; both, PV projects in Bangladesh (Table 5.1).

Table 5.1 Solar Projects for Carbon Finance at the World Bank

Project Name	Fund	ERPA* Emission Reductions** (tCO2e)	Total Project Emission Reductions Generation (tCO2e)
Installation of Solar Home Systems in Bangladesh (Grameen)	CDCF	372,000	1,130,000
Installation of Solar Home Systems in Bangladesh (IDCOL)	CDCF	192,000	313,600

Note: *ERPA: Emission Reductions Purchase Agreements; ** Exclusive of options
Source: World Bank, 2008.

The CDM, which was regarded as a key instrument to promote GHG mitigation projects in developing countries, has not helped much yet in promoting solar power either. In the following sub-sections we will discuss solar energy development under the CDM so far, identify the main barriers for promoting solar energy under the mechanism, and present some suggestions to improve the situation.

5.2 Clean Development Mechanism and Solar Energy Development

5.2.1 CDM and Solar Energy Development

There are 4,541 CDM projects in the pipeline as of March 1 2009. Of them, there are 29 solar projects (including the seven that were registered prior to March 1, 2009, see Table 5.2), with annual CERs of 742,000 tons. By the end of 2012, accumulated CERs would be 3,160,000 tons (UNEP Risoe, 2009). In terms of project numbers, solar CDM

projects in the pipeline account for only 1% of all projects, while the percentage of CERs is close to 0% (UNEP Risoe, 2009).

Table 5.2 CDM Projects Grouped in Types

Type	number		CERs/yr (000)		2012 CERs (000)		CERs Issued (000)	
Hydro	1195	26%	122465	20%	482633	17%	9086	3%
Biomass energy	688	15%	42990	7%	213611	7%	11619	4%
Wind	661	15%	57020	9%	253115	9%	10642	4%
EE own generation	408	9%	60795	10%	276790	10%	10543	4%
Landfill gas	336	7%	50519	8%	263827	9%	5771	2%
Biogas	288	6%	14293	2%	64734	2%	1111	0%
Agriculture	231	5%	8650	1%	51925	2%	3670	1%
EE Industry	181	4%	5991	1%	29925	1%	921	0%
Fossil fuel switch	140	3%	44408	7%	204642	7%	1817	1%
N2O	66	1%	48320	8%	253765	9%	56523	22%
Coal bed/mine methane	66	1%	28685	5%	132298	5%	638	0%
EE Supply side	52	1%	16193	3%	34704	1%	328	0%
Cement	39	1%	6970	1%	40393	1%	1103	0%
Afforestation & Reforestation	39	1%	2205	0%	11600	0%	0	0%
Fugitive	30	1%	10876	2%	57193	2%	5153	2%
Solar	29	1%	742	0%	3160	0%	1	0%
HFCs	23	1%	83066	14%	492986	17%	142337	54%
Geothermal	15	0%	3433	1%	17179	1%	318	0%
EE Households	14	0%	945	0%	3936	0%	0	0%
EE Service	12	0%	184	0%	783	0%	4	0%
Transport	9	0%	981	0%	4885	0%	129	0%
PFCs	8	0%	1142	0%	4751	0%	0	0%
Energy distrib.	8	0%	2374	0%	9891	0%	0	0%
Tidal	1	0%	315	0%	1104	0%	0	0%
CO2 capture	2	0%	24	0%	149	0%	43	0%
Total	4541	100%	613587	100%	2909982	100%	261756	100%
HFCs, PFCs & N2O reduction	97	2%	132528	22%	751502	26%	198860	76%
Renewables	2877	63%	241259	39%	1035537	36%	32777	13%
CH4 reduction & Cement & Coal mine/bed	704	16%	105724	17%	545786	19%	16378	6,3%
Supply-side EE	468	10%	79362	13%	321385	11%	10871	4,2%
Fuel switch	140	3,1%	44408	7,24%	204642	7,0%	1817	0,7%
Demand-side EE	207	4,6%	7120	1,16%	34645	1,2%	925	0,4%
Afforestation & Reforestation	39	0,9%	2205	0,4%	11600	0,4%	0	0,0%
Transport	9	0,2%	981	0,2%	4885	0,2%	129	0,0%

Source: UNEP Risoe Center, 2009

Table 5.3 lists all the 29 solar projects in the CDM pipeline. In total there are 19 solar PV projects, six solar cooking projects, two solar water heating projects, and two solar thermal electricity projects. With respect to geographical distribution, except one solar PV and one solar thermal electricity project hosted in Morocco, all other solar projects are in Asia. Specifically: 13 in South Korea, six in India, four in China, two in United Arab Emirates, one in Bangladesh and in Indonesia, respectively.

Table 5.3 Solar Projects in the CDM Pipeline

ID	Title	Host country	Status	Sub-type	1st period ktCO2e/yr	yrs.	Credit Buyer
CDM0546	Installation of 30,000 Solar Home Systems in Rural Households	Bangladesh	At validation	Solar PV	6.2	7	n.a.
CDM2750	Federal Intertrade Pengyang Solar Cooker Project	China	Request review	Solar cooking	36	10	Switzerland (Swiss Re)
CDM3294	Federal Intertrade Hong-Ru River Solar Cooker Project	China	Reg. request	Solar cooking	36	10	Netherlands (Swiss Re)
CDM2753	Federal Intertrade Yulin Solar Cooker Project	China	At Validation	Solar cooking	34	10	n.a.
CDM3631	Ningxia Federal Solar Cooker Project	China	At Validation	Solar cooking	40	10	Finland (Finland Ministry for Foreign Affairs)
CDM0256	Solar steam for cooking and other applications	India	Registered	Solar cooking	0.6	7	Germany (GTZ)
CDM0957	Bagepalli CDM Solar Hot Water Heating Programme	India	At validation	Solar water heating	109	7	n.a.
CDM0958	Karnataka CDM Photovoltaic Lighting Programme	India	At validation	Solar PV	20	7	n.a.
CDM2952	Rural Education for Development Society (REDS) CDM Photovoltaic Lighting Project	India	At Validation	Solar PV	46	10	n.a.
CDM3029	CDM Solar Hot Water Project of M/s Emmvee Solar Systems Private Limited Serial No 0001	India	At Validation	Solar water heating	52	7	n.a.
CDM4374	d.light Rural Lighting Project	India	At Validation	Solar PV	46	10	Netherlands (OneCarbon)
CDM0159	CDM Solar Cooker Project Aceh 1	Indonesia	Registered	Solar cooking	3.5	7	Germany (Klimaschutz)
CDM0250	Photovoltaic kits to light up rural households (7,7 MW)	Morocco	Registered	Solar PV	39	10	France (European Carbon Fund)
CDM3572	Greenhouse Gas Emission in the Fish Meal Industry in Morocco – Central Steam Production Plant	Morocco	At Validation	Solar thermal electric	5	7	Austria (Kommunalkredit)
CDM0559	1 MW Donghae PV(photovoltaic) Power Plant	South Korea	Registered	Solar PV	0.6	10	Japan (Natsource)
CDM2976	Daegu & Shinan PV(photovoltaic) Power Plant Project	South Korea	Registered	Solar PV	0.8	7	n.a.
CDM3047	1 MW Hwaseong PV(photovoltaic) Power Plant	South Korea	Registered	Solar PV	0.8	10	n.a.
CDM3122	Samryangjin PV(photovoltaic) Power Plant	South Korea	Registered	Solar PV	2.2	10	n.a.
CDM2730	Korea Land Corporation Pyeongtaek Sosabul-district new and renewable model city (Photovoltaic system + solar heating system)	South Korea	Correction request	Solar PV	4.5	7	n.a.
CDM3762	South West Solar Power Plant Project	South Korea	At Validation	Solar PV	0.8	10	Japan (Eurus Energy

