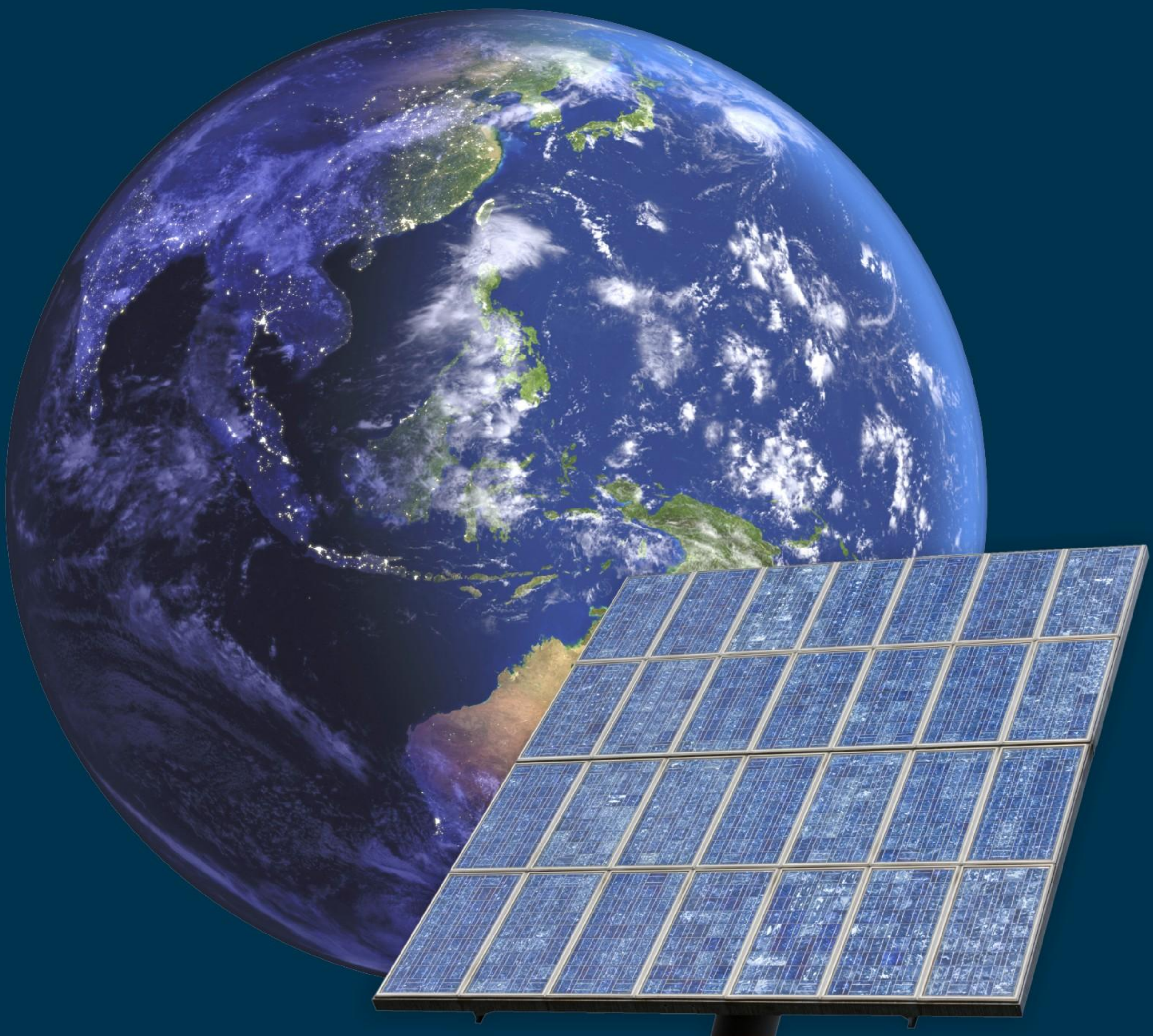
Technology Action Plan

SOLAR ENERGY



MAJOR ECONOMIES FORUM
ON ENERGY AND CLIMATE

DECEMBER 2009

Technology Action Plan: Solar Energy

Report to the Major Economies Forum on Energy and Climate

By Germany and Spain
in consultation with MEF Partners

December 2009

PREFACE

The Leaders of the 17 partners[1] of the Major Economies Forum on Energy and Climate (MEF) agreed on 9 July 2009 that moving to a low-carbon economy provides an opportunity to promote continued economic growth and sustainable development as part of a vigorous response to the danger posed by climate change. They identified an urgent need for development and deployment of transformational clean energy technologies, and established the Global Partnership to drive such low-carbon, climate friendly technologies.

Plans were created to stimulate efforts among interested countries to advance actions on technologies, including advanced vehicles; bioenergy; carbon capture, use, and storage; buildings sector energy efficiency; industrial sector energy efficiency; high-efficiency, low-emissions coal; marine energy; smart grids; solar energy; and wind energy. These plans include a menu of opportunities for individual and collective action that may be undertaken voluntarily by interested countries, in accordance with national circumstances. Further actions may be identified in support of these plans in the future.

[1] Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, South Africa, the United Kingdom, and the United States. The authors of *Technology Action Plan: Solar Energy* like to express their gratitude to the experts of the MEF countries and those of the IEA. This plan benefited significantly from their expertise.

OVERVIEW

Solar energy is clean, inexhaustible, sustainable, and secure. Solar technologies, such as photovoltaics (PV), concentrating solar power (CSP), and solar heating, are already deployed in a very broad range of applications, covering electricity generation, heating, and cooling. Further technology development and increased cost-efficiency is expected to make solar energy a mainstream energy source within the next decade.

In addition to helping facilitate the smooth transition toward a low-carbon economy, improvements in solar technologies can also enhance long-term energy security and foster economic growth at the local level. Successful deployment of these technologies can also help to accelerate the market dynamics, innovations, and synergy effects for the overall renewables sector. Costs are expected be further reduced by massive, policy-driven deployment, which allows for increasing market pull, technology progress, and economies of scale. Cooperative efforts between countries (especially between those with and without developed solar industries) can bolster the effects of advanced solar technologies by enabling the industry to take advantage of the huge untapped solar potential in the "sunbelt."[2]

For solar power to fulfill its potential in significantly reducing greenhouse gas (GHG) emissions, a range of barriers must be addressed. Countries are currently employing a range of policies and practices to overcome these barriers with varying degrees of success. These experiences are leading to enhanced approaches and goal setting to assure effective action on climate change.

HIGHLIGHTS OF THE SOLAR ENERGY TECHNOLOGY ACTION PLAN

1. GHG Emissions Production and Mitigation Potential

- **Fossil fuel-based power generation accounts for 41% of global energy-related CO_2 emissions**, and its emissions are expected to increase by almost 50% from now to 2030,[3] considering business-as-usual policies. Solar energy will help to reduce GHG emissions in the power sector.
- **Solar deployment is required to cost-effectively meet abatement targets.** The IEA estimates in its BLUE Map (2008) scenario and PV Roadmap (2009) that *solar electricity* could contribute 7,000 terawatt-hours (TWh) of electricity generation per year in 2050, corresponding to a 16.5% share of global electricity generation. Together with *solar heating*, about 4.5 gigatonnes (Gt) of CO_2 emission reductions could be achieved in 2050. The solar industry expects figures that are nearly twice as high. In 2020, solar energy could contribute approximately about 220 megatonnes (Mt) of the additional CO_2 emission reductions needed to remain on track toward the 2°C target, according to the IEA BLUE scenario.

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2 A large, available land area close to the equator (10°–40° North/South), including Africa and the Middle East, that coincides with high average radiation (DLR 2009).

3 In an International Energy Agency (IEA) reference case under business-as-usual policies.

2. Development and Deployment: Barriers and Best Practice Policies

- **Barriers** to the development and deployment of solar technologies include economic, technological, grid and system integration, and attitudinal hurdles.
- **Best practice policies** to foster the growth of solar energy aim to increase demand; improve consumer confidence and public awareness; enable grid access and system integration; provide sufficient and affordable financing; raise public acceptance and promote sustainable production; improve planning and reduce administrative burdens; ensure legal certainty; support technology research, development, and demonstration; and expand technology cooperation.

3. Actions to Accelerate Development and Deployment

- **Supporting innovation:**
  - Follow a combined approach of RD&D and consequent deployment policy to benefit from cost reductions due to technology progress along the learning curve and economies of scale effects, as well as from spillover effects between research and mass-scale testing.
  - Pursue a balanced set of instruments that ensure support of new, innovative concepts and all promising renewables technologies for a broad technology basket for future energy security.
  - Increase and coordinate public sector investments in RD&D in line with the L'Aquila declaration, while recognizing the importance of private investment, public-private partnerships, and international cooperation, including regional innovation centers.
- **Accelerating deployment:**
  - Set ambitious concerted targets and establish reliable support schemes to provide long-term investment security for solar energy; formulate these targets as minimum targets to achieve sustainable market development without "stop-and-go" cycles.
  - Internalize external costs for all energy technologies in order to enhance demand-pull technology progress.
  - Ensure sufficient grid capacity through extending and upgrading the grid and/or optimized grid operation, and through facilitating technologies and concepts that enable system and market integration of high shares of solar electricity.
  - Promote strategic dialogue with investors to access untapped financing sources and establish public-private partnerships to accelerate investment in developing and emerging countries.
  - Follow a holistic approach in planning activities to integrate renewable energy into the overall system and balance rival interests.
- **Facilitating information sharing:**
  - Support transparent consumer information on the effect that their green power purchase agreements have on the deployment of additional renewables installations.
  - Develop jointly a global solar atlas with all relevant information to attract cross border investments.
  - Make information accessible and facilitate know-how transfer by training, workshops, and Internet libraries/databases.
  - Support international institutions, such as IRENA, that focus on capacity building in cooperation with existing institutions (e.g., REEEP).

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1. SOLAR ENERGY: GHG EMISSIONS PRODUCTION AND MITIGATION POTENTIAL

Solar energy offers a clean, renewable energy source that holds great promise for helping to reduce the greenhouse gases emitted during power generation. The power sector's current reliance on fossil fuels and rapid projected growth raise grave concern over the impact of the sector's emissions on climate and the environment. The extent to which solar photovoltaics (PV), concentrating solar power (CSP), and solar heating can help to mitigate these harmful emissions will be determined by the degree to which this rapidly emerging energy technology can effectively displace the use of coal and other fossil fuels in the power sector or, in the case of solar heating, replace the direct use of fossil fuels in homes (e.g., for heating and hot water) over the next two decades and beyond.

GHG Emissions from the Power Sector

The power sector's current reliance on fossil fuels and rapid projected growth raise grave concern over the impact of sector emissions on climate and the environment. If business continues as usual, the power sector is projected to account for 44% of total global emissions in 2050. Today, power generation accounts for 41% of global energy-related CO_2 emissions, with such emissions projected to increase by almost 50% by 2030 (IEA 2009d).[4] The member countries of the Major Economies Forum (MEF) account for 78.8% of the global CO_2 emissions from fossil fuel combustion (with wide variance among member countries) (IEA 2009b).

Solar energy technologies offer an opportunity to produce clean electricity, heating and cooling because their operation does not need any fuel. Only a small amount of carbon dioxide (CO_2) is generated by producing the technology and enhancing the necessary transmission infrastructure, which would occur with the production and integration of other electricity technologies as well. Research indicates that current solar cell applications offer close to a 90% reduction in air pollution over the generation life cycle compared to fossil fuels (Choi 2008).

Mitigation Potential for the Solar Energy Sector

Market Development: Current Status

The world's installed photovoltaic (PV)[5] capacity has reached nearly 15 GW. For more than a decade, the global PV market has been characterized by a significant average growth rate of 40% per year. From 1999 until 2008, the installed capacity increased more than tenfold. While PV's share in global electricity generation is still small (about 0.1%), the current installed PV capacity can supply about 5 million households with electricity,[6] thereby saving about 10 Mt CO_2 annually. Three

[4] Increase projected in a Reference case under business-as-usual policies.

[5] For further description of the technology, see Appendix A.

[6] Based on the assumption that each household consumes about 3,000 kWh.

leading markets, Germany, Spain, and Japan, account for approximately 75% of the global installed PV capacity, largely because of their ambitious support policies.

Total global capacity of concentrating solar power (CSP)[7] currently stands at about 500 MW. CSP produces enough energy to supply about 500,000 homes with electricity, equal to a 0.01% share of global electricity generation. This saves about 1 Mt CO_2 annually. Due to its ambitious support policies, Spain represents the most dynamic CSP market today. Many projects are also planned in the United States, the Middle East, and Africa. Projects currently under construction will triple global capacity; projects in the planning stages could increase it more than fifteen-fold.

Worldwide solar heating markets have been growing for years, with average, annual growth rates of about 20% in China and Europe, and about 16% worldwide in 2007 (IEA/SHC 2009, Sarasin 2008). In the last decade, the total solar heating capacity has increased nearly fivefold, to about 165 gigawatts thermal (GW_{th}) by the end of 2008. Current solar heating capacity meets about 0.2% of global heat demand, supplying about 6 million households with heat for warm water and space heating (each consuming about 15 megawatts thermal [MW_{th}]), thereby saving about 30 Mt of CO_2 annually. Most of the total capacity is installed in industrialized or emerging countries such as Germany, Japan, China, or Turkey. The market is dominated by systems for solar water heating in single-family homes, while combine space and water heating has only modest market shares in Europe and Japan (IEA/SHC 2009, OECD 2009).

Future growth rates continue to look very promising. The estimated global technical potential for solar energy (i.e., the energy that could be effectively harnessed given current technological progress) is estimated to be up to 40 times today's energy consumption (de Vries et al. 2007). Estimates of the exact technical potential vary considerably due to technological specifications, regional differences, environmental conditions, and other underlying assumptions. Nevertheless, the technical potential of solar energy is higher than that of any other energy technology.[8]

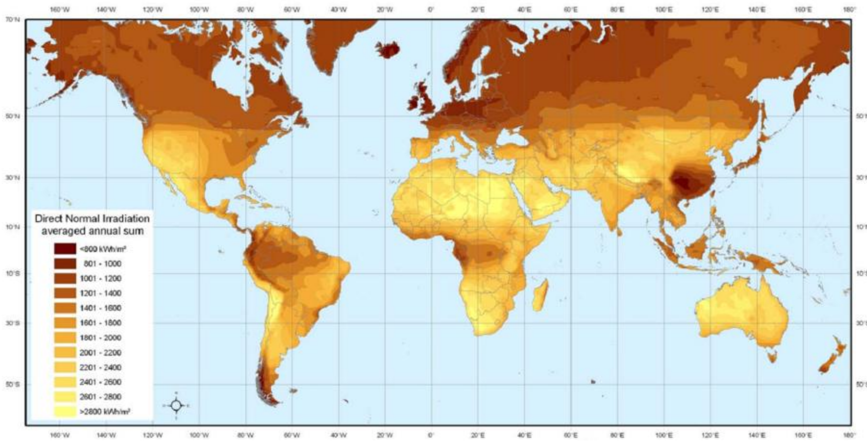
The highest PV potential is estimated to be in Africa and in the Middle East (both in the "sunbelt") where large available land area coincides with high average irradiation (Figure 1). The technical potential for PV in each of these two regions alone exceeds today's global final energy consumption (Figure 2). In all regions of the world, however, considerable PV technical potential can be found.