							Japan)
CDM3928	LG Solar Energy Taean Photovoltaic Power Plant Project	South Korea	At Validation	Solar PV	12	7	n.a.
CDM3955	9.85MW SECHAN POWER PV(photovoltaic) power plant	South Korea	At Validation	Solar PV	10	7	n.a.
CDM4548	Gimcheon PV Power Plant Site 2 CDM Project	South Korea	At Validation	Solar PV	8	10	n.a.
CDM4557	Gimcheon PV Power Plant Site 1 CDM Project	South Korea	At Validation	Solar PV	9	10	n.a.
CDM4571	Taean Solar Farm PV(photovoltaic) power plant project	South Korea	At Validation	Solar PV	2	10	n.a.
CDM4804	Gochang solarpark 14.98MW photovoltaic power plant Project	South Korea	At Validation	Solar PV	14	10	n.a.
CDM4819	24MW DONG YANG ENERGY PV(photovoltaic) power plant	South Korea	At Validation	Solar PV	22	7	n.a.
CDM3644	Abu Dhabi solar thermal power project	United Arab Emirates	At Validation	Solar thermal electric	168	7	n.a.
CDM3990	ADFEC 10 MW Solar Power Plant	United Arab Emirates	At Validation	Solar PV	15	7	n.a.

Source: UNEP Risoe, 2009

5.3 The Barriers to Solar Technologies in the CDM

5.3.1 Low CER Return

The revenue from the sale of CERs is expected to help renewable energy projects compete with other generation technologies. However, it appears that the revenue from CER has not provided sufficient financial advantages for renewable energy, particularly solar technologies, which are relatively expensive and often installed in smaller in system size configurations.

Solar technologies have a cost disadvantage and cannot compete with reduction of industrial gases such as hydrofluorocarbon (HFC) and nitrous oxide (N_2O). Such gases could be the cheapest options to reduce GHG for two reasons. First, their capital costs are small as they are normally implemented in already existing infrastructure (Willis et al., 2006) and second, their global warming potential is hundreds to thousand times higher than that of CO_2[29]. For example, a 50 MW wind farm in India is estimated to create 112,500 CERs per year, whereas HFC-23 destruction plants in China generates 19 million CERs per year. As shown in Table 5.4, those industrial gas destruction facilities are more cost effective in mitigating GHG emissions than solar PV. Thus, renewable energy projects receive disproportionately small financial benefits from the CDM (BMU, 2007).

[29] HFC and methane are 11,700 and 21 times more potent in global warming effects than carbon dioxide (BMU, 2007).

Table 5.4 CO_2 Abatement Cost by Selected Technologies

Sector	Abatement Options	Average cost $(2005 real)/ton CO_2e	Description of Opportunity
Building and Appliances	Electronic equipment	-93	Increased in-use efficiency and reduced stand-by losses in PCs, office equipment, TV, audio systems, and similar devices
	Lighting	-87	Substitution of advanced lighting technologies
Transportation	Cellulosic biofuels	-18	Commercialization of cellulosic biofuels
	Light-duty vehicle fuel economy cars	-81	Technology upgrades improving fuel efficiency
Industrial and Waste	Recovery and/or destruction of non-CO_2 GHGs	3	Methane management in coal mining, natural gas and petroleum systems, HFCs/PFCs in manufacturing processes
	Combined heat and power	-15	Additional CHP capacity in primary metals, food, refining, chemicals, pulp and paper
Terrestrial Carbon Sinks	Afforestation-pastureland	18	Planting trees, primarily on marginal/degraded or idle pastureland where erosion is high and/or productivity is low
	Conservation tillage	-7	Planting crops amid previous harvest's residue using various approaches, including ridge tillage and no-till farming
	Carbon capture and storage	44	Rebuilds of pulverized coal plants with CCS, plus CCS new builds
Power Sector	Wind	20	Class 5-7 on-shore winds with economic grid integration costs
	Nuclear	9	Nuclear power plant new-builds
	Conservation efficiency	-15	Improved heat rates of base-load pulverized coal power plants
	Solar PV	29	Residential and Commercial distributed power generation with solar photovoltaics

Source: McKinsey & Company, 2007[30]

5.3.2 High Transaction Cost in Modalities and Procedures of Solar CDM Project

The registration of a CDM project and issuance of CERs involves a significant transaction costs that incurs in preparation and, validation of the PDD, project registration, monitoring, verification and certification of emission reductions. Moreover, the transaction costs do not tend to vary significantly across the project size, the small projects inevitably bear a proportionally

[30] The report is intended to help inform economically sensible strategies for reducing greenhouse gas emission within the borders of the United States. It shows that non-CO_2 recovery technologies are almost ten times cost effective than solar PV system in terms of GHG abatement. The mitigation cost may vary in different regional context but solar PV is one of the least cost-effective options to reducing GHG to date.

higher burden of the transaction costs. For solar projects, particularly small scale PV, the transaction costs could often turn to prohibitive (see Table 5.5).

Table 5.5 Examples of Transaction Costs of Renewable Energy CDM Project

Project types	Typical reduction (t CO_{2e}/year)	Transaction costs (€/t CO_{2e})	Size category
Large hydro, geothermal, large CHP and gas power plants, landfill/pipeline methane capture, cement plant efficiency, large-scale afforestation	>200,000	0.1	Very large
Wind power, solar thermal, energy efficiency in large industry	20,000-200,000	0.3-1	Large
Small hydro, boiler conversion, DSM	2,000-20,000	10	Small
Mini hydro, energy efficiency in housing and SMEs	200-2,000	100	Mini
Solar PV	<200	1,000	Micro

Source: Rio, 2007

Although the simplified modalities and procedures for small-scale CDM projects help reduce the overall transaction costs, these costs per unit of GHG reduction are still high for solar energy technologies because of fewer economies of scale of small-scale PV (Rio, 2007). Therefore, additional efforts are required for further reduction of transaction cost to promote solar energy under the CDM.