A similar regional distribution of technical potential can also be found for CSP and solar heating. See Appendix A for further details.

[7] Often referred to as "solar thermal electricity". For further description of the technology, see Appendix A.

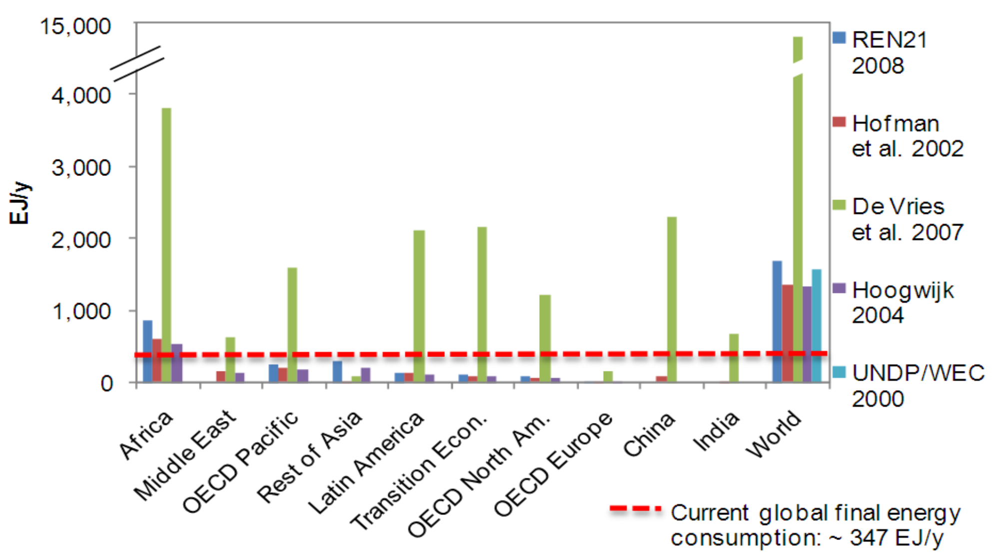
[8] Even according to the most conservative estimates, the technical potential is about 4 times higher than global demand (Hoogwijk 2004).

FIGURE 1. WORLDWIDE ANNUAL DIRECT NORMAL IRRADIATION (BRIGHTER AREAS INDICATE HIGHER IRRADIATION)



Units: kWh/(m²*y)
Source: DLR 2009, which was derived from NASA SSE 6.0 dataset (NASA 2009)

FIGURE 2. PV: REGIONAL DISTRIBUTION OF THE TECHNICAL POTENTIAL OF PV FOR THE YEAR 2050



Note: The estimates of Hofman et al refer to the year 2020.
Source: Hofman et al 2002

Scenarios Estimates: Market Potential and Emissions Reductions[9]

According to the International Energy Agency (IEA) *Energy Technology Perspectives* (ETP) BLUE Map scenario,[10] to achieve emissions stabilization in the most cost-effective manner by 2050, the application of renewable technologies in power generation will need to contribute 46% of global power, accounting for 21% of CO_2 emissions reductions (IEA 2008b).

IEA Carbon Reduction Scenarios

This document refers to several CO_2 emissions reduction scenarios, a couple of which are summarized briefly below.

The International Energy Agency's *Energy Technology Perspectives 2008* (IEA 2008c) set forth several scenarios for energy-related CO_2 emissions through 2050: the Baseline (business as usual) scenario puts the world on track for a global temperature increase of around 6ºC, which is not sustainable, while a set of BLUE scenarios outline how CO_2 emissions could be reduced to 50% *below* 2005 levels by 2050. The BLUE scenarios are consistent with stabilizing CO_2 concentrations at 450 ppm, implying a 2ºC temperature rise. To attain this, emissions would need to be lowered from 41 Gt in 2030 to 26 Gt—a 15 Gt reduction relative to the Baseline scenario.

As shown in Tables 1–3 and Figures 3–5 below, the installed capacity and energy production from PV, CSP, and solar heating technologies are expected to increase significantly, leading to considerable reductions in CO_2 emissions. For instance, according to the BLUE Map, CSP alone is likely to provide 2,500 TWh/year, or 6% of global electricity supply, in 2050 (IEA 2008b). Such growth in CSP would reduce emissions by 1.2 Gt of CO_2 per year in 2050 relative to the Baseline scenario. Industry forecasts even more rapid growth. For example, SolarPACES (2009) published a moderate scenario that projected that CSP will provide 3,600 TWh/year, or 8.6% of global electricity supply, in 2050, reducing CO_2 emissions by 1.7 Gt relative to the Baseline scenario.[11]

Solar heating technology also has very promising prospects for growth. According to the BLUE Map, solar heating is likely to reach 3,000 GW_{th} of capacity in 2050 (IEA 2008b), up from roughly 165 GW_{th} installed today (IEA/SHC 2009). As with CSP, industry expects even more rapid growth. For instance, the industry figures for 2050 exceed the corresponding IEA estimates threefold.[12]

In 2020, solar electricity could contribute nearly 500 terawatt-hours (TWh) per year (IEA 2009g, IEA 2008b) and thereby about 310 megatonnes (Mt) of CO_2 emission reductions—about 180 Mt CO_2 from PV electricity and about 130 Mt CO_2 from CSP electricity.

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[9] Long-term projections for the potential of solar energy technologies to mitigate CO_2 emissions are necessarily tied to defined scenarios. Scenarios are, by their nature, subject to a number of uncertainties and assumptions. Nevertheless, as existing scenarios have been revised, the share of solar energy has tended to increase rather than decrease, reflecting improved support policies.

[10] ETP BLUE Map is based on a balanced set of ambitious policy measures. Accordingly, the estimated figures are higher than in other IEA scenarios such as ETP Baseline, which assume less ambitious policy measures.

[11] The IEA projections are lower than those from industry because the IEA takes into account the competition of renewables with other energy technologies, such as nuclear or CCS. The more optimistic industry scenario, on the other hand, is based on the assumption that renewables will not be hindered by conventional energy technologies, but will instead be given priority to the extent that they can be deployed at appropriate costs.

[12] In the case of solar heating, the industry scenario is more optimistic than the BLUE Map scenario because it assumes that barriers, such as a lack of technology awareness, can be overcome in time.

The CO_2 savings related to *solar electricity* would represent CO_2 reductions of about 220 Mt CO_2 beyond those in the IEA reference scenario.[13] Solar electricity could thereby accomplish the following:

- Provide up to 6% of the 3.8 Gt of additional CO_2 emission reductions needed to meet the IEA 450 ppm scenario for 2020[14]
- Provide up to 4% of the 5 Gt of additional CO_2 equivalent (CO_2e) emission reductions needed to meet the "Stern 44 Gt scenario" for 2020[15]

CO_2 emission savings via solar heating would further increase the total solar contribution.

TABLE 1. PROJECTED PV CAPACITY, ELECTRICITY PRODUCTION, AND CO_2 SAVINGS UNTIL 2050

Year	Capacity Installed (up to)	Electricity Production (≅)	Share in Global Electricity Production (≅)	CO_2 Abatement (≅)[16] (see Figure 3)
2020	210 GW	290 TWh/year	1%	180 Mt
2030	870 GW	1,200 TWh/year	3.7%	710 Mt
2050	3,200 GW	4,500 TWh/year	11%	2,300 Mt (2.3 Gt)

Note: Figures are rounded.
Source: IEA 2009g

[13] In the reference scenario, solar electricity contributes about 150 TWh per year, whereas in the optimistic IEA PV Roadmap and IEA ETP BLUE scenarios described in this report, total solar electricity from PV and CSP would contribute about 500 TWh per year in 2020. The difference of 350 TWh per year corresponds to a CO_2 emission reduction of about 220 Mt per year.

[14] In the IEA 450 ppm scenario, to be on track in 2020 to comply with the 2°C target, global energy-related CO_2 emissions should be around 30.7 Gt instead of the estimated 34.5 Gt in the IEA reference scenario (IEA 2009k). Optimistic scenarios put the estimated additional CO_2 savings in 2020 from solar electricity at 220 Mt, representing 6% this 3.8 Gt difference.

[15] Nicholas Stern has provided further input on scenarios, in particular, presenting a scenario (Stern 2009) in which a target of 44 Gt of CO_2e emissions should be achieved by 2020 to keep the world on the trajectory for the 2°C target. Note that the 3.8 Gt under the IEA reference scenario corresponds to energy-related CO_2 emissions, while the 5 Gt under the "Stern 44 Gt scenario" relates to all CO_2e emissions.

[16] Estimates are based on TWh projections in IEA ETP Blue and Industry scenarios. CO_2 abatement is calculated as energy-related CO_2 savings relative to the mix of conventional power generation in the ETP Baseline scenario. Figures are based on IEA data on the global average of energy-related CO_2 emissions in 2020, 2030 and 2050 (IEA 2009d and IEA 2008a). For 2020, on average globally, one generated MWh of solar electricity saves about 600 kg of CO_2 (dividing the current CO_2 emissions resulting from the estimated conventional power generation [=11,896 Mt] by the generated electricity from the estimated conventional power mix [coal, oil, gas, nuclear and hydropower =19,256 TWh, IEA 2009d]). Until 2050, conventional power plants will become more efficient, and the mix of conventional power generation will change. As a result, one generated MWh of solar electricity will, on average globally, save about 500 kg of CO_2 by 2050 (IEA 2009d and IEA 2008c). Please note that the regional mix of power generation may deviate from these average values and may consequently lead to lower or higher regional CO_2 savings.

TABLE 2. PROJECTED CSP CAPACITY, ELECTRICITY PRODUCTION, AND CO_2 SAVINGS UNTIL 2050

Year	Capacity Installed (GW, up to)		Electricity Production (TWh/year) (≅)		Share in Global Electricity Production (≅)	Associated CO_2 Abatement (≅)[17] (see Figure 4)
	IEA (ETP BLUE)	**Industry** (moderate)	**IEA** (ETP BLUE)	**Industry** (moderate)	**IEA / Industry**	**IEA / Industry**
2020	75	69	210	250	0.8 / 0.9%	130 / 150 Mt
2030	250	230	800	870	2.4 / 2.7%	470 / 510 Mt
2050	630	830	2,500	3,600	6.0 / 8.6%	1,200 Mt (1.2 Gt) / 1,700 Mt (1.7 Gt)

Note: Figures are rounded.
Source: IEA 2008b, SolarPACES 2009

TABLE 3. DEVELOPMENT OF SOLAR HEAT GENERATION IN TWO SCENARIOS, THROUGH 2050

Year	Capacity Installed (GW_{th}, up to)		Heat Production (TWh/year) (≅)		Share in Global Heat Production (≅)	Associated CO_2 Abatement (≅)[18] (see Figure 5)
	IEA (ETP BLUE)	**Industry** (Energy Revolution)	**IEA** (ETP BLUE)	**Industry** (Energy revolution)	**IEA / Industry**	**IEA / Industry**
2020	650	3,000	400	1,800	1.6 / 4%	140 / 650 Mt
2030	1,400	6,000	1,500	4,800	6.1 / 11%	470 / 1,500 Mt
2050	3,000	9,700	3,600	11,600	17 / 26%	930 / 3,000 Mt (3 Gt)

Note: Figures are rounded.
Source: IEA 2008b, EREC/Greenpeace 2008

[17] Calculated as energy-related CO_2 savings relative to the mix of conventional power generation in the ETP Baseline scenario.

[18] Calculated as energy-related CO_2 savings relative to the mix of energy sources used for heat generation in the ETP Baseline scenario. In the Industry scenario, the share of solar heat production refers to total heat production (residential, service sectors and industry) without electricity for heat applications. The CO_2 savings in the Industry scenario can be reached when mainly heat generation from fossil fuels is replaced with solar heating.