5.3.3 Other Barriers to Solar CDM Projects

Initially, it was envisioned that developed countries would participate in CDM through capital investment in the projects. However, they limited their roles in purchasing CERs for payment on delivery rather than providing project finance or becoming equity stakeholders of the project (BMU, 2007).

The uncertainty of market prospects may be the obstacles for the development of solar CDM projects. In order to attract investment, PV system requires steady stream of revenue for long period of its life cycle. As the Kyoto framework expires in 2012, most CER purchasers are reluctant to undertake binding obligation after 2012, which results in significant barriers to CDM

project developers. Although the parties to Kyoto Protocol agreed in Montreal in 2005 to continue the CDM framework for a second commitment period, uncertainty about binding emission reduction targets in the post-Kyoto regime still exists.

In addition, the impact of the so called 'hot air' on the CER price can be a significant financial barrier to PV development under the CDM. If Russia and Ukraine decide to sell their surplus carbon emission credits during the first commitment period, the demand for CER from small and expensive renewable energy projects like solar power may diminish (Rio, 2007).

5.4 Areas of Improvement of CDM for Solar Energy Development

5.4.1 Higher Price for Solar-based CERs

Renewable energy projects like solar PV could provide substantial social and environmental benefits to the developing countries such as reduction of local air pollution, enhancing energy security and low carbon economic growth.

Hence, solar power needs a special treatment under the CDM. One approach introduced by a number of countries is that CERs generated from solar power projects should be provided some premium over other low-cost CDM projects, so that solar technology can get a more level playing field with. For example, some CER buyers such as Netherlands and Austria have excluded the projects without direct sustainable development benefits from their portfolio criteria, or are prepared to pay a premium to CERs from renewable energy projects (Willis et al., 2006). China and Malaysia have given formal priority to the projects with significant contribution to the country's sustainable development goal when approving CDM projects (Willis et al., 2006).

One of the innovative ways to differentiate the CERs is implemented in China. China established a regulatory environment where the sales of CERs from the projects with less sustainable development benefits are taxed at higher rates over the projects with larger benefits. The revenue can be reinvested to advance sustainable development technology (Willis et al., 2006). For example, China taxes 65% on HFC-23 projects, 30% for N_2O, and 2% for priority projects and others. This differentiating tax rate structure for the types of CDM projects not only

creates revenues for the country's own sustainable development goals but also displaces the comparative advantage of the projects with few environmental and social benefits.

5.4.2 Bundling of Small Solar Technology

One of the effective approaches to reduce the transaction cost of diffused, small-scale solar CDM projects is to bundle them into a single larger portfolio project.[31] By bundling, several small-scale CDM projects, transaction costs associated with CDM project cycle including project design, validation, registration, monitoring, verification, and issuance stage can be reduced. Different organizations can bundle applications, including private companies (e.g., energy service companies, ESCOs), financial institutions (e.g., the World Bank), government or non-governmental organizations (Mariyappan, 2007). However, the bundling organization should be able to carry out the project efficiently with required skills and technical capacity. In order for bundling to be more effective, it will need to incorporate small-scale projects with similar baseline methodologies as standard CDM projects, in order to avoid the need to create additional PDDs, and separate monitoring plans and reports (Mariyappan, 2007). And it is also observed that transaction cost can be reduced more substantially for grid-connected project than stand-alone projects because monitoring for off-grid project is much higher (Mariyappan, 2007). Given the fact that off-grid solar home systems (SHS) or solar lanterns projects in remote areas in developing countries can contribute to rural sustainable development along with their great market potential,[32] it is necessary to provide further favorable conditions for the off-grid solar systems to reduce inhibitive transaction costs.

5.4.3 Programmatic CDM Projects

Due to high transaction cost, it is difficult for small-size projects such as efficiency upgrades activities and installations of residential solar panels to register as a single CDM project. However, it was allowed that project activities under a program of activities can be

[31] The bundling similar CDM project activities were further extended to larger-scale projects at COP/MOP1 (Ellis, 2007).
[32] It is estimated that developing world households spend nearly $40 billion annually for kerosene lighting alone (PV News, 2007).

registered as a single clean development mechanism project activity, which is known as programmatic CDM.

Programmatic CDM strategies can also create valuable opportunities for developing countries to pursue their local, regional and national policy objectives for sustainable development (Willis et al., 2006; Figueres, 2005). To a certain extent the concept of programmatic CDM overlap with bundling CDM in that multiple activities are involved, the project is implemented in several locations and/or occurs in more than one sector (Ellis, 2006). However, there are some differences between these two mechanisms identified as follows (UNEP Risoe, 2007):

> First, while in a bundle each activity is represented as an individual CDM project, in a program, the individual activities are not CDM project activities but rather the entire set of activities constitutes a single CDM project activity. In other words, each entity participating in a bundle is a project participant (PP) but program enacting agent is a PP in programmatic CDM. Second, in a bundle the composition does not change over time and the exact type and site of each project activity must be identified ex-ante. On the contrary, in a programmatic CDM exact site, crediting time and actual volume of GHG emission reduction may not be clearly confirmed until monitoring and verification.

The examples include replacing diesel-powered water pumps largely used in rural areas with solar-powered pump or installation of solar water heater in a particular district of the city (BMU, 2007). As of June 2007, ten programmatic CDM-like projects were registered, half of which were renewable energy supply for households and another half were energy efficiency improvement projects. Among the renewable energy projects, only two were solar-based projects. One of the solar projects is Morocco PV lighting project for rural households (7.7MW), which is coordinated by ministry of electricity. And the other is solar cooker project in Aceh province in Indonesia, which was invested by German company in return for 100% CER produced from the project (UNEP Risoe, 2007).

Some important steps, such as the bundling and programmatic CDM strategies, have already been taken, creating greater opportunities for micro-scale renewable technologies. For the further improvement, institutional and technical coordination will be necessary in terms of deciding baselines, calculating number of emission reduction, and tracking the implementation (Willis et al., 2006).