FIGURE 3. SCENARIOS OF PV CAPACITY, ELECTRICITY PRODUCTION, AND CO_2 SAVINGS UNTIL 2050

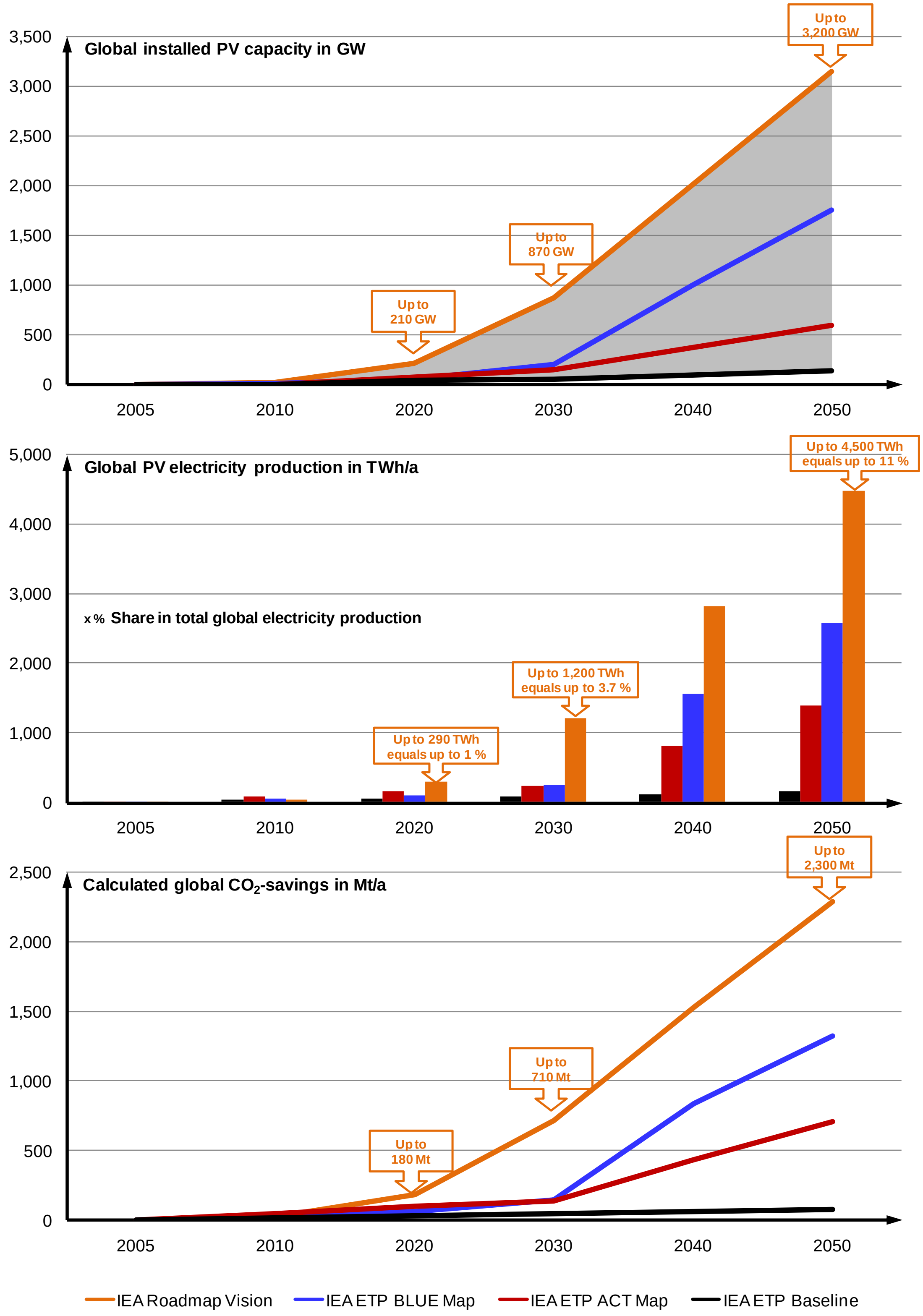


FIGURE 4. SCENARIOS OF CSP CAPACITY, ELECTRICITY PRODUCTION, AND CO_2 SAVINGS UNTIL 2050

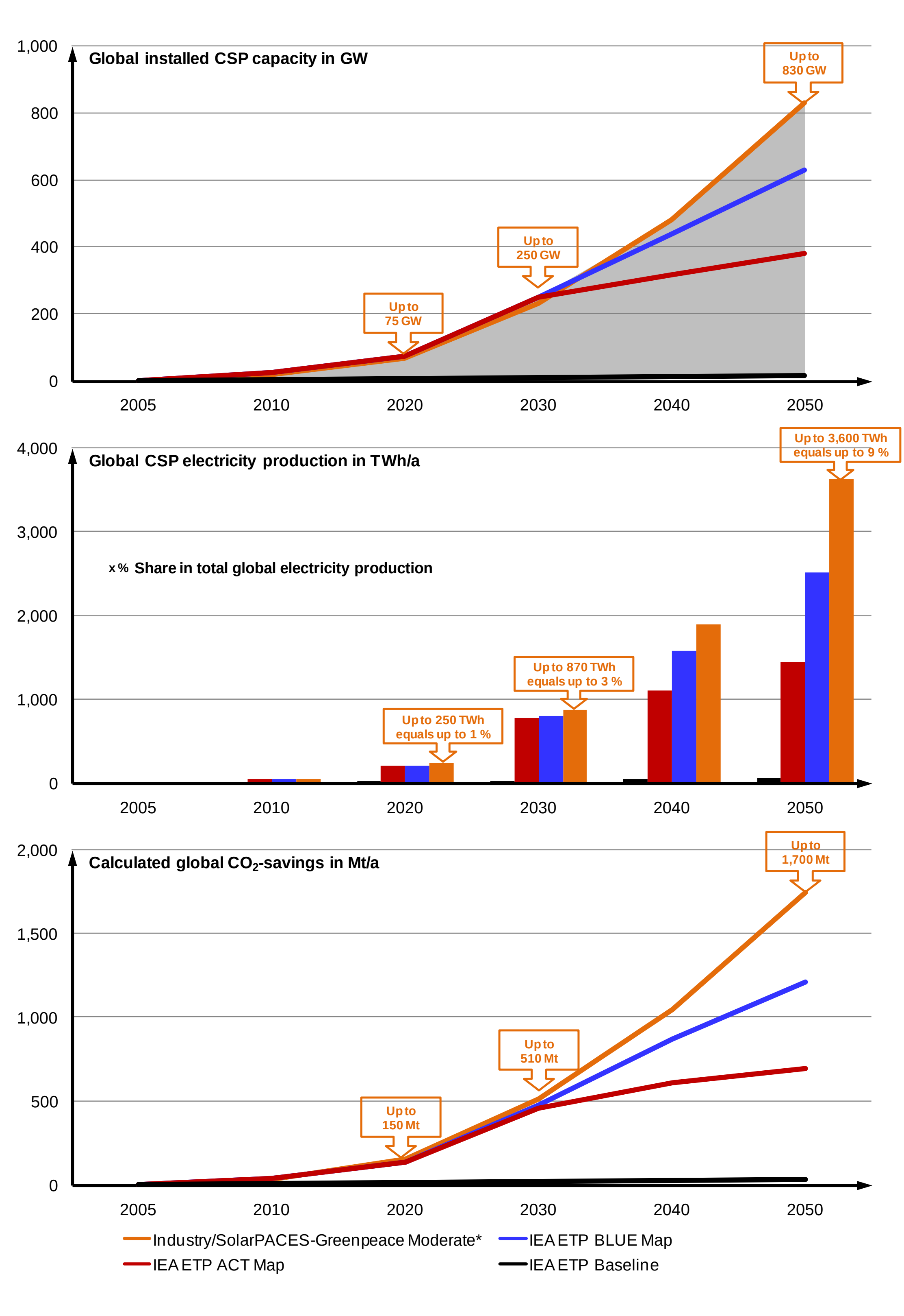
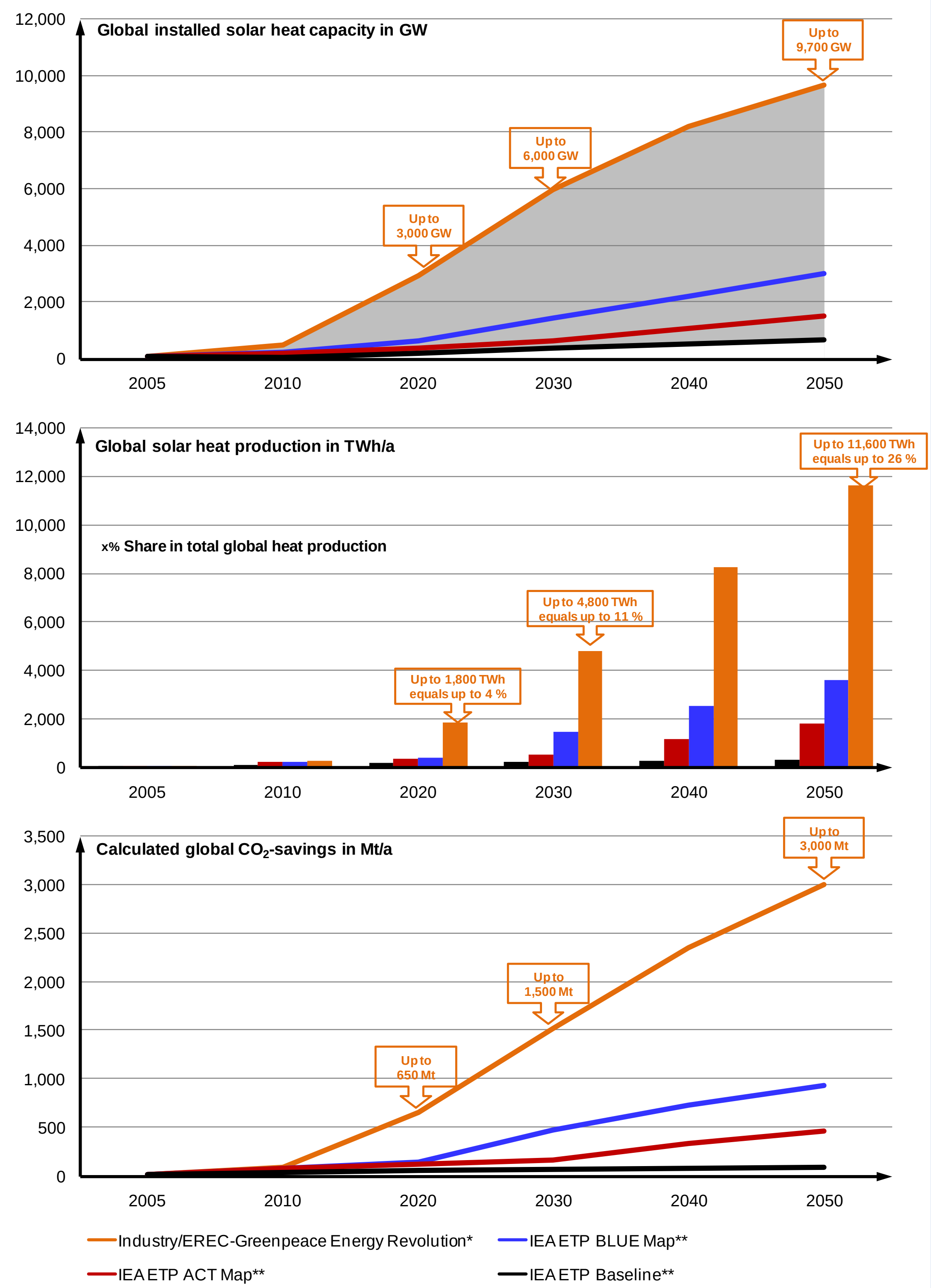


FIGURE 5. DEVELOPMENT OF SOLAR HEAT GENERATION IN VARIOUS SCENARIOS UNTIL 2050



* In the Greenpeace scenarios, the share of solar heat production refers to total heat production (residential, service sectors and industry) without electricity for heat applications.

** In the ETP\ scenarios, the share refers to the building sector only (residential and service sector) without electricity for heat applications.

Achieving the Potential: Solar Technology Development and Deployment

To achieve the enormous solar power potential, a combined approach of successive RD&D and mass-scale deployment policy is needed in order to make use of synergetic effects between development, improved technology efficiency along the learning curves, and economies of scale.

IEA's analysis of the Global Gaps in Clean Energy Research, Development, and Demonstration (GCERD) finds a global annual spending gap of approximately US$900 million to meet 2050 targets (IEA 2009f).

The advantage of PV technology is that it is well proven and, because of its highly modular character, it can be applied in rooftop applications, which provides a promising outlook for consumer self-supply in the future. CSP offers unique opportunities to support the system integration of large shares of renewables because it can deliver dispatchable electricity. Solar heating and cooling is an underestimated technology that can meet increasing heating and cooling demands.

As a result of increasing PV and CSP deployment and R&D efforts of recent years, the cost-efficiency of PV and CSP technology has improved tremendously, making most solar technologies widely available and applicable today. The prospects for future deployment-driven cost reductions are very promising because solar technologies have high technology learning rates

For PV, the IEA estimates future learning rates for investment costs to equal 18% (compared with, for example, a 3% estimated rate for some fossil energy power technologies) (IEA 2008b, IEA 2009g). This means that, for every doubling of global installed PV capacity, investment costs are reduced by 18%.

Based on these promising learning rates, the IEA expects that ambitious deployment policies combined with further R&D efforts can cut current generation costs in half by 2020 for utility-scale PV systems in regions with sufficient solar radiation. In such regions, utility-scale systems could then generate a kilowatt-hour of electricity at around US$0.12.

Once PV electricity generation costs equal private household electricity prices (i.e., for purchases of grid-supplied electricity), demand-pull for roof-top PV applications is likely to increase, because self-supply becomes an option (so called "grid parity"). Such a shift would need to be supported by flexible tariffs, smart meter and storage capacity.

For CSP, future technical learning rates are expected to reach 10% (IEA 2008b). Based on the expected increase in CSP capacity by 2020, power generation costs are estimated to decrease to a range of US$0.10–0.13/kWh (IEA 2009i). According to these projections, more than 200 GW could be installed by 2020, resulting in electricity generation costs of about US$0.11/kWh in regions with less solar radiation and only US$0.08/kWh in regions with high solar radiation. By 2050, further learning could decrease the generation costs for CSP to almost less than US$0.07/kWh.

Thus, for both PV and CSP, substantive deployment policy for solar technology today would likely drive technology competitiveness and demand-pull, leading to less dependence on support schemes and lower support costs tomorrow.

Finally, for solar heating and cooling applications, similar promising figures are expected; see Appendix A for further detail.

When considering costs for support policies, a system-wide approach is needed that takes into account effects for the whole economy as well as the relative, long-term, economic costs of inaction. Support costs are offset by the external costs of conventional power generation, including healthcare and environmental costs and climate change (Stern 2006). Additional benefits that accrue from investments in solar technology include long-term energy security, avoided costs for energy imports, economic growth and new jobs in dynamic renewable energy markets, spillover innovation effects in the whole economy, know-how transfer and investment in developing markets, and improved energy access in remote areas.

Trends and Emerging Technologies

Despite remarkable technology progress, further improvement is needed to drive down costs and increase performance.

Several major thrusts in PV technology development include the following:

- Organic PV cells
- Increased efficiency rates
- Emerging technology and novel concepts (e.g., building on progress in nanotechnology and nanomaterials)

For CSP, major areas of technology development include the following:

- Improved efficiency rates
- Higher operating temperatures (e.g., of heat transfer fluids)
- Further improvements for cost reduction (e.g. new materials, optimized construction process, improved quality control)
- Storage capacity
- Solar fuels (e.g., production of hydrogen for fuel cells) and desalination

Finally, for solar heating, research is ongoing in many areas, including the following:

- Improved materials and components
- Scaled-up solar heating systems (e.g., for schools or hotels)
- Compact heat storage
- Use of CSP technologies for solar heating applications
- Solar cooling

All of these advances will require sustained investment and mass-scale deployment enhanced by a range of supportive policies, incentives, and other mechanisms. Appendix A provides some perspectives and specifications, historical and forward-looking, on solar energy potentials, the development of solar energy technologies, and related technology markets, costs, and economics.

2. Development and Deployment: Barriers and Best Practice Policies

Technological improvements and economies of scale have helped to decrease the cost of generating energy from solar power, and solar technologies have already achieved selective competitiveness in specific circumstances where the cost of carbon is reflected to some extent and the region has a very high solar radiation potential. The rapid progress in solar technologies has largely been driven by a few countries with ambitious support policies. While these policies initially emphasized technology research and development (R&D), they have shifted toward large-scale deployment, enabling further economies of scale and tapping into synergies with ongoing R&D. Despite the technology progress already achieved, solar energy must still overcome a range of hurdles in order to fulfill its full potential in helping to reduce global CO_2 emissions.

A brief overview of the main barriers facing solar energy technologies provides a useful context for examining some of the best practice policies currently being used to foster development and deployment around the globe. Understanding the strengths and weaknesses of these policies can facilitate the process of selecting and tailoring supportive policies and practices to maximize effectiveness taking into account national circumstances.