5.4.4 Use Domestic Policy Instruments Aligned with CDM

There was concern that a host country's domestic renewable energy policy would make a negative impact on CDM projects because it may result in many projects no longer being 'additional' (BMU, 2007). For example, if a country introduced feed-in-tariff for PV system, it would make PV more attractive in the market, and therefore the PV project would have difficulty in passing the 'additionality' criteria in CDM approval process. However, the CDM Executive Board ruled that baseline for measuring the impacts of domestic policies to promote low-emission technologies like PV and solar cookers "may be calculated on the basis of a hypothetical scenario without the policy" (BMU, 2007: 16). According to this ruling, feed-in-tariff for PV adopted by Chinese and Indian government would not negate the additionality of the future projects, and rather, make them more attractive for investment. Therefore, in order to maximize CDM benefits and dissemination of solar energy use, it is crucial to combine local and regional policy instruments with CDM since they are synergistic rather than off-setting each other. Host countries can consider many supportive measures for renewable energy that have been successful around the world. Those supportive renewable energy policies includes 30% of federal investment tax credits for PV in the U.S.[33], new building code requiring a minimum renewable energy usage in South Korea, or a favorable feed-in-tariff for renewable energy in Germany.

[33] In October 2008, Emergency Economic Stabilization Act of 2008 was passed in US congress and signed by President Bush. The bill includes a number of provisions supporting energy efficiency and renewable energy development. Among them, investment tax credits for commercial and residential solar investment has been extended to 8 years and the monetary cap ($2,000) for residential solar electric system is removed.

5.4.5 Capacity Building

Despite broadened opportunities for development of small-scale renewable energy projects such as residential PV in host countries, local communities may not be aware of mechanisms of programmatic/bundling CDM. Further, the complexity in coordinating CDM programs, which includes tracking the implementation of the program, estimation of emission reduction and developing an effective baseline might require the enhancement of technical capacity in local government (Uddin & Taplin, 2008). Therefore, in order to promote CDM programs relevant to sustainable development, a technical and managerial capacity levels almost always need to be enhanced. Substantial capacity building is essential for market participants, including businesses and other stakeholders to become active in the promotion of solar projects qualifying for CDM investments (BMU, 2007).

5.4.6 Streamline Procedure

One of the key barriers of CDM implementation is insufficient competent staff in designated national authority (DNA) to evaluate and approve CDM projects (BMU, 2007). Delays in approval process can increase legal uncertainty and transaction cost for the project developers. One option is pre-qualify clearly defined and designed small renewable projects (e.g., roof-top PV or solar thermal) for CDM investment (Rio, 2007).

6. THE FUTURE PROSPECTS OF SOLAR ENERGY SUPPLY

As discussed in earlier sections, the solar energy market has grown rapidly during the past several years. A key question for policy makers and investors around the world, however, is how fast the markets will continue to grow. This section reviews recent literature about solar energy market growth and discusses the potential applications of solar energy in the future.

6.1 Photovoltaics

In recent years, there have been numerous national and regional PV market projection efforts (e.g., Australian Business Council for Sustainable Energy, 2004; European Photovoltaic Industry Association, 2004; Fechner et al., 2007; Solar Energy Industries Association, 2004), as well as a series of high-profile global projections. The grid-connected application of PV that emerged as the primary driver of global market growth is also the cornerstone of these projections.

6.1.1 Short-term Projections

In the short-term projections, the key demand-side driver for PV is government policy, whereas the primary supply-side drivers have been the global silicon supply and downstream manufacturing capacity. Table 6.1 below presents an illustrative selection of short-term global PV supply and demand projections made by some financial analysis and consulting firms during the last twelve months.

Table 6.1 Global Annual PV Market Projections for 2010

	Demand, MW	Supply, MW
Goldman Sachs, 2008	7,000	13,000
Simons and Company, 2008	7,500	13,500
JP Morgan, 2008	7,500	8,000
Deutsche, 2008	-	15,000
Photon, 2007	20,000 (by 2011)	

Data sources: Photon, 2007; DOE, 2008a; Luschetsky, 2008

As seen in Table 6.1, there is a wide range of variation in both supply and demand projections. The reasons for the divergence in supply projections are different assumptions about

polysilicon supply, thin-film production, manufacturing capacity, whereas the divergence in demand projections results from different assumptions about policy stability and about demand elasticity (Luschetsky, 2008). Most of these projections estimate global PV market in 2010 to fall between 7,000 MW to 15,000 MW. Goldman Sachs projects that demand will reach 7,000 MW in 2010, whereas PHOTON, the most optimistic, projects demand will exceed 20,000 MW in 2010. PHOTON forecasts that both supply and demand for PV will remain strong for the future and financial markets will continue to provide capital to the solar sector leading to rapid expansion. It is expected that the growth of the solar sector is likely to continue at a rapid pace with high profitability beyond 2010 (Rogol, 2008).

In terms of annual demand, most short-term projections envision that Europe will continue to dominate the global market. Table 6.2 below shows a snapshot of global demand in 2010. Europe and North America will represent well over 75% of projected installations for that year, with Asia and the rest of the world accounting for only one-quarter of near term market development (Bradford, 2008). According to EPIA's (2007) projection, Europe, the United States and Japan together account for over 75% of new PV installations in 2010.

Table 6.2 Projection of Global Demand for PV in 2010

Bradford, 2008	**Europe**	**US/Canada**	**Asia**	**Rest of the World**	**Total**
	50.08%	26.32%	20.21%	3.39%	100.00%
EPIA, 2007	**Europe**	**US**	**Japan**	**Rest of the World**	**Total**
	46.00%	11.00%	22.00%	21.00%	100.00%

6.1.2 Long-term Projections

It is difficult to project how supply and demand will interact in the mid- to long-term. As a result, long-term projections tend to focus less intensively on PV supply and demand interaction, and more on the convergence of PV experience curves (Poponi, 2003; Wene, 2000) with retail electricity rates, and product diffusion curves for PV under grid parity scenarios. In other words, long-term forecasts tend to focus on how fast PV could reasonably grow when PV generation becomes cheaper than grid electricity. It is estimated that with adequate policies in the transition phase, PV could represent 25% of global electricity consumption in 2040 (EPIA, 2007).

As with short-term forecasts, long-term forecast projections also differ. A recent study jointly prepared by Greenpeace International and the European Renewable Energy Council (Teske et al., 2007), for example, projects that installed global PV capacity would expand to 1,330 GW by 2040 and 2,033 GW by 2050. IEA/OECD ACT scenarios (2008) are designed to bring global CO_2 emissions back to current levels by 2050; the BLUE scenarios target a 50% reduction in CO_2 emissions by 2050. To satisfy these conditions, PV capacity is expected to fall between 1,150 MW and 600 MW (for the BLUE and ACT scenarios, respectively).