Barriers to Development and Deployment

Solar energy technologies face economic, technological, systems integration, and attitudinal barriers to more widespread deployment around the globe. Strong markets are needed to stimulate the required investment in technology development and deployment, yet further technology advances are needed to increase market demand. The lack of sufficient market pull for solar energy, due to its comparatively higher costs, creates the need for policy-driven support to bridge this cost disadvantage.

<table>
<tr><th colspan="3">Barriers to Development and Deployment of Solar Energy Technologies</th></tr>
<tr><td rowspan="3">Economic</td><td>Inadequate market pull</td><td>• Failure to reflect external costs in energy prices, in particular
• Lack of an effective global carbon market
• Limited consumer influence on additional solar technology deployment in green power purchase agreements
• Lack of consumer awareness of benefits of solar energy</td></tr>
<tr><td>Investment risks</td><td rowspan="2">• Lack of demand due to higher electricity generation costs
• Long and unpredictable planning and permitting procedures
• Lack of transparency in international funding schemes
• Restricted access to project funding in developing countries</td></tr>
<tr><td>Project funding</td></tr>
<tr><td>Technological</td><td>Technology needs</td><td>• Lack of technology-specific support schemes
• Lack of expertise, particularly on installers and advance operation and maintenance (O&M) strategies
• Inadequate transfer of knowledge to developing regions</td></tr>
</table>

Barriers to Development and Deployment of Solar Energy Technologies		
Technological (continued)	**Technology costs**	• Need for further improved technological efficiency and further reduced technology manufacturing costs • Inadequate demonstration and test sites for emerging technologies
Grid, System and Market Integration	**Integration of large shares of solar electricity into the grid and the energy system**	• Need for guaranteed grid connection and priority or guaranteed dispatch • Need for increased grid capacity (lack of infrastructure or poor grid operation) • Need for system and market integration for growing shares of solar power (e.g. solar power curtailment, demand-side management, balancing power plants, storage technology, joining adjacent markets)
Attitudinal	**Public attitude**	• Potential public resistance to large-scale solar installations or buildings-integrated solar applications
	Public confidence	• Lack of adequate consumer information and confidence in reporting on source of power

Current Best Practice Policies

The primary driver for accelerating the market competitiveness of solar technologies is the establishment of appropriate framework conditions that reduce market barriers and attract robust private investment in the research, development, demonstration, and large-scale deployment of solar technologies. Effectively fostering the development and deployment of solar power requires a comprehensive approach that successfully and strategically integrates a balanced set of instruments and renewable energy policies.

Key elements in establishing an appropriate framework for the successful development and deployment of solar technologies include the following:

- Support stronger demand-pull for solar energy
- Grid access and system integration
- Sufficient, affordable financing
- Research, development, and demonstration projects
- Improved planning of large-scale solar installations and transmission infrastructure, and reduced administrative burden
- Legal certainty
- Sufficient labor and intellectual resources
- Technology cooperation

Current best practice policies to address of each of these principals are discussed in the remainder of this chapter. Where appropriate, existing gaps and strategies for addressing those gaps are also identified. Appendix B provides further detail and context for several items in the Chapter.

Support Stronger Demand-Pull for Solar Energy

Today, the most successful approaches to accelerate the deployment of solar energy involve the establishment of a balanced set of technology-specific support measures that will help generate sustained demand-pull. Collectively, these measures can establish enabling frameworks conditions, bring solar energy technologies closer to cost-competitiveness with conventional technologies, and ensure broad technology progress, which is increasingly driven by demand-pull and which will help to ensure a broad technology mix for future energy security. Such support measures include the following principles:

- Internalize the external costs for all forms of energy production
- Establish reliable and predictable technology-specific support schemes
- Improve conditions for marketing green electricity and improving consumer awareness (covering also grid-parity)

The following table summarizes current approaches in use by various countries.

Support Stronger Demand-Pull for Solar Energy		
Policy	**Description**	**Examples / Details**
Internalization of external costs: Solar energy would be more competitive if external costs (particularly climate change costs) were more accurately reflected in the costs of conventional power generation. External costs are incurred by society but their extent is not generally included in cost calculations because they can be hard to quantify. Thus, internalizing external costs of all forms of energy production would provide a more level playing field.		
Carbon tax	A market-based instrument to reduce emissions. Many EU Member States impose energy taxes, some including a levy on the CO_2 content (carbon tax).	Denmark and Sweden use a carbon tax, and France is considering it. The EU is discussing the introduction of CO_2 content as part of a revision to its energy taxation directive. To avoid distortion of markets by overlapping instruments that set a price on CO_2, energy use that falls within the scope of the EU greenhouse gas emissions trading system (ETS) may be excluded from the CO_2-related tax.
Cap and trade scheme	Places mandatory cap on emissions yet provides sources flexibility in how they comply. Successful cap and trade programs reward innovation, efficiency, and early action and provide strict environmental accountability without inhibiting economic growth.	Since 2005, the EU ETS has placed a cap on more than 40% of CO_2 emissions and limited the quantity of tradable emissions allowances, with the intent to create a reliable price signal for CO_2 emissions. In 2013, a single EU-wide cap will replace the current system of 27 national caps. The cap on emission allowances for covered sectors (power generation, energy-intensive industry, and as of 2012, aviation) will then be reduced each year after 2013 (allowances in 2020 will be 21% below 2005 levels). Businesses, instead of receiving allowances at no cost, will have to buy a progressively higher share at auction. By 2013, around 50% of all allowances will be auctioned, with the goal of 100% by 2027.
	Gaps: Emission cap and trade schemes and/or carbon taxes alone cannot provide sufficient support for the accelerated deployment of renewables. Energy-intensive sectors facing challenges in global competitiveness would likely continue to receive many or all of their allowances at zero cost as long as they use state-of-the-art technology. A global carbon market would improve cap-and-trade effectiveness in the long run. Cap and trade also does not provide the technology-specific support needed to ensure that each promising technology is developed to its full potential as part of a balanced portfolio of energy technology options, ensuring future energy security. A balanced set of policy instruments is needed.	

Support Stronger Demand-Pull for Solar Energy (cont.)		
Policy	**Description**	**Examples / Details**
Renewables energy targets and support schemes: Best practice examples and IEA analysis (IEA 2008a) suggest that an effective renewable support scheme should reflect the following principles: • Predictable, reliable support of sufficient duration for re-financing of investment conditions • Technology-specific support that accounts for different stages of technology development and the need for a balanced technology portfolio for future energy security • Transitional incentives that decrease over time to provide incentives for further cost reductions • Incentives for energy produced, as opposed to capacity installed • Favorable grid access conditions • Grid and market integration of large shares of fluctuating solar electricity to ensure system reliability and overall cost-efficiency • Support that is uncomplicated and easy to implement, with low administrative barriers, to attract private investment • Efficient interaction with other schemes and other national policy frameworks		
Renewables targets: solar power	Various countries have set targets for deploying renewable energy at a national or regional level. This provides a clear signal to private investors regarding the reliability of the countries' support policy. Most targets relate to final energy or electricity consumption. Different targets may be set by sector and/or by resource.	At least 73 countries have set renewable energy targets (REN21 2009). The European Union has adopted a target of 20% of final energy consumption in 2020. This target is distributed among EU Member States. For example, Spain has a target for final energy consumption of 20%; Germany, 18%; Denmark, 30%; Sweden, 49%; France, 23%; and Italy, 17%. The U.S. plans to double its renewable capacity in three years. Germany and Australia have set sector-specific targets for renewable energy in electric power (30% and 45 TWh by 2020, respectively). Several countries have set specific targets for solar energy. Korea plans to connect at least 1.3 GW of solar PV by 2011 (IEA 2008a). France has a solar PV target of 5.4 GW by 2020. Spain has a CSP target of 2,520 MW by 2013. Most recently, India announced an ambitious national plan for solar power, targeting an installed capacity of 20 GW by 2020 and 200 GW by 2050.
Renewables targets: solar heating and cooling	Policies encouraging the development and deployment of renewable heating and cooling have largely been neglected (IEA 2008a). Yet, recent signs suggest this is changing.	The new EU Directive on the promotion of renewable energy sources provides that national action plans must include targets for different sectors, including heating and cooling. Israel was the first country to mandate solar heating in new buildings (IEA 2009a), while Spain was the first country to mandate hot sanitary water from solar at both a national and local level. Germany recently adopted a renewable energy heat act, setting a 14% goal of renewable in the heating sector (space heating, process heating, water heating, cooling). This was accompanied by minimum renewables requirements for new buildings and a bonus for installing renewables in older buildings. Several other countries (e.g., Norway, Syria), regions or states (e.g., Hawaii) and municipalities (e.g., New Delhi, Cape Town, Barcelona) have also mandated renewable heating (REN21 2009).
Support schemes: solar power*	Support schemes for solar power can generally be divided into price-based mechanisms and quantity-based mechanisms, all with different advantages and disadvantages. They may be combined in various ways.	Price-based mechanisms include: • Feed-in tariffs and premiums • Tax and investment incentives Quantity-based mechanisms include: • Quota systems / tradable green certificates (TGCs) • Tender schemes ** Please see below for support schemes for off-grid solar power and support schemes for solar heating and cooling.*

SUPPORT STRONGER DEMAND-PULL FOR SOLAR ENERGY (CONT.)		
Policy	**Description**	**Examples / Details**
Price-based mechanisms for solar power		
Feed-in tariffs	Feed-in tariffs may guarantee a fixed, technology-specific tariff to the operator of a renewable facility over a long period (e.g., 20 years). The grid operator is usually required to purchase all power produced and pay the tariff; the cost is absorbed by consumers. These schemes are often complemented by soft loans or even additional investment subsidies. Distinct tariffs may be used for different regions and/or technologies.	According to the IEA, three of the five countries with the highest policy effectiveness in developing solar energy (i.e., Luxembourg, Germany, and Switzerland) primarily use feed-in schemes (IEA 2008a). At least 63 countries, states, and provinces have applied feed-in tariffs, including Turkey, Brazil, and China, as well as the municipal utility in Gainesville, Florida (U.S.) (Cory et al. 2009; Couture and Cory 2009). Recent adjustments of feed-in schemes in Spain and Italy have led to a boost in the PV market resulting, in both countries, in 400% increases in installed capacity in 2008 relative to 2007. If well-designed, feed-in schemes provide effective, cost-efficient, and technology-specific support that is transparent and predictable over long periods. This leads to better access to financing and lower interest rates for loans, attracting diverse market players, including small installations by final consumers. Well-designed feed-in schemes tie the remuneration costs to the technology-specific costs of production, thus avoiding excessive market revenues for producers that would have to be paid by the support scheme and thus, consumers. In the current economic crisis, feed-in schemes have provided important backing for the renewables market.
	Gaps: Price determination is not market based. Thus, feed-in tariffs may not progressively employ market forces nor sufficiently provide incentives for further innovation and cost-efficiency. Moreover, fixed feed-in tariffs provide fewer incentives for matching supply and demand to promote system integration; operators do not sell electricity on the market and thus, are not forced to track load curves.	**Potential Solutions:** To overcome potential drawbacks, feed-in tariffs should be continuously evaluated and decreased, as appropriate, as for example, is the approach in the German Renewable Energy Source Act. An appropriate incentive should also be established for the direct marketing of renewable energy. To improve system integration, incentives should be provided for the installation of storage capacity, the provision of firm and dispatchable electricity, and for system (ancillary) services.
Feed-in premiums	This variation of feed-in tariffs intends to improve the integration of renewables into the market by letting operators sell renewable electricity on the wholesale market without specifying it as renewable and receive an additional bonus (premium). This can provide incentives for renewable operators to follow the load curve.	Spain introduced an optional premium, which lets the operator decide between a fixed tariff and a premium. Feed-in-premiums are also applied in Canada and the Netherlands.

Support Stronger Demand-Pull for Solar Energy (cont.)		
Policy	**Description**	**Examples / Details**
Price-based mechanisms for solar power (cont.)		
Tax and investment incentives	Tax credits attract private investors as the credits can be sold on the market, allowing private investors to reduce their taxes by investing in renewable technologies. They are particularly useful in the early stage of market development to foster demonstration projects. They are also often used as supplementary support to address upfront costs.	Investment incentive programs are the main strategy pursued in several countries, including Japan, Finland, and Mexico. In the United States, at the federal levels, solar energy receives incentives in the form of a Business Investment Tax Credit (ITC) (IEA 2008a). At the state level financial incentives are often combined with a quota obligation system. In practice, most investment has occurred in states with additional support programs for solar PV capacity. California, for instance, offers additional investment subsidies for residential and commercial PV installations (IEA 2008a). Recently, several new financial models have been developed in the U.S. to reduce the up-front cost of residential PV systems: Third-party ownership models can better take advantage of tax incentives and remove the responsibilities of homeowners regarding operations and maintenance. The property tax assessment model facilitates long-term financing, as well as the transfer of PV system ownership to subsequent homebuyers. Solar renewable energy certificates help monetize the value of PV installations and make it easier for homeowners to repay solar loans. Similarly, new community-based financial models are available for those people who do not own houses (Coughlin et al. 2009).
	Gap: Support stability is highly dependent on the dynamics of the overall economy. Tax credits can lose value in times of economic crisis, jeopardizing system stability.	**Potential Solutions:** In response to the economic downturn and associated decrease in profits and tax liability, a new program was introduced in the U.S. in early 2009 that provides the option of monetizing the ITCs in the form of cash grants of equivalent value (“grants-in-lieu”) for a limited amount of time (Bolinger 2009).

Support Stronger Demand-Pull for Solar Energy (cont.)		
Policy	**Description**	**Examples / Details**
Quantity-based mechanisms for solar power		
Quota systems based on certificates **(TGCs or RPSs)**	In a quota obligation scheme, suppliers must validate their obligation to produce or purchase a set quantity of renewable energy with a certificate. Suppliers can produce renewable electricity themselves or buy certificates from others. Whereas in price-based support schemes it is more or less the policymaker who is bound by a renewable target, in a quota scheme, the producer or supplier is obliged to fulfill the renewable target set by a quota.	Quota systems are applied in 49 countries, states, and provinces, including the UK, Belgium, Sweden, Australia, the United States (together with tax schemes), Italy, Poland, and Japan. The certificates are called Tradable Green Certificates (TGCs) in Europe and Renewable Portfolio Standards (RPSs) in the United States. Quota schemes provide market-based incentives for innovation and for integrating renewable electricity into the power system. They support cost-efficient energy generation at sites with the highest solar radiation (i.e., the best potential).
	Gaps: In a quota scheme, demand is not consumer driven; when the target has been met, it can lead to a full stop in demand. Aside from these risks, difficulty in forecasting prices raises uncertainty and investment costs, thus raising electricity costs. Most quotas today are based on green energy as a whole, not specific technologies. Thus, they support the most cost-efficient technology (often wind). If the quota cannot be met by the most cost-efficient technology, market price is set by the more expensive technology, allowing higher revenues for producers but creating higher costs for the support scheme and thus, consumers.	**Potential Solutions:** One approach is to establish technology-specific quotas. Another solution is technology banding, whereby less mature technologies receive a higher ratio of TGCs, as is the case in the UK. Several RPS programs in the United States also mandate that utilities purchase electricity from different renewable sources at fixed ratios. Another approach, recently introduced in the UK, introduces feed-in tariffs for small installations with a capacity of up to 5 MW and applies a quota scheme for all other installations. Australia combines its national quota, the Renewable Energy Target, with research, development, and demonstration grants for less mature technologies
Tender schemes	In tender schemes, a government specifies a set amount of technology-specific renewable capacity to be installed by a certain date, then offers concessions to implement the projects for tender. The project with lowest costs wins the concession and receives a fixed price for a fix amount of production. The technology can be designed for a specific technology, allowing support for less mature industries that need large scale demonstration projects.	Several countries use tender schemes for the deployment of solar energy. In April 2009, France set up a tender process for large-scale, free-standing PV systems. To ensure PV plants are distributed evenly across the whole of France, the tender is divided into four different geographical sections (MEEDDAT 2009). Once risk is that if competition for the concession is too strong, the prices offered become too low and projects are not implemented.

Support Stronger Demand-Pull for Solar Energy (cont.)		
Policy	**Description**	**Examples / Details**
Support schemes for off-grid solar power		
Support schemes for mini-grid and other off-grid applications	Currently, most support schemes aim to promote the deployment of grid-connected installations. Support for off-grid solar power should also be considered, particularly in developing countries. A possible off-grid alternative is to promote renewable energy in mini-grids, i.e., small generation sources interconnected to form small-scale distribution systems. Successful policies promoting grid-connected solar power can also be transferred to off-grid areas. For example, standard feed-in tariffs schemes can be modified so that they apply to mini-grids as well (JRC 2008).	With around 1.5 billion people worldwide lacking any access to electricity at all (IEA 2009k), solar off-grid applications are an increasingly appealing option for rural electrification. Costs have fallen, and off-grid electricity generation is now considered more economically viable than grid extension. For example, in China, solar off-grid is already competitive with diesel generation (diesel generation costs today range between US$0.20–0.30 per kWh depending on the local fuel price [Prognos 2009][19]). Additionally, micro-credit schemes have proven to be a successful policy for rural electrification. The micro-credit company Grameen Shakti in Bangladesh has managed to electrify more than 38,000 villages by installing more than 210,000 solar home systems throughout the country (Barua 2007).
Support mechanisms for heating and cooling		
Tax and investment inventives	Tax and investment incentives are a straightforward way to reduce the up-front investment costs and are easy to administrate. They take a number of different forms, e.g., an amount calculated on the basis of the capacity installed (e.g., US$/kW). Soft loans and loan guarantees are further forms of investment incentives. Tax and investment schemes can be complemented by regional or local incentives.	Many countries offer investment grants for solar heating (IEA 2008a). Strong market penetration has already been seen in Austria and Germany. Austria, for example, offers incentives for companies, associations, public entities and, as of 2003, for residential buildings. Germany has recently adjusted its support mechanism for heating in the Renewable Heat Act, following a combined approach of minimum renewable requirements in new buildings, and an additional financial incentive (bonus) for installing renewables in existing buildings or in new buildings if the installed renewables application exceeds the minimum requirements. France offers investment grants for the purchase of individual and collective solar thermal systems (IEA 2007). France also has a tax rebate system for renewable heating in which costs are recovered via an individual's income tax return (La loi de finances 2005). Tax credits are temporarily available for up to 50% of the capital costs of renewable heating equipment and materials, the specific amount depending on the precise type of technology installed. In Austria, incentives are linked to the construction or refurbishment of residential buildings (IEA 2007, Mader 2007).
Renewable heat certificate schemes	In these schemes, the owners of renewable heat installations receive a certificate for the amount of heat that they generate. The suppliers of conventional heating fuels then purchase the certificates so that they can meet their set targets (IEA 2007).	In Japan, the Tokyo Metropolitan Government Office (TMG) introduced a certificate system in April 2009 called the "Tokyo Cap and Trade Program." The TMG offers financial support to individuals purchasing solar thermal installations and, in this manner, generates heat certificates. Tokyo's environmental authorities then sell the certificates to companies that have to reduce their CO_2 footprint (Schober 2009).

[19] Based on current Chinese diesel prices according to the IEA Energy statistics (http://data.iea.org).

Support Stronger Demand-Pull for Solar Energy (cont.)		
Policy	**Description**	**Examples / Details**
Support mechanisms for heating and cooling (cont.)		
Feed-in tariffs	As no country has yet fully implemented feed-in tariffs for renewable heating and cooling, it is too early to assess their effectiveness and efficiency for this application.	Several countries, including the UK and France, are currently working on a feed-in tariff scheme for renewable heat.
Inclusion of solar heating and cooling in other mechanisms	Solar heating and cooling could be included in other renewables or energy efficiency support schemes, such as quota systems.	Solar water heaters in homes or businesses could be counted towards utilities' targets in renewable energy portfolio standards (e.g., in Australia, and some U.S. States). In France and Italy, solar water heaters and solar heating systems can receive "white certificates" that energy distributors can use to meet their obligations for improved energy efficiency.
Note on developing countries:	In countries where solar heating is competitive with conventional heat supply systems due to a lack of overall infrastructure, it is essential to raise awareness and to provide training opportunities on solar heating in order to deploy this technology more widely (IEA 2007).	
Improving marketing conditions and consumer awareness: Consumer confidence and public awareness is necessary to improve a market pull-driven deployment of renewables (see Appendix B for further detail).		
Green power purchase agreements and labeling of additionality	Green power purchase agreements could considerably strengthen consumer driven demand for solar energy.	The EU has launched the electricity labeling directive to tackle this issue with some progress. But the system does not work at full effectiveness yet due to the complexity of disclosure-related issues.
	Gaps: Even though consumers may pay higher electricity prices for green energy with the firm belief that the additional cost will support accelerated solar deployment, often green power purchase agreements do not actually result in additional solar technology deployment.	**Potential Solutions:** To assure consumers that the prices they pay for renewables contracts (e.g., to buy green power) actually result in additional deployment of new renewables installations, several private eco-labeling initiatives require that suppliers who want to sell an eco-labeled renewable contract have to invest a given amount of their margins into new renewable installations. Nevertheless, public information on this issue needs to be improved. In Australia, GreenPower is a government accreditation program for renewable energy. The government GreenPower program organizes publicly available independent auditing of energy retailers' sales and purchases, making sure retailers are investing in renewable energy on behalf of the purchaser.
Improving customer awareness	Raising consumer awareness of the benefits from electricity generation from renewables would considerably improve marketing conditions and could provide critical market pull in this sector.	To facilitate demand and an appropriate investment environment, consumers need accessible information on the benefits of solar technology for climate change, the environment, the economy, and energy security. In particular, emphasis appears to be needed on the economic benefits of investing in solar technologies, as this might attract a broader range of customers. Appropriate public campaigns should be launched and all appropriate marketing options used.
Grid parity	Grid parity is when electricity generation costs of PV installations are identical to consumer household costs.	Grid parity refers to the point in time when PV electricity generation costs fall below the electricity price for private households. This opens a new scope for PV applications through self consumption of PV generated electricity by consumers since PV electricity would be competitive with household power prices. Grid parity might allow a new level of consumer influence.

Developing demand for and investment in solar energy will require reliable and predictable support. Support schemes and incentives need to be consistent with existing regulations ensuring free trade, such as the WTO rules or the provisions of the European Treaty, particularly the principle of the free movement of goods and state aid rules.

The different support scheme options discussed above each provide particular advantages. Feed-in tariffs and quota obligations are the most widely applied support schemes (REN21 2009). Analyses by the IEA and on behalf of the European Commission have concluded that, so far, well-adapted feed-in schemes appear to be the most cost-effective support schemes (IEA 2008a, European Commission 2008).

However, well-adapted quota and other support schemes can be effective drivers for renewable deployment as well. Moreover, with growing shares of fluctuating renewables, both feed-in schemes and quotas systems need to be adapted in order to fulfill the basic requirement of a reliable and predictable support scheme that allows effective support and cost-efficient system and market integration. This might facilitate new innovative concepts and ideas that may also include inventive combinations of existing support elements (see, for instance, discussion in Cory et al. 2009).

Hybrid CSP Plants

When developing policies for hybrid CSP plants (e.g., combined CSP/natural gas facilities), countries should consider not putting restrictions on the use of fossil fuel back-up when determining the eligibility of a CSP installation for public support. Fossil fuel back-up in hybrid plants can help reduce costs where full back-up by thermal storage is not possible or too costly. Although public support should ideally cover only the share of electricity generated by solar, countries may wish to incentivize the construction of hybrid CSP plants, as they can increase the overall system capacity of firm and dispatchable electricity to meet energy demand.

An ambitious support policy targeted at accelerating deployment on a massive scale could attract investment and spur innovation, thereby facilitating technology progress and improving technology efficiency. This would drive costs down for renewable energy investment and electricity generation (i.e., along the learning curve). Deployment-driven cost reductions, combined with internalization of external costs, could create increasing demand-pull. Consequently, an ambitious support policy today would lead to less dependence on support schemes and lower support costs tomorrow.

Provide Grid Access and System Integration

Successful uptake of solar energy technologies will require solutions to the challenges of grid and system integration, which vary among regions or countries depending on the level of market development type (for instance, ground mounted or building integrated) and size of solar installations.

Developing Countries

In developing and emerging countries, grid infrastructure must first be installed, with rural electrification presenting additional challenges. If no high-voltage transmission grid is in place, small off-grid PV applications could facilitate rural electrification. Integrating large amounts of renewables only becomes more complex with substantive shares of electricity supplied from fluctuating renewable sources. Historical development in Western Europe, the United States, and Japan indicates that, in an early market stage, system and grid integration can be handled easily (up to a 5% share for renewables seems negligible from a power system operations standpoint [IEA 2009j]). Significantly increasing shares, however, raise more complex issues. Thus, new grid deployment in developing economies should be implemented in a manner that will produce a robust and flexible power network that will be able to cope with a larger share of variable renewable energy in the future.

Industrialized Countries

Given the existing grid infrastructure in industrialized countries, integrating large amounts of solar energy without negatively affecting grid access is also a complex issue, largely because of grid stability. Three key issues have to be addressed in the context of grid and system integration:

- Grid access for new producers and order of dispatch
- Transmission and distribution capacity (to accommodate additional renewable installations)
- System operation with large amounts of variable renewable power (system and market integration)

These are described, with best practice examples, in the table below.

PROVIDE GRID ACCESS AND SYSTEM INTEGRATION		
Policy	**Description**	**Examples / Details**
Grid access and dispatch: Investors need clear assurances that their solar installation will be able to connected to the grid and be dispatched in a profitable manner. Lacking this clarity, a vicious circle may develop in which neither the solar plant operator nor the transmission operator initiates investments until the other one does.		
Guaranteed grid access and priority dispatch[20]	Three critical elements for investor assurance are: a) Guaranteed connection to the grid, i.e., the grid system operator must connect the solar installation to the grid, if the stability criteria are fulfilled, and give early confirmation on this connection. b) Transmission system operators (TSO) should either give priority dispatch (i.e., power from the solar installation is dispatched prior to power from a conventional power plant in cases of capacity conflicts) or guaranteed dispatch to solar power, provided that net grid stability is not jeopardized. c) Appropriate allocation of network connection costs	The German Renewable Energy Source Acts and the Spanish Royal Decree 661/2207 provide for both guaranteed connection and priority dispatch if the grid stability criteria are fulfilled per the grid codes of the Transmission System Operator (TSO). Standardizing grid codes, including definitions and terminology, would enhance transparency and reliability for investors. The European Directive on the promotion of the use of renewable energy (2009/28/EC) requires Member States to provide either priority or guaranteed access. Usually, costs for grid connections are borne by the operator of the renewable installation as part of their investment costs. In some circumstances this might be different. For example, for offshore wind installations Denmark and Germany provide free grid connections financed by electricity consumers, because the connection costs are very high and the connection is managed by the TSO. In general, the degree to which costs for grid connection are borne by the developer or by the operator may vary depending on a country's electricity market structures.

[20] The issue of guaranteed connection and priority dispatch is often discussed under the term "guaranteed access," see for instance Article 16 of the European Renewable Directive, 2009/28/EC.

PROVIDE GRID ACCESS AND SYSTEM INTEGRATION (CONT.)		
Policy	**Description**	**Examples / Details**
Increasing transmission and distribution capacity: Sufficient grid capacity at both the transmission and distribution levels is a prerequisite to integrating growing shares of renewables into the grid.[21] The grid has to be able to reliably and instantaneously balance supply and demand fluctuations. Grid capacity can then be increased in two ways: by installing new grid infrastructure (or up-scaling existing grid capacity) or optimizing the operation of existing grid infrastructure. Integrated strategic planning can facilitate grid infrastructure projects. Given that renewables help reduce climate change costs and that grid capacity is a central "backbone" for energy security, countries might consider socializing the costs of upgrading grids, rather than imposing them on renewable installation operators. If these costs are socialized, appropriate frameworks conditions are needed to avoid inappropriately increasing costs.		
Integrated strategic and accelerated planning	A strategic, holistic spatial planning approach takes into account an array of options to complement and balance installations using fluctuating renewable sources (see IEA 2009j). It also ensures that different land use interests are addressed early and reflected in the plans, helping to prevent third-party claims during the permitting or construction phases. As spatial planning of large grid infrastructure projects is complex, detailed grid studies involving system operators, industry, and policymakers are needed.	The United States has an effort to identify Renewable Energy Zones (REZ) and to conduct transmission planning to access these zones. Similar approaches can be found in several countries in relation to offshore projects. In China, the government has proposed a "Green Silk Road" project: a new transmission corridor to gather output of seven planned 10 GW wind power clusters, over six provinces. The German DENA grid study identifies grid improvements and transmission priorities to achieve Germany's renewable targets. Specific transmission lines were prioritized in the power line extension law in summer 2009. Ireland's TSO EirGrid published an "All Island Electricity Grid Study" in January 2008.
Installing new grid infrastructure (see Appendix B for further detail)	In many countries, the main bottleneck for integrating higher shares of renewable energy is the lack of transmission capacity. New capacity is needed to connect renewables installation with demand centers.	Much of the existing transmission infrastructure in OECD countries is more than 40 years old and needs to be upgraded regardless of renewable energy deployment (IEA 2009j). This provides a window of opportunity to ensure that capacity upgrades are conducive to greater integration of intermittent renewable energy sources. Upgrading transmission networks should make use of new line technologies that increases grid flexibility. Several options for new grid infrastructure include high voltage direct current (HVDC) transmission, underground transmission cabling (to increase public acceptance), and improved power electronic devices for load flow control. Appendix B provides further information on these options.
Improving existing grid infrastructure (see Appendix B for further detail)	Beyond the addition of new grid infrastructure, which requires rather long spatial planning processes, grid capacity can be increased considerably by optimized operation.	Two examples for improving existing grid infrastructure are: • Dynamic line rating to take into account weather conditions • Rewiring with lower sag, high temperature wires Appendix B provides further information on both options.