According to the ACT scenario, PV is expected to be competitive with retail electricity in 2035 and reach full maturity with regard to thin-film technology in 2050 when third-generation technologies will emerge. According to its BLUE scenarios, PV will be competitive with retail electricity by 2020-2030 and 50% market share will belong to third-generation devices by 2050.

An EPIA/Greenpeace (2008) advanced scenario is based on the assumption that continuing and additional market support mechanisms will lead to a dynamic expansion of worldwide PV installed capacity. Even the study's moderate scenario envisages substantial growth for PV despite a lower level of political commitment. This study projects very rapid growth with the PV market reaching 2,000 GW of installed capacity by 2030. IEA's alternative policy scenario (2006b) analyze how the global energy market could evolve if countries were to adopt current policies related to energy-security and energy-related CO_2 emissions and forecasts to a lower growth rate less than 800 GW in 2040. Figure 6.1 summaries predictions of PV capacity by various sources. Thus, projections of long-term market opportunities for PV remain varied and are very sensitive to assumed policy conditions.

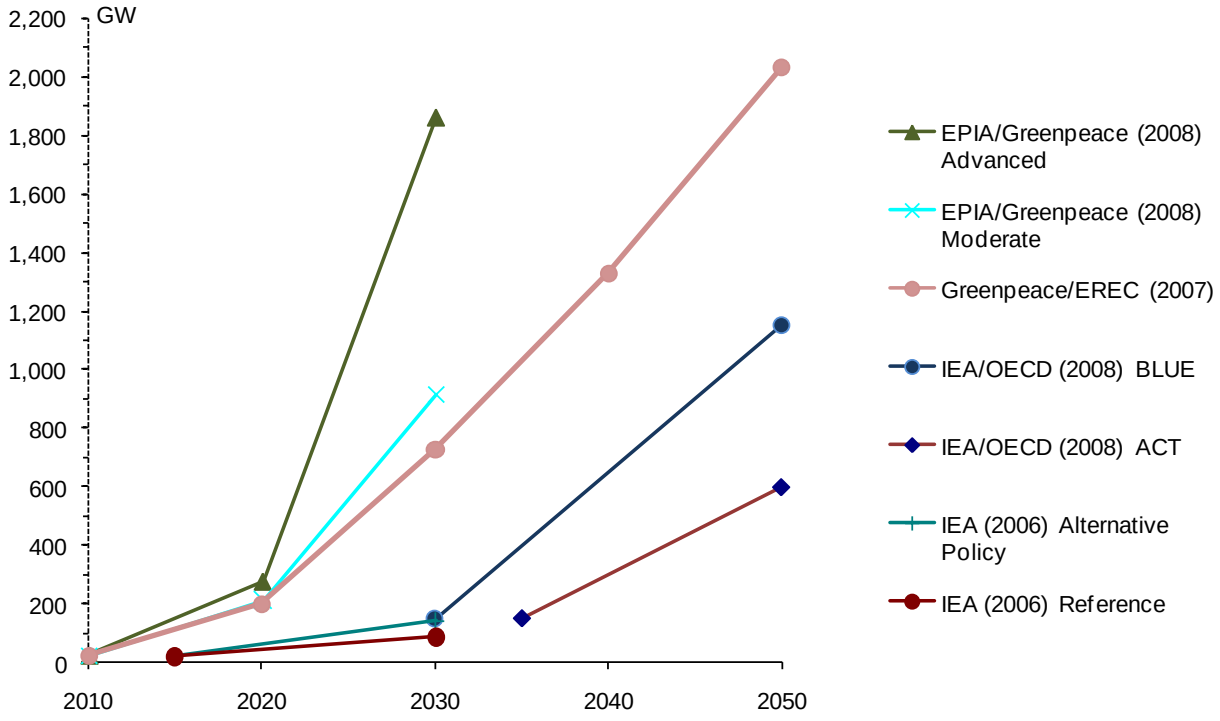

Figure 6.1 Global Installed PV Capacity Projections
Data Sources: IEA/OECD, 2008; EPIA/Greenpeace, 2008; EPIA, 2007; IEA, 2006b

These results clearly show that, starting from a very small base, installed capacity of PV electricity can grow rapidly to make a significant contribution to future energy supply and climate change mitigation.

6.2 Solar Thermal Heating and Cooling

Renewable heating and cooling has been referred to as a "neglected giant" (Schaefer, 2006) because of its global technical potential and because of its ability to be cost-effectively deployed to reduce greenhouse gas emissions. Together, heating and cooling demand comprise approximately 40%-50% of global energy demand (Langniss et al., 2007). Solar thermal technology could potentially supply a significant share of these loads in the future. The global solar thermal market is currently dominated by water heating applications (Weiss et al., 2007). Unlike CSP, which feeds electricity into a centralized grid, solar water heating markets are inherently limited—not by roof space or land area—but by onsite heating loads. In the United States, for example, a recent National Renewable Energy Laboratory study recently estimated

that the total US technical potential for solar water heating was only 1 quadrillion BTUs of energy, or approximately 1% of national primary energy consumption (Denholm et al., 2007). By contrast, a recent comparison between PV and oil in the United States concluded that PV could surpass domestic oil production in terms of contributions to US primary energy in the middle of this century (Byrne et al., 2004).

Although the technical potential of solar water heating specifically may be limited, the technical potential of solar heating and cooling more broadly is far larger. The markets for solar process heating (Weiss et al., 2006), solar space heating (Weiss et al., 2004), and solar cooling (Dienst et al., 2007) could expand dramatically. According to the IEA's World Energy Outlook (2006), solar thermal energy could expand by tenfold to approximately 60 Mtoe by 2030, with China continuing to lead the global market in terms of installed solar thermal capacity. A more optimistic scenario from the European Renewable Energy Council (2004) projects that solar thermal will grow to over 60 Mtoe *by 2020*, and that the market will continue to expand to 244 Mtoe by 2030 and to 480 Mtoe, or approximately 4% of total global energy demand, by 2040.

6.3 Concentrating Solar Power (CSP)

As discussed in previous sections of this report, the market for CSP was comparatively limited until recently, with existing projects largely limited to California and to Spain. Development is now starting to accelerate, after a lengthy period of stagnation, and additional projects are either under construction, or have been built in several US states, in Spain, in Morocco, and in Algeria (Geyer, 2008; Wiser & Barbose, 2008). By the end of 2007, the world cumulative installed capacity for CSP was 457 MW (Earth Policy Institute, 2008). The US is by far the leading country in the development of CSP technology. The state of California alone installed 354 MW and 64 MW parabolic though plants in Nevada started production in 2007. In Spain, the second largest developers at large margin, completed PS10 soar tower (11MW) near Sevilla in March 2007. The year of 2008 saw a boom of CSP projects under construction. These countries include the US, Spain, Israel, Australia, Jordan, Portugal, Morocco, Egypt, China, United Arab Emirates, and other countries. As of June 2008 about 3,400 MW of CSP was under construction in US, Spain and Israel, and due for completion between 2011 and 2013 (Earth Policy Institute, 2008). Table 6.3 shows world CSP installations with capacity of over 10MW.

Table 6.3 World Concentrating Solar Thermal Power Plants Greater than 10 Megawatts in Operation as of June 2008

Location	Company	Project	Power Capacity (MW)	Year of Initial Operation
California, USA	Luz International Ltd.	SEGS I	14	1985
California, USA	Luz International Ltd.	SEGS II	30	1986
California, USA	Luz International Ltd.	SEGS III	30	1987
California, USA	Luz International Ltd.	SEGS IV	30	1988
California, USA	Luz International Ltd.	SEGS V	30	1989
California, USA	Luz International Ltd.	SEGS VI	30	1989
California, USA	Luz International Ltd.	SEGS VII	30	1990
California, USA	Luz International Ltd.	SEGS VIII	80	1991
California, USA	Luz International Ltd.	SEGS IX	80	2007
Andalucia, Spain	Abengoa Solar	PS10	11	2007
Nevada, USA	Acciona Energy	Solar One	64	2007

Source: Earth Policy Institute, 2008

Many projections for solar thermal electric development envision significant growth. Greenpeace, the European Solar Thermal Power Industry (ESTPI), and the IEA's SolarPaces Program conducted one of the studies jointly. This research demonstrated that there are no technical, economic or resource barriers to supplying 5% of the world's total electricity from solar thermal power by 2040 (Greenpeace et al., 2005). According to the study, global CSP capacity would expand by one hundred fold to 36,854MW by 2025 and then grow to 600,000MW by 2040 (Figure 6.2).

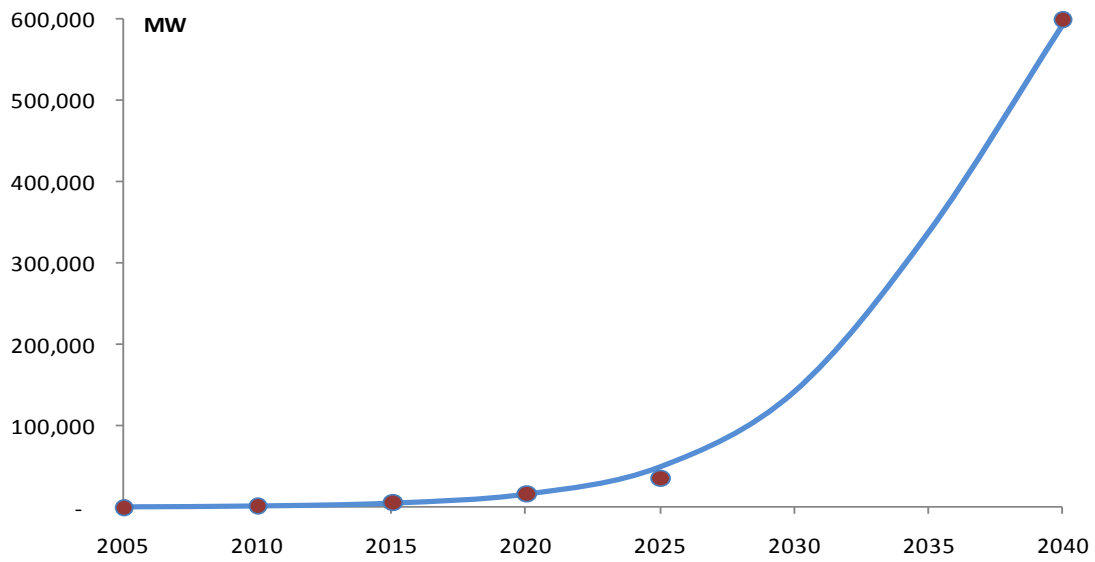

Figure 6.2 CSP Scenario by Greenpeace-ESTIA 2005-2040
Data Source: Greenpeace et al., 2005

The European Renewable Energy Council (EREC) and Greenpeace International published a world energy scenario, entitled *Energy Revolution: A Sustainable World Energy Outlook*, in 2007. This scenario is seeks to provide a practical blueprint for sustainable and affordable global energy supply scenario on the basis of steady worldwide economic development (Teske et al., 2007). The report expects that the market share of CSP will see significant increases after 2020 as generation cost is expected to be around 5-8 cents/kWh (Teske et al., 2007). Global CSP generation capacity is projected to be 29 GW, 137 GW and 405 GW in 2020, 2030 and 2050, respectively, which would mean that CSP might account for about 6% of the total global electricity generation capacity in 2050.

IEA (2008) concluded that CSP would not be commercially competitive in IEA's Baseline Scenario, but in the ACT and BLUE scenarios, CSP would be competitive by 2030. As shown in Table 6.4, total capacity of CSP installed by 2050 is projected to be 380 GW and 630 GW in the ACT and BLUE scenarios, respectively. CSP is expected to provide approximately 3% to 5.5% of global electricity production in the ACT and BLUE scenarios, respectively (IEA, 2008).

Table 6.4 Summary of CSP Scenarios by Selected Sources

Energy Technology Perspectives scenarios		2010 (GW)	2020 (GW)	2030 (GW)	2040 (GW)	2050 (GW)
Greenpeace, ESTIA & IEA, 2005		2.2	16.9	N/A	600	N/A
Teske et al., 2007		2.4	29.2	137.8	N/A	404.8
IEA, 2008	Baseline (Business-As-Usual)	N/A	N/A	<10	N/A	Not commercially competitive
	ACT	N/A	N/A	250	N/A	380
	BLUE	N/A	N/A	250	N/A	630

6.4 Share of the Future Global Energy Portfolio

The projections for PV, solar heating and cooling, and CSP markets indicate that growth across all three market segments will continue to be steady and rapid for the next several decades. The statistics discussed in the sections above can be made more meaningful, however, if they are situated in the context of global final energy demand. There are several projections showing how global energy portfolio will shift due to the increased role of solar energy. This section briefly reviews several such projections.

The European Renewable Energy Council (2004) projects global renewable energy growth through 2040. According to this EREC scenario (2004), renewable energy is expected to supply nearly 50% of total global energy consumption by 2040. Solar energy, is projected to meet approximately 11% of total final energy consumption, with PV supplying 6%, solar heating and cooling supplying 4% and CSP supplying 1% of the total. According to the study by the German Advisory Council on Global Change (WBGU, 2004), renewable resources supply a comparable amount of the world's final energy by 2040 as projected by EREC (2004).