[21] Although sufficient transmission capacity is currently of particular importance for the integration of wind power into the system, it will be increasingly important for solar energy as well.

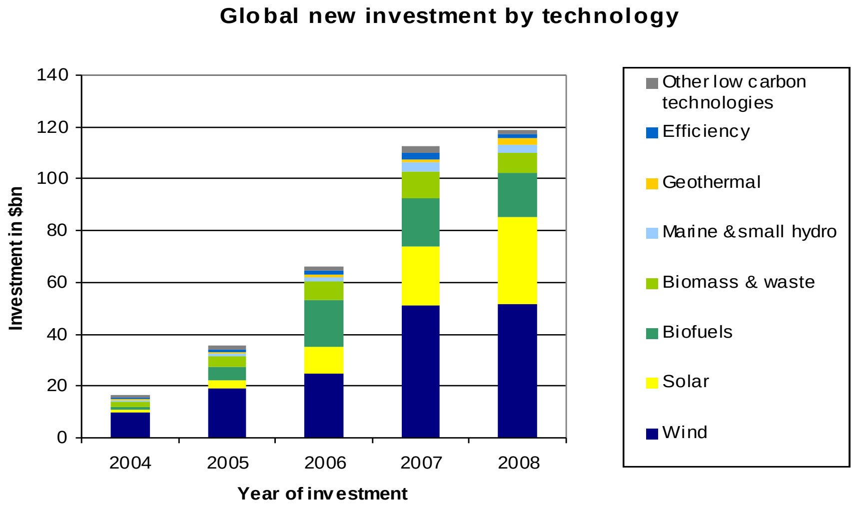
Provide Grid Access and System Integration (cont.)		
Policy	**Description**	**Examples / Details**
System and market integration: The task of reliably integrating increasing shares of fluctuating renewables into the power system becomes more significant as their share of total electricity production increases. Many options exist for improving system integration and are discussed below. An integrated, holistic power system management approach using all these options would provide significant advantages.		
Flexible power plants and storage technologies	Flexible power technologies and storage capacity can increase the ability of the power system to reliably balance larger shares of variable renewable energy. Such technologies will be operated for the benefit of the entire electricity system, and not only for a specific renewables installation.	By far the most important tool today is the use of "flexible" power plants, such as gas turbines and hydropower, which can be quickly dispatched or turned off according to the output of solar energy. Advanced storage technologies may have the potential to reduce the need for flexible reserves, instead enabling excess solar power to be stored and dispatched later as needed. Options include pumped hydro storage; compressed air energy storage (CAES, undergoing testing but relies on geology that is not found everywhere); electric vehicle batteries; and production of hydrogen for use in hydrogen cars. .
Solar power curtailment	Solar power curtailment entails the quick reduction of electricity fed into the grid to ensure system stability.	Spain and Germany have had good experiences with solar power curtailment by providing that it is limited to disturbances or other situations where grid stability is threatened and other options, such storage or demand management, are inappropriate or not available. This ensures the concept of guaranteed or priority dispatch. If firm network rights are allocated, operators of solar energy installations should receive compensation for being subject to curtailment. This creates an incentive to expand grid capacity and install additional flexible power plants or energy storage
Wide-area monitoring and improved weather forecasts	The integration of a wide variety of different power sources and the optimization of energy flows require a computer-based, wide-area monitoring approach for future and predictable congestion situations. Improved weather forecast models provide a necessary tool in this context that should be used by system operators.	Such systems are already applied in the United States and China. In Europe, neighboring TSO's have launched a collaborative security cooperation (TSC), whereby they share the results of the TSO's grid state prediction calculations and follow a joint strategy of counter measures in case of grid stability problems. The Spanish power systems operator Red Electrica started a control center in 2006 to control production and energy flow in the network for all renewable energies and to ensure system stability (CECRE).

Provide Grid Access and System Integration (cont.)		
Policy	**Description**	**Examples / Details**
Demand-side management	A comprehensive system management approach should not only manage electricity supply but also electricity demand, a concept known as demand-side management (DSM).	Today, DSM tends to concentrate on large electricity consumers, such as large cooling houses, steel or aluminum plants, or waterworks. In this case, the short-term balancing potential is easier to control than for a large number of small consumers. Many future power system strategies including the European SmartGrids initiatives and the U.S. GridWise initiative highlight the need for increased end-user involvement. End users could potentially defer their demand to low load periods. Necessary policy conditions are needed, e.g., variable tariffs that set incentives for deferrable price-responsive demand. In concert with other innovations, such as smart household appliances, smart metering will be a key capability for consumer DSM. It allows analysis of consumer demand patterns and price signals and perhaps, control of individual household devices either through individualized programming or remote control.
Connection of adjacent power systems and markets	The more power systems that are linked with each other, the greater share of renewable electricity that can be integrated into the grid; interconnected power systems are more flexible as they can share dispatchable electricity and exchange excess supply of electricity from renewable sources. Sufficient interconnection capacities are needed between the grid infrastructures of different electricity markets. Consideration should be provided for the harmonization of converter and control standards (e.g., to allow a multi-terminal HVDC-system to be connected to different networks in different countries, which requires coordinated load flow control).	Interconnected power systems imply a need for collaboration among neighboring system operators and governments based on a transparent and advanced exchange of information to avoid the spread of faults throughout the entire region. A prime example is the Nordic power market, which covers the whole of Scandinavia. Based on strong interconnection and transmission capacities, large amounts of wind power can be integrated into the system. This system also benefits from the large Norwegian and Swedish share of hydropower and has supported Denmark in achieving a 20% wind share of the electricity market. Recently, the new European Network of Transmission System Operators body (ENTSO-E) has dedicated a special regional group to studying the feasibility of a North Sea grid. Furthermore, the European Commission appointed a European Coordinator in 2007 to facilitate coordinated offshore interconnections (IEA 2009j).
Smart grid	If fully implemented, a smart grid would intelligently connect all actors in the power market and thereby allow for integrated real-time, online visualization, analysis, and management of electricity supply and demand.	A number of demonstration, pilot, and deployment projects are underway, e.g., the German E-Energy project. The SmartGrids European Technology Platform for Electricity Networks of the Future began its work in 2005, aiming at developing a concept for the development of European electricity networks looking towards 2020 and beyond. For further detail on smart grids, please see the MEF Global Partnership *Technology Action Plan: Smart Grids*.

Sufficient, Affordable Financing

Increasing solar power and solar heating capacity to address climate change and ensure energy security requires a number of financing instruments that foster predictable and sufficient investment conditions and create long-term price signals for the market. It is crucial to design and use financial instruments that are effective, efficient, and equitable. Investment in the solar energy sector increased steadily in recent years (Figure 6). However, financing activities have stagnated during the current financial crisis (UNEP 2009). Fortunately, stable and effective support mechanisms have limited the impacts of the crisis.

FIGURE 6. GLOBAL NEW INVESTMENT IN SOLAR ENERGY FROM 2004 TO 2008 (IN US$ BILLION)



Source: New Energy Finance 2009

A number of projects provide mezzanine and other financing to small businesses. In some cases, these funds are linked with technical assistance and training. Financing of entrepreneurs along the supply chain does not appear to present a major barrier to solar energy deployment in most MEF countries, or at least no more than other sectors suffering from the overall financial crisis. By contrast, the availability of additional financing is critical to investment in developing countries. Current carbon prices and carbon-based financing measures have not significantly increased the financial viability of solar projects.

Concessional financing (soft loans, i.e., loans with less or free interest, and further relief regarding payback methods) can address these financing gaps in most developing countries and enable infrastructure projects. In addition, if the project is approved under the framework of the Clean Development Mechanism of the Kyoto Protocol, Certified Emission Reduction certificates (CERs) can augment other support schemes (e.g., feed-in tariffs, green certificates, and investment subsidies). More generally, adequate financing instruments must be appropriately matched to project size.

For a large-scale rollout of solar electric power generation to occur, two major investor groups need to be addressed: utilities (large scale) and end-users (small scale). For these two groups, project sizes and access to financing differs and "grid parity" (the competitiveness of solar electricity compared to other types of generation) is measured in different contexts. Consequently, best practices in financing also differ for utility-scale projects and residential or commercial projects.

Several best practice financing policies and instruments are summarized in the following table. See Appendix B for further detail.

Sufficient, Affordable Financing		
Policy	**Description**	**Examples / Details**
Public-driven financing mechanisms providing equity	Provision of fundamental capital support for projects that cannot obtain equity capital from corporate treasuries, strategic investors, private equity funds, or the capital markets	• Connecticut Clear Energy Fund (CCEF) provides capital support on a case-by-case basis for small-scale, decentralized renewable energy projects in Connecticut (U.S.) (UNEP 2005, CCEF 2005).
Public funds providing mezzanine capital	By providing mezzanine capital to bridge the debt-equity gap, public funds can lower risks for investors and lenders or leverage private capital.	• FIDEME (Fonds d'Investissements de l'Environnement et de la Maîtrise de l'Energie) in France: a public-private mezzanine fund in which ADEME, the French Environment and Energy Management Agency, has invested € 15 million, providing a first loss guarantee to senior lenders in the fund (UNEP 2005). • Sustainable Development Fund of Pennsylvania offers innovative financing for renewable energy projects (in Southeastern Pennsylvania) not easily financed on a commercial basis.
National public sector loan instruments	Aimed at facilitating corporate and/or project financing to the solar energy sector, focusing on small to medium-sized projects	• Loan credit lines of the KfW (the German bank for reconstruction and development): Project developers contact partner banks, who assume the credit risk and then lend the funds provided by KfW. The loans offer attractive conditions for developers. • Netherland-Green Funds: offers individuals the possibility to receive a tax incentive of 2.5% and an earned interest of 1.0-1.5% on green savings accounts. Thus, banks offer soft loans to environmental projects and project developers (UNEP 2005). • Bulgarian Energy Efficiency and Renewable Energy Credit Line: offers loans, technical assistance, and grant support to Bulgarian Sustainable Energy projects, capitalized by international financing institutions and bilateral donor agencies.
Loans of international financial institutions	Loans with special conditions to renewable energy projects; banks offering those loans often have a specific share of renewable energy financing within their portfolio	• Loans of the World Bank • European Investment Bank (EIP) • Activities of individual countries, e.g., Germany has developed a strategic partnership with the Inter-American Development Bank (IDB)

Sufficient, Affordable Financing (cont.)		
Policy	**Description**	**Examples/Details**
Global partnerships	Interest-free loans, risk sharing, and co-funding options for renewable energy projects, are mechanisms that are focused on support to developing and emerging countries. (CanREA 2006)	• Global Environmental Facility (GEF) • Global Village Energy Partnership (GVEP) • Global Energy Efficiency and Renewable Energy Fund (GEEREF) of the European Commission (European Commission 2006) • Renewable Energy and Energy Efficiency Partnership (REEEP)
Third-party financing	Another form of off-balance-sheet financing, instead of debt financing	• IDAE model in Spain: An investor provides 80-100% of the initial investment in addition to technical and management solutions. The investor owns the project up to the recovery of the investment, at which time ownership of the equipment is transferred to the user.
Micro-Financing	Useful for off-grid PV projects, especially in rural areas that are financially disadvantaged and/or geographically remote.	• The Bangladesh Grameen Shakti program: Using a combined approach of micro-financing and technical expertise delivered by the same supplier, more than than 210,000 solar home systems were installed, leading to 38,000 villages being equipped with electricity (Barua 2007)
Financial risk management	Loan and partial risk guarantees to transfer project risks, usually implemented in conjunction with private financial institutions	• French FOGIME • Canadian GMIF • RE and EE Program of U.S. Department of Agriculture • Guarantee facilities of the World Bank in developing countries

Key areas to be considered when analyzing sufficient and affordable finance include:

- Incentives for private investments
- Utility-scale project financing
- Pilot projects financing
- Risk mitigation
- Micro-financing
- Carbon financing

Appendix B provides further detail on these areas.

Research, Development, & Demonstration

As a result of robust research, development, and demonstration (RD&D) policies, tremendous technology progress and significant cost reductions have been achieved in the solar sector in recent years. Promising new technologies and novel concepts are providing further opportunities for generating economies of scale and greater cost reductions.

Demonstration and Test Facilities

The gap between R&D success and market entrance for new technical solutions, sometimes called the "valley of death," can be bridged, at least partially, by demonstration projects and test facilities. Test facilities and demonstration projects help accelerate technology development, bring about cost reductions and spur technology deployment. They provide prototype and component testing, supporting future R&D and serving as starting points for further technology refinement (e.g., improved materials, quality management, increased efficiency and reliability, extended service life). Furthermore, large-scale demonstration projects improve public awareness and publicity of various solar technologies. The number, quality, and funding of active testing facilities varies significantly by solar technology.

Current Best Practices in RD&D

The greatest technological progress in solar energy thus far has been achieved through a combined approach of stable RD&D policies, combined with significant deployment policies, thereby benefiting from synergies between laboratories and economies of scale in deployment. In recent years, such dynamics have spurred progress in PV and solar heating, and a similar effect is becoming increasingly apparent with CSP installations. RD&D experience in the solar sector has shown the critical importance of an appropriate research environment that includes stable and reliable funding, protection of intellectual property rights, and the availability of suitable research facilities capable of pursuing a strategic research agenda.

The following table provides several examples of best practice RD&D efforts. See Appendix B for further detail.

RD&D PROJECTS	
Policy	**Examples/Details**
RD&D leadership	• The European Union's Framework Programs for Research and Technology Development and the German Energy Research Program on Renewable Energy have been very successful in supporting major technology development programs, according to the German renewable energy institute, IWR (2009). • The U.S. Department of Energy's Solar Energy Technologies Program serves as an example of a customized R&D program focused on developing cost-effective solar technologies. The program's four sub-programs (PV, CSP, Systems Integration and Market Transformation) focus specifically on reducing costs, improving system performance, and finding new ways to generate and store energy captured from the sun. • Introduced in 2004, Japan's PV Roadmap towards 2030 (PV2030) shows a broad set of technology option pursued in its R&D program.
Cooperative industry RD&D	• The European platforms for solar thermal energy (ESTTP) and photovoltaics (EUPVTP), the IEA implementing agreements on PV (PVPS), solar heating and cooling (SHC), and CHP (SolarPACES), and the Renewable Energy and Distributed Generation Task Force of the Asia-Pacific Partnership on Clean Development and Climate, provide best practice examples of R&D cooperation that bring together various stakeholders (research and industry). • The solar tower plant in Jülich, Germany, provides a best practice example of a CSP test facility established through a public-private partnership. It was co-funded by three different ministries in Germany and realized through the collaboration of the German Aerospace Center (DLR), Solar Institute Jülich, the municipal energy supplier Stadtwerke Jülich, and the construction company Kraftanlagen München.

RD&D PROJECTS (CONT).	
Policy	**Examples/Details**
Demonstration and test facilities	**PV:** The primary test facilities for PV cells are installed at the National Renewable Energy Laboratory (NREL) in Colorado, U.S., the Fraunhofer ISE in Freiburg, Germany, and the Research Center for Photovoltaics at the National Institute of Advanced Industrial Science and Technology (AIST) in Ibaraki, Japan. **Solar Heating:** The major players at the international level are, for example, the Institute for Solar technology (SPF) in Rapperswil, Switzerland and the "Testzentrum Solarthermie" (TZS) in Stuttgart, Germany. Other major test facilities for solar thermal systems are located at CRES in Athens, Greece and at the National Centre for Quality Supervision and Testing of Solar Water Heating Systems in Beijing, China. **CSP:** Worldwide, several test facilities and large-scale demonstration projects in the CSP sector are currently in operation including, for example: • The Plataforma Solar de Almería (PSA) in Spain, which continues its success due to the unique and constant growth of its facilities, constant funding and great demand for its capacity. With participation from nine IEA countries under the leadership of the German Aerospace Center (DLR), several small CSP-plants were initially installed in Andalusia in 1980. Since 1999, the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) has maintained sole management responsibility for PSA by continuing its close and successful cooperation with the German research partner DLR. • In the U.S., the Sandia National Laboratory (New Mexico) operates the National Solar Thermal Test Facility (NSTTF), with an installed 5 MW solar power tower for component testing. Other solar tower test facilities include the Weizmann Institute in Rehovot (Israel), the former THEMIS plant in the French Pyrenees (planned to be revived as a research platform), and in Australia, at CSIRO's Energy Centre. Australia has recently announced an AUD$1.5 billion initiative "Solar Flagships" to support the construction and demonstration of up to four large-scale solar power plants in Australia, using both CSP and PV technologies. • To investigate key properties of CSP plant components including efficiency, durability and verifiable usability, DLR has recently constructed a unique qualification and evaluation center for solar thermal power plant technology (QUARZ) in Cologne, Germany. The center also focuses on the development of certifiable standards and testing techniques for technical performance capabilities.

RD&D Gaps

Overall government expenditures on energy RD&D have steadily declined compared to levels achieved in the late 1970s and early 19080s (see Appendix B). This decline has impacted development of solar technologies. According to IEA's findings in its recent analysis for the MEF Global Partnership (IEA 2009f), current global R&D investments are insufficient to achieve needed advancements in solar energy technologies. If the BLUE Map scenario 2050 goals are to be met, then a global annual spending gap for RD&D in solar energy of approximately US$900 million must be filled.

Raising Public Acceptance and Sustainable Production

Public acceptance is required in order to avoid costly delays for solar projects that can be caused by third-party claims. Although public acceptance of solar technologies has generally been good thus far, the growing number of large-scale ground mounted installations, as well as concepts for increased building integration of PV, might result in a more critical public response in the future.

Both policymakers and investors may find it necessary to address the following:

- Need for improved public awareness of the benefits of solar technology, through, for example:
  - Appropriate public or private promotion campaigns
  - Periodically evaluating the impacts of an increasing use of solar technology
  - Introducing ambitious labels for quality
  - Improved design concepts for building-integrated PV applications
  - An integrated and holistic spatial planning approach, including environmental impact assessments, that addresses possible conflicts regarding the protection of historic buildings and evaluates land-use conflicts. Such an approach can assist in settle rivaling interests earlier than otherwise and may help avoid costs caused by project delays in the implementation stage.
- Sustainability of all stages of the product life cycle (see text box below)

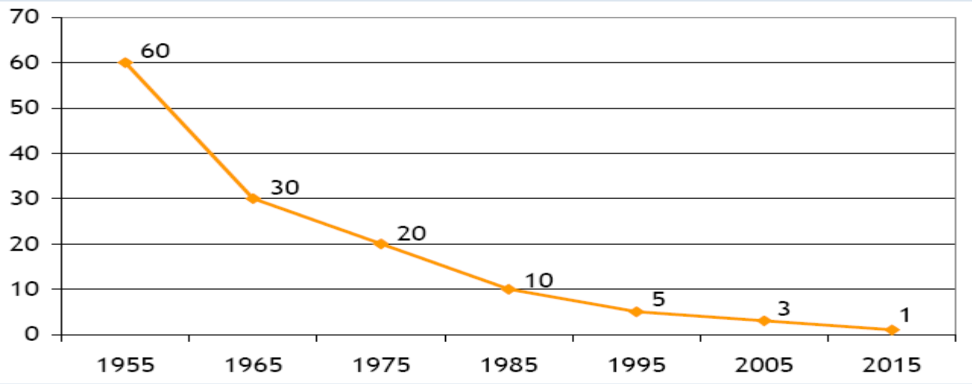
ENVIRONMENTAL SUSTAINABILITY

The PV industry is working to create truly sustainable energy solutions that take into consideration the environmental impacts of all stages of the product life cycle, from raw material sourcing through end-of-life collection and recycling. At present, the energy needed to produce and install a PV system connected to the network has an energetic pay-back period from 1.5 to 4.5 years, depending on the specific technology (e.g., monocrystalline silicon, polycrystalline silicon, think film) and the location (IDAE 2007).

In relation to the management of the PV components, industry agrees on the challenge of clean production and the need to close the cycle by recovering and recycling PV modules as much as possible. Analysis has shown that significant ecological relief can be achieved, in particular, if high value recycling solutions are realized (e.g., if both glass as well as semiconductor materials are reintroduced into the production process) (BMU 2007c).

In the European Union, research studies show that the waste generated in Europe from the decommissioning of PV will amount to 130,000 tonnes in 2030. Several initiatives are underway in the European Union, via the European Industry Association PV Cycle, and in the U.S. Department of Energy's Brookhaven National Laboratory and National Renewable Energy Laboratory to design and implement best practice strategies to address the sustainable management of the whole PV life cycle (BMU 2007c).

FIGURE 7. ENERGETIC PAYBACK PERIOD IN YEARS



Source: IDAE 2007

Improved Planning and a Reduced Administrative Burden

Streamlined and Harmonized Procedures

Potential investors in a solar energy project need an effective and stable policy framework with clear, rationale administrative procedures that minimize their transaction costs.

Complex, bureaucratic approval and permitting processes can significantly increase investment risks and even lead to project failure. Moreover, differing requirements among regions and their application by multiple jurisdictions (local, state, federal), each with different methods of assessing costs, benefits, and environmental impacts, can mean increased effort, longer delays, and added investor uncertainty.

Countries with a long history in renewable energy projects, such as Denmark, Germany, and Spain, recognize the value of a streamlined, integrated, and efficient process. Such a process incorprates a combination of simplified approval procedures, grid access, and comprehensive information for all actors involved.

Permitting institutions can establish internal guidelines that promote fast-track approval procedures and set clear expectations or obligations for response periods (i.e., guarantee that a "yes" or "no" decision will be made by a specific date). In this context, one approach has been to give permitting authorities ambitious targets for approval rates. In addition, solutions are needed to limit the negative impacts of speculators on clogged transmission study queues.

Integrated and Reliable Planning

While the public generally accepts solar installations, planning and permitting procedures can create challenges that can hinder investments. These challenges differ depending on whether the solar installation is large- or small-scale, and whether investments on a national or international level. Integrating a small-scale installation into a building or urban area may lead to conflicts regarding the installation's aesthetic appearance, disturbances caused by the reflection of sunlight, or the preservation of a site's historical integrity. In the case of large-scale, ground-mounted solar installations, land use conflicts may arise due to the size of the system. Installations with a capacity of over 1 MW require a surface area greater than 1,000 square meters. CSP plants may require an even greater surface area. For example, the CSP plant "Andasol I" in Spain covers approximately two square kilometers. In addition, the high population densities of some emerging economies, many of which have an abundant solar resource and significant growth potential for solar energy, will likely complicate planning and permitting processes in these countries as well.

Such concerns can be addressed through an integrated yet streamlined planning process that balances different land use, building-related and environmental conflicts and helps avoid delays during the permitting process. This process should begin soon after a project's inception, in particular for large-scale solar projects, and ensure early contact between investors and relevant authorities. In fact, potential investors could help reduce planning challenges by providing early advice on complications that have arisen during the prior history at a given building site.

To reduce investment uncertainty further, solar installation operators could also be guaranteed legal claims to their installation sites, if they fulfill all necessary requirements (which should not discriminate against solar energy projects).

Facilitating Information Access

Challenges related to planning, permitting, and other administrative procedures increase exponentially when viewed in a global context. Differences in complex procedures and requirements among countries can hinder global investment in solar energy even more than bureaucratic challenges at a national level, in part, because it can be much more difficult to gain access to needed information internationally.

A comprehensive global database that provides easy access to information on procedures, requirements, and framework conditions (e.g., support schemes and financing) could help mitigate this challenge. Such a database might also provide geo-specific information on technology-specific solar potential, recognizing that accurate site assessment is one of the most important preconditions for investment.

Ultimately, an integrated approach, whether country-specific or international, should improve transparency and information for investors. Best-practice planning standards and guidelines should be refined and regularly updated to reflect new knowledge.

Provide Greater Legal Certainty

Development in solar energy markets illustrate that deployment occurs where markets and support policies are sufficient. Investment decisions do not appear to depend on the highest solar radiation so much as the prevailing framework conditions. A major factor in investment decisions is the degree of legal certainty, referring to the reliability and predictability of the judicial system and intellectual property rights frameworks. A lack of legal certainty can increase investment risk, and thus, poses a major obstacle to global investments in solar energy projects.

Support Human Resources: Training and Capacity Building

Capacity building is of key importance for the development and large scale deployment of solar energies. Capacity building entails developing the core knowledge, skills, and capabilities of organizations or individuals. It comprises a number of key features that enable the use of solar energies. Ultimately, it shapes the operational, organizational, and political processes of change.

In developing countries, capacity building efforts are need to provide technical and administrative assistance for private and public stakeholders to close remaining knowledge gaps. This also includes advising on the establishment of policy and legal frameworks to create an enabling environment for solar technology. Furthermore, joint efforts between the public and private sectors are necessary to overcome the currently weak dissemination of information about solar technologies. Such efforts are vital to enhancing the effectiveness and sustainability of organizations, and strengthen their ability to meet the needs of their clients (IEA PVPS 2003, Sobeck and Agius 2007).

Several best practices are described in the table below. A relatively new initiative that may have significant impacts on capacity building, the International Renewable Energy Agency (IRENA), is described in a text box below.

Supporting Human Resources		
Policy	**Description**	**Examples / Details**
Provide technical assistance	Technical assistance helps individuals and groups identify and address issues and gain the knowledge and experience needed to perform tasks effectively (IEA PVPS 2003). It involves public institutions and independent organizations providing technical support and assistance, training, and resource networking.	The Global Environment Facility (GEF), a global partnership between 178 countries, international institutions, NGOs, and the private sector, is engaged in a large-scale solar energy project in the Philippines. GEF provided support, including technical assistance on the development and operation of clean electricity and financing solutions to the electricity utility Cepalco as it built a one-megawatt PV plant, which provides enough electricity for at least 900 households (GEF 2005). Another example of successful capacity building in developing countries is the engagement of the GTZ, a German federal enterprise, in technical cooperation and support for small-scale, local solar power systems in Uganda. In addition, the GTZ is promoting Ugandan-German business partnerships to jointly tap business potential in the solar sector. By conducting advanced technical and business seminars for project development in solar energy learning processes and sharing design experience, the operation and maintenance of solar systems is promoted (GTZ 2009a, GTZ/BMWI 2009).
Offer administrative assistance	Technology based on renewable energy has a wide range of applications, from providing basic domestic electricity and heating/cooling services to health-related, educational, agricultural, and commercial uses. This breadth of application is often underestimated by government ministries and local experts in developing countries. Thus, administrative assistance to build up expertise, not only in developing countries' national energy ministries, but also in their ministries of rural development, is thus a key capacity building activity (IEA PVPS 2003).	Developed and developing countries, public institutions and independent organizations can all actively engage in administrative knowledge transfer. A useful example of administrative assistance is the "Transfer Renewable Energy & Efficiency" (TREE) project of the Renewables Academy (RENAC) in Berlin. TREE is a scholarship program that facilitates the transfer of knowledge in renewables to decision-makers from public institutions, high potentials and engineers from developing countries and emerging economies. The organization offers seminars in Berlin and its partner countries, South Africa, Namibia, Chile, Peru, and Jordan (TREE 2009). RENAC is financially supported by the German Federal Ministry for the Environment under the framework of the International Climate Initiative.
Create an enabling environment	Capacity building involves creating an enabling environment in developing countries. This means shaping appropriate policy and legal frameworks, institutional development, human resources development, and strengthening managerial systems (IEA PVPS 2003).	Policies, tariffs, and incentives supporting the rapid growth of solar power technology are useful in this context. For instance, developing countries may choose to offer tax breaks on imported solar power equipment. Similarly, policy and legal frameworks can be strengthened by creating renewable energy enterprise zones (REEZ). The Sustainable Energy for Africa (SUSEA) initiative is a good example of such effort. The International Solar Energy Society (ISES) (a non-profit global NGO) seeks to bring together African governments, utilities and the renewable energy industry to discuss the potential of using renewable energy technology in Africa (ISES 2007). ISES encourages governments to create REEZ in which individual energy concepts can be developed for each area, tailored to specific local needs and circumstances.

Supporting Human Resources (cont.)		
Policy	**Description**	**Examples / Details**
Promote information dissemination	Public institutions and independent organizations can improve the transparency of ongoing capacity-building activities, including encouraging companies to join forces with them to improve information dissemination on solar energy technologies. This would allow better coordination of activities and enable organizations to focus on the areas and methods that produce the best results (IRENA 2008). To facilitate joint efforts between the public and private sectors, capacity building should be addressed during the early stages of planning solar programs and viewed as one of the core planning components (IEA PVPS 2003)	The project-by-project nature of many agencies can lead to local skills not being developed strategically. When projects are finished, the skills gained–particularly in the areas of operations and maintenance–tend to fall out of date or are even lost. However, the private sector relies on qualified staff for operations and management services and thus, has a stake in the capacity building process. It needs well-informed and educated installers, technicians, program designers, administrative officers, and end users (IEA PVPS 2003). Given these interests and the rapid technical advancement of renewable energy technologies, capacity building, using accurate, up-to-date information, should be incorporated as a core component of planning.
Build a knowledge base	Experience has taught that capacity building efforts require continuous development and improvement. Therefore a comprehensive, strategic approach is needed, covering the development of all renewables, and permanently gathering, concentrating and updating all relevant information.	Valuable knowledge base initiatives are active at a global level, including the Renewable Energy Policy Network REN 21 and the Renewable Energy and Energy Efficiency Partnership (REEEP), which applies the search engine reegle for information on renewable energy and efficiency.