Shell Energy Scenario to 2050 (Shell, 2008) has developed two scenarios that describe alternative ways to forecast future energy mix. The Scramble scenario reflects a focus on national energy security, which builds on an assumption that policymakers pay little attention to more efficient energy use until supply becomes tight. Demand-side policy and environmental policy are not seriously taken into account until supply limitation becomes acute or global climate change events stimulate response (Shell, 2008). In this context, development of coal is favored as a largely abundant and low-cost energy option (Shell, 2008).

On the other hand, Blueprints scenario assumes that growing local actions begin to address the challenges of economic development, energy security and environmental pollution. It expects that a price will be applied emissions from conventional fuels thereby giving a huge stimulus to the development of clean energy technologies. By 2050, the Blueprints scenario projects that non-fossil fuel generation accounts for over 60% (~1/3rd of which comes from solar energy) of global electricity consumption (Shell, 2008).

By 2050 it is noticeable that solar energy is projected to supply between 9.6% and 10.7% of the total primary energy, respectively, in the Blueprints and Scramble scenarios (See Table 6.5).

Table 6.5 Shell Energy Scenario by 2050 (EJ/Year)

Fuel Type	***2010***		***2020***		***2030***		***2040***		***2050***	
	S[1]	**B[2]**	**S**	**B**	**S**	**B**	**S**	**B**	**S**	**B**
Oil	176	177	186	191	179	192	160	187	141	**157**
Gas	110	109	133	139	134	143	124	135	108	**122**
Coal	144	137	199	172	210	186	246	202	263	**208**
Nuclear	31	30	34	30	36	34	38	41	43	**50**
Biomass	48	50	59	52	92	59	106	54	131	**57**
Solar	0	1	2	7	26	22	62	42	94	**74**
Wind	2	1	9	9	18	17	27	28	36	**39**
Other Renewables	19	18	28	29	38	40	51	50	65	**62**
Total	**531**	**524**	**650**	**628**	**734**	**692**	**815**	**738**	**880**	**769**

Note: [1] Scramble [2] Blueprint
Data Source: Shell, 2008

Table 6.6 summarizes the projections of solar energy in global energy mix by 2040. The scenarios developed by EREC (2004) and WBGU (2003) project 10.3% -11% *by 2040*. Shell (2008) offers a more conservative projection of 5.7% - 7.6% by 2040, and 9.6% - 10.7% *for 2050*.

Table 6.6 Projections of Global Solar Energy Production by 2040

Sources	*Total Energy (Mtoe)*	*PV*	*CSP*	*Solar Thermal*	*Solar Total*
Shell Energy Scenario (Scramble)	19,451.1	N/A	N/A	N/A	**7.6%**
Shell Energy Scenario (Blueprint)	17,613.4	N/A	N/A	N/A	**5.7%**
European Renewable Energy Council	13,310	6.0%	1.0%	4.0%	**11.0%**
WBGU	24,415.3	6.2%		4.1%	**10.3%**

Data Sources: Shell, 2008; EREC, 2004; WGBU, 2003.

6.5 Future Integration of Renewable Energy and Transportation

There are several possible approaches to integrate PV into the transportation sector. One groundbreaking new technology is hydrogen as a transportation fuel that could receive a huge boost from solar power (Waegel et al. 2006). Hydrogen fuel cell vehicles are particularly interesting because they represent best features of vehicles: zero emissions, high efficiency, quite, long life, fast refueling time, and so forth. There has been a great deal of discussion about future hydrogen transportation infrastructure, fuel cell cars, and the ability of renewable resources, such as solar power to create hydrogen fuel (Middleton et al., 2003). However, photovoltaic hydrogen generation, as it functions today, is still much too expensive to be a realistic alternative for the short or medium term (Byrne et al. 2006b).

The price of hydrogen derived using wind power (by electrolysis of water and steam) would now cost less than $3 for an amount equivalent in energy to that in a gallon of gasoline ("equivalent"). Similarly, price of hydrogen "equivalent" derived using solar power is likely to reduce from $8 to $5 even as the efficiency of PV increases to 20% (Bockris and Veziroglu, 2007). Solar hydrogen generation will see a major breakthrough when a cheap production of solar energy is realized (Tributsch, 2008).

It has also to be considered that photovoltaic hydrogen generation will not serve electricity demand but instead would help satisfy energy demand for transportation and industrial use. Photovoltaic hydrogen generation technology offers a huge promise for a sustainable energy economy but massive research in a few innovative directions will be required to make it become

real in a not too distant future (Tributsch, 2008). Felder and Meier (2008) conducted a well-to-wheel analysis for future production, transport and usage of solar hydrogen in passenger cars and concluded that despite high infrastructure demands and associated environmental impacts, solar energy stored in hydrogen and used in fuel cell cars is a promising option for a sustainable future transportation systems. On the other hand, hydrogen has been criticized for its serious drawbacks as an energy carrier and as a transportation fuel (Romm, 2004). According to Waegel et al. (2006) while hydrogen may be a companion to the future solar economy, it will not anchor the transition.

Whether or not a "hydrogen future," is realized solar energy has an important role to play in the emerging electric transportation infrastructure. Recent studies have argued that electric vehicles powered by intermittent renewable resources are the most appropriate solution for simultaneously addressing air emissions and energy security (Jacobson, 2008). Solar powered electric vehicles could also be an important component of vehicle-to-grid strategies (Letendre et al., 2006). PV panels convert solar energy into electric energy, which is then transferred to an electric vehicle when it is plugged in. However, this option also remains uneconomical at this time and several technical problems and infrastructure issues must be addressed for such an alternative affect the transportation market.

7. CONCLUSION

7.1 Key Findings

This review of the status of solar energy technologies, their markets and policies has revealed the following broad picture:

First, solar energy constitutes the most abundant renewable energy resource available. Effective solar irradiance reaching the earth's surface ranges from about 0.06kW/m^2 at the highest latitudes to 0.25kW/m^2 at the low latitudes. In most regions of the world the technically available potential is far in excess of the current total primary energy supply. As such solar energy technologies are a key tool to lower worldwide carbon emissions.

Second, a wide range of technologies are available today to harness the sun's energy. These solar energy technologies can be characterized broadly into passive and active technologies. The passive technologies, not discussed in this review, include age-old applications such passive heating and it's modern variants, as well as passive cooling, day-lighting and agricultural applications. The active technologies, which formed the content of this review, include photovoltaic and solar thermal, where solar thermal can be further classified into solar-thermal electric and non-electric applications. As noted in this report, it is also important to remember that these categories are spread along a continuum of size classes.

Third, the market for technologies to harness solar energy has seen dramatic expansion over the past decade – in particular the expansion of the market for grid-connected PV systems and solar hot water systems have been remarkable. The world market for PV grew from over 1,700 MW of annual installations in 2006 to over 2,800 MW of annual installations in 2007. Presently, the cumulative installed PV capacity of the world is estimated at about 22 GW. The leading PV markets that have fueled this growth include Germany, Spain, Japan and the United States. Outside this group, countries such as India, China, South Korea, Thailand, Bangladesh and Philippines, among others, are emerging as important markets for PV.

Four, there are broadly three types of PV applications, viz. Centralized utility scale PV installations; grid-connected distributed PV installations and off-grid installations. The primary driver for the growth in the installed volume of the PV market has been, for over a decade, the grid-connected distributed segment. More recently, in the past five years, the centralized utility scale PV applications have also emerged as a strong growth area. Off-grid applications, responsible for the early growth of the PV industry, now dominate the application of PV in developing country markets. While the number of Solar Home Systems installed in developing countries are significant, they are of comparatively small capacities (40-100 W) and as such, were not perceived as an important market even when the human welfare implications are very significant.

Five, the market for solar thermal technologies is growing rapidly. The larger solar thermal-electric applications (e.g. CSP) that first emerged in the early 1980s and waned under the Regan administration, are now gathering momentum again. There are a number of new projects that are either online or in preparatory stages.

Six, the dominant solar thermal market however is that of solar hot water applications. In countries from Europe, especially the Mediterranean region, to China and United States, this application has grown rapidly. Notably, solar hot water systems enjoy the important benefit of being cost competitive in most situations with conventional water heating applications and as such, have expanded rapidly. More comprehensive policy approaches can benefit this market.

Seven, while the cost of energy from many solar energy technologies remains high compared to conventional energy technologies, the cost trend of solar energy technologies demonstrates rapid declines in the recent past and the potential for significant declines in the near future. For instance the cost of PV declined over 80% during the last two decades (1985-2005).

Eight, the experience curve of different PV and CSP show high learning rates. Additionally, if the negative externalities of conventional generation technologies and positive externalities of solar technologies are incorporated comprehensively, the emergence of cost competitiveness of solar technologies can be further accelerated.

Nine, the rapid growth and spread of solar technologies are however, stunted by various technical barriers like the efficiency of solar cell and performance of BOS; economic barriers such as high upfront cost and lack of finance mechanisms; and institutional barriers of inadequate infrastructure and shortage of trained manpower.

Ten, a number of highly effective policy instruments have come together in some of the most successful markets for solar energy. In the industrialized countries, the PV market has been driven by the feed-in-tariff approach in Germany, while leading solar states in the U.S. have assembled a policy suite that combines federal and state incentives and rebates along with regulatory and market mechanisms such as renewable portfolio standards, net metering and renewable energy certificates. While their continued operation is imperative for the future growth of these markets, it is also becoming apparent that innovative ways to reduce the fiscal burden of the various policy incentives are needed. As such, there is also growing interest in a greater role for market mechanisms to complement existing policy incentives.

Eleven, the sensitivity to policy costs is significant in developing countries. As such, the policy approach broadly, is to "rationalize development and deployment strategy" of renewable energy technologies. Thus, while renewable energy sources such as wind, biogas, and solar hot water are seen as candidates for immediate attention, the policy incentives for grid-connected PV and solar thermal electric have tended to be more cautious and emphasize pilot projects, with the plan to accelerate when the costs decline further.

Twelve, small scale PV applications such as Solar Home Systems, are recognized as serving an important market in developing countries; namely electrification of rural and peri-urban areas. This rapidly growing market supported by innovative financing mechanisms, is important and offers the potential for improvements in human welfare not reflected in the cumulative capacity of the SHS installations as a market segment.

Thirteen, the potential of Clean Development Mechanism (CDM) to complement the available support for solar energy technologies is discussed. It was found that the low cost of carbon emission reduction (CER) limit the ability of CDM to support solar energy technologies.

Thus, large investment tends to concentrate on facilities with larger volume of CER and less capital-intensive investment, such as HFC destruction projects.

Fourteen, in order to make CDM work for solar energy technologies, some policy incentives need to be considered. As well, participants including host government, investors and local NGOs need to make full use of new opportunities recently introduced in CDM framework. They may include: 1) providing a premium for solar-based CER as a way to put solar technologies on a more level of playing field with other low-cost CDM projects; 2) using 'bundling' diffused small-scale solar CDM projects in to a single large portfolio project; 3) using 'programmatic CDM' by local government or private initiative; 4) discussing the role of domestic policy instruments; 5) building a technical and managerial capacity at local and regional level; and 6) a more streamlined procedure for approval of small-scale solar projects.

Fifteen, the future projections for solar energy technologies are broadly optimistic. According to the various projections considered here, the market for solar energy technology is expected to grow significantly in the long-term as well as short-term. Further, despite its technical and economic limitations at present, it is expected that solar energy will play an important role in the transportation sector in the future.

7.2 Research Gaps

1) The research literature revealed connection between energy policies and rapid growth of solar energy applications. However, there is no rigorous quantitative analysis connecting solar market growth with supporting policies.

2) The literature presents information on the content of supporting policies for solar energy technologies. However, key reasons for the supporting policies, such as energy security, climate change mitigation, local employment, electrification for rural communities in the developing countries need to be further evaluated. Specifically the sustainability of these supporting goals over the long-term, and their impact on the shaping of these policies need to be explored.

3) The surveyed literature clearly recognizes the large potential of solar resources across the world. The recent growth of a number of solar energy technologies (PV, CSP) is largely driven by grid-connected applications in industrialized countries where a significant body of policies supporting these applications has emerged at national and local levels. Developing countries present a different reality with a substantial demand for rural energy services that are decentralized. However, this vast potential market for off-grid applications of solar energy remains largely untapped given the limited evolution of supporting policies and institutions. The surveyed literature lacks a comprehensive analysis of policy tools, which can be applied in this context.

4) Overall, in both developed and developing countries, the surveyed literature can be improved by exploring coordinated policy approaches for further development of solar energy markets. For example, a number of policies were reviewed in the literature; however, each policy tool is treated individually without evaluating their collective impact as a policy suite.

5) Explored literature presents wide range of future projections on diffusion of solar technologies, all of which demonstrate significant increase in solar applications. Yet, an assessment of the impact of the large scale adoption of solar energy resources on existing energy infrastructure, conventional energy policies, and current market organization is still limited.

6) Finally, a major gap in the literature is an analysis of the combined requirements for lower cost solar energy options and the policy tools to spur rapid diffusion of these technologies in order to meet aggressive carbon reduction targets.

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