The International Renewable Energy Agency (IRENA)

Despite the many valuable capacity building initiatives underway today (e.g. REEEP, REN21, UNDP), no central authority currently exists to function as a "one stop shop" for gathering and concentrating knowledge on renewable energy technologies and performing capacity building and technology and knowledge transfer.

The International Renewable Energy Agency (IRENA) aspires to provide such an international hub for all renewables. Founded in January 2009, IRENA plans to provide practical advice and support on renewable energy for both industrialized and developing countries, thereby helping to improve frameworks and build capacity. In addition, it intends to facilitate access to all relevant information, including reliable data on the potentials for renewable energy, best practices, effective financial mechanisms, and state-of-the-art technological expertise. Moreover, IRENA plans also to cooperate with and build networks of existing institutions in this field.

Currently, IRENA is being built up. To date, 137 countries and the European Community have signed the Statute of IRENA, with seven having ratified it.

Technology Cooperation

Technology cooperation has the potential to accelerate technical development and foster the transfer of technology to places where high levels of solar radiation remain untapped. In general, international collaboration is required among all regions of the globe. However, the situation in developing countries is complex and requires an integrated policy strategy that provides appropriate support from industrialized countries in technology cooperation, funding, and capacity building. Perspectives are needed on how to strengthen international cooperation on RD&D and specialized research centers. Nevertheless, cooperation is required not only in the development of new technology, but also in its deployment. Hence, the private sector should play a strong role in this effort.

In the past, most technology cooperation in the solar sector has focused primarily on cooperation among countries of the North. For example, the IEA Implementing Agreements (IAs), which pool the resources of participants to foster the research, development, and deployment of specific technologies, were focused, at least initially, on cooperation among IEA Member Countries. For over 30 years, such international technology cooperation has served as the fundamental building block of progress toward new and improved energy technologies (IEA 2009d).

Although such North-North cooperation is essential in promoting the development and application of solar technology, it is not in itself sufficient. To achieve the large-scale deployment of solar energy (and other advanced technologies), more cooperation is needed between countries of the North and those of the South. The IAs, for instance, now allow interested member states, non-member governments—including those from developing countries or countries in transition—and other organizations to participate. In addition, further cooperation among countries in the South is needed.

Apart from the need to strengthen North-South collaboration and mutual exchange, and enhance South-South technology cooperation, a step change is needed in the scale and depth of international strategic cooperation to deliver low-carbon technologies, including the large-scale deployment of solar energy. The historical framing of the technology debate, based on an "ask" and then "response" between developed and developing countries, has generated a large amount of distrust and does not reflect the way effective innovation systems currently operate (Mabey and Tomlinson 2009). More public and private partnerships across different countries of the North and South are needed. A further element in this regard is stronger cooperation between solar energy research centers.
Please see the table below for best practice examples of existing solar energy or renewables technology cooperation.

TECHNICAL COOPERATION	
Policy	**Examples / Details**
North-centered cooperation (Note: Emerging and developing countries often participate in these processes.)	In the field of solar energy (electricity and heating and cooling), the IEA has created a number of implementing agreements: the IA Photovoltaic Power Systems Program (IA PVPS); the IA Renewable Energy Technology Deployment (IA RETD); the IA Solar Heating and Cooling Program (IA SHC); and the IA Solar Power and Chemical Energy Systems (IA SolarPACES). The IEA has also recently begun drafting Energy Technology Roadmaps targeted at unlocking the full potential of current and emerging technologies. Solar technology is one of the priority technology areas (IEA 2009e). Set up in 2006 with support from the European Commission, the European Solar Thermal Technology Platform (ESTTP) relies on cooperation and exchange of information between public and private stake-holders all over Europe to pursue its objectives of developing a comprehensive strategy and increasing R&D activity accordingly (ESTTP 2009a, ESTTP 2009b)
North-South cooperation	The PROSOL project was established and designed by Italy, Tunisia, UNEP/DTIE, the Tunisian ANME and the Mediterranean Renewable Energy Centre to help overcome financial barriers to the large-scale diffusion of solar water heaters (SWH) in Tunisia. It targets the residential sector by involving all actors active in the sector: government, electricity state utility, bank sector, technology suppliers and installers. By mid 2009, more than 73,000 SWH have been installed, corresponding to 218,000square meters of solar collectors (PROSOL 2009). Announced by France and Germany in June 2008, the Mediterranean Solar Plan (MSP) calls for 20 GW of new renewable energy capacity, focusing on CSP. It was developed within the framework of the Union for the Mediterranean (UfM), an organization comprising all the EU member states and 21 countries with a Mediterranean coastline or participating in the Euro-Mediterranean Partnership. The UfM has institutionalized an equal-basis cooperative framework between EU- and non-EU countries by establishing a co-presidency to be shared by the North and South. Priority tasks in the MSP include the large-scale deployment of solar energy, the promotion of electricity interconnections to establish a solid grid infrastructure, and cooperation on technology. According to the EU's Strategic Energy Technologies Plan, the MSP will be integrated with new and existing initiatives such as Solar Europe (Hoyer-Klick 2008, RCREE 2009). The STE Research Platform in Spain (Platforma Solar de Almería or PSA) is the largest center of research, development and testing of concentrated solar technologies in Europe. It has an exemplary record in building up and maintaining large cooperation networks and combining a north-north and a north-south approach toward technological cooperation (PSA 2009b). Solaterm, an EU-funded project initiated in 2006, focuses on technology cooperation between the EU and its southern Mediterranean partners such as Algeria, Morocco and Tunisia. The overall objective is to meet the increasing demand for hot water and cooling and to exploit the high potential of solar energy in the Mediterranean region. Therefore, Solaterm, which relies on a cooperative network of administrations, research institutions and national energy agencies, aims at the widespread application of a new generation of solar systems for hot water, heating and cooling in the Southern Mediterranean partner countries (GTZ 2009a, 5f.).
IRENA	The International Renewable Energy Agency (IRENA, described in the text box above) aims at becoming an international hub for all renewables and might add North-North and North-South technology cooperation as soon as it becomes operational.

3. Actions to Accelerate Development and Deployment

This plan has outlined the potential for greatly reducing GHG emissions through deployment of solar energy technologies. Effective solar technology implementations are not based on "one size fits all" solutions. Specific country and regional factors will determine the appropriate set of technologies, applications and solutions for each geographic area and country that wishes to implement effective solar technology policy. Nonetheless, all countries seeking to catalyze progress on solar energy should consider similar categories of action. Countries can also work together to expedite their programs and develop standards that enable the wider dissemination of solar energy technologies.

To achieve transformational gains in solar energy technologies globally, MEF countries have developed a menu of opportunities to develop and deploy such technologies. Many of these actions rely on, or can be effectively leveraged through, coordinated action among countries, including support for existing international forums. This chapter discusses both opportunities for individual country action as well as opportunities for cooperative action among MEF countries.

Menu of Opportunities for Individual and Collective Action

Chapter Two illustrates multiple best practices that point to specific individual and collective country actions that can help to reduce market barriers and realize the full potential of advanced vehicles. Key categories of action for consideration include the following:

- Supporting innovation:
  - Develop new technologies.
  - Demonstrate new technologies.
- Accelerating deployment:
  - Support stronger demand for solar power.
  - Improve grid and system integration.
  - Improve planning of solar plants and transmission, with reduced administrative burden.
  - Provide legal certainty.
  - Support training and knowledge management to ensure sufficient labor and intellectual resource.
  - Ensure sufficient, affordable financing.
  - Establish voluntary industry standards and otherwise reducing investment risk.
  - Build deployment capacity.
  - Improve relative economics between advanced clean energy technologies and conventional technologies to encourage market-based adoption.
  - Establish and strengthen regulation.

- Facilitating information sharing:
  - Share best practices and knowledge.
  - Enhance public awareness.

The following section outlines a menu of actions within each category, *generally listed in increasing order of ambition*. Interested countries should consider the actions in each category to identify those that may be appropriate to their unique circumstances.

Supporting Innovation

- Consider the benefits of possible joint RD&D projects between public institutions (e.g., laboratories, universities).
- Strengthen the role of the private sector in technology cooperation.
- Strengthen cooperative networks of solar energy research centers and other important players.
- Consider promoting an increase in the number of test facilities and large-scale demonstration projects in different regions of the world, but especially for CSP in sunbelt countries.
- Follow a combined approach of RD&D and consequent deployment policy benefiting from economies of scale and spillover effects between research and mass-scale testing.
- Follow a balanced set of instruments that ensures support of new, innovative concepts and all promising renewables technologies for a broad technology basket for future energy security.
- Provide, as appropriate, for sufficient test facilities and demonstration projects, particularly to address specific needs of new and emerging technologies.
- Establish appropriate R&D framework conditions and environments, covering also legal certainty and intellectual property rights.
- Strengthen North-South collaboration and mutual exchange, and enhance South-South technology cooperation; also address the issue of rural electrification.
- Increase and coordinate public sector investments in RD&D in line with the L'Aquila declaration, while recognizing the importance of private investment, public-private partnerships, and international cooperation, including regional innovation centers.
- Additionally focus on technology cooperation in the deployment phase.

Accelerating Deployment

- Encourage universities to initiate or further develop and deepen curricula in all relevant fields of renewable energy such as engineering, energy, environment, policy, economics, finance, urban planning, and natural resources management.
- Develop specific curricula in engineering disciplines at colleges and universities and set up technical schools to provide practical and theoretical training for mechanics, electricians, etc. in solar energy.

- Facilitate capacity building as one key element of solar energy projects.
- Develop and follow a strategic and sustainable capacity building approach, not only concentrating on project-by-project training.
- Continue to focus on technology cooperation during the deployment phase.
- Promote strategic dialogue with investors to access untapped financing sources and establish public-private partnerships to accelerate investment in developing and emerging countries.
- Establish control centers that optimize flow, enable a wide-area monitoring approach, and improve weather forecasts (e.g., Spanish power systems operator Red Electrica).
- Conduct detailed grid studies involving system operators, industry, and policymakers.
- Develop comprehensive grid studies that reflect a long term strategy for improving grid infrastructure.
- Ensure an early start for grid infrastructure planning and provide for early involvement of stakeholders.
- Provide streamlined and concentrated administrative procedures; consider the benefits of a "one stop shop" approval system.
- Introduce simplified approval procedures for small plants.
- Establish streamlined permitting and planning procedures for offshore projects.
- Accelerate appropriate permitting procedures and give clear time horizons to facilitate project planning.
- Make international funding schemes more transparent.
- Follow an integrated spatial planning approach that settles rival claims, assesses environmental impacts, balances different land use interests, and prevents third party claims during the permitting or construction periods.
- Follow a holistic approach[22] in planning activities to integrate renewable energy into the overall system and balance rival interests.
- Support efforts to cooperatively set or harmonize standards such as technical standards, labor and safety standards, and grid codes.
- Provide for clear, transparent, harmonized and sufficient regulations, requirements, and procedures to facilitate investments.
- Ensure sufficient grid capacity either through extending and upgrading the grid and/or through optimized grid operation (e.g., using demand side management).
- Create an enabling environment by offering tax incentives and create renewable energy enterprise zones to promote the use of solar heating and PV systems.

[22] Such an approach would cover a flexible mix of power plans and advanced storage capabilities; advanced demand-side management; improved congestion management; connection of different power systems and market in order to enhance flexibility and grid adaptability; improved weather forecasting models and wide-area monitoring; and facilitation of new concepts, intelligent applications and devices (e.g., smart meters) to intelligently interconnect supply and demand side in a way that allows online-based real-time system management.

- Launch a major market enhancement initiative for off-grid PV systems with the objective to significantly increase the number of households with access to off-grid PV systems in developing countries.
- Launch a strategic campaign to install solar heating in developing countries that lack a sufficient solar heating market, to be guided by the Solar Water Heating Market Transformation and Strengthening Initiative implemented by the Global Environment Facility in cooperation with UNDP and UNEP.
- Make appropriate use of novel concepts and new technologies in grid infrastructure and operations.
- Ensure that permitting requirements are transparent and do not discriminate against solar energy projects.
- Provide that solar energy installations are privileged, as appropriate, when balancing interests in the permitting process.
- Provide for pre-designation of priority and reserved areas.
- Provide legal claim for permitting, if requirements are fulfilled.
- Enact policies that provide for guaranteed connection and guaranteed or priority access to the grid for solar energy, with appropriate allocation of connection costs.
- Provide public funding to pay for grid connection (e.g., Denmark and Germany provide free grid connection for offshore wind installations).
- Interconnect power systems and neighboring markets to enable greater share of renewables (e.g., proposed North Sea grid).
- Establish stable and predictable legal frameworks.
- Set ambitious concerted targets to provide long-term investment security for solar energy; formulate these as minimum targets to achieve sustainable market development without "stop-and-go" cycles.
- Establish a predictable and reliable support scheme, taking into account unique national circumstances.
- Consider the use of tax and investment incentives, particularly during the early stages of market development. Soft loans can offer an additional incentive.
- Consider the benefits of mandatory minimum requirements for use of solar energy technologies in buildings.
- Promote micro-financing in combination with technical assistance to reach rural populations and alleviate poverty, especially in developing countries.
- Implement, as appropriate, large-scale strategic financing programs with a sustainable impact.
- Consider leveraging more commercial financing through guarantee elements.
- Internalize external costs, e.g., through a cap-and-trade scheme or carbon tax.

Facilitating Information Sharing

- Facilitate best practice guidelines.
- Develop transparent and easily accessible information on requirements and procedures.

- Develop databases to make information more accessible.
- Improve consumer awareness of the benefits from electricity generation from renewables through appropriate public information campaigns and all other appropriate marketing options.
- Ensure transparent and cost-effective disclosure for consumers of renewable energy origin (e.g., via labeling).
- Support transparent information for consumers on the effect that their green power purchase agreements have on the deployment of additional renewables installations.
- Build up solar energy expertise in governments and in the private sector and keep decision makers informed.
- Provide training opportunities for solar energy technologies.
- Make information accessible and facilitate know-how transfer by training, workshops, and Internet libraries/databases.
- Support international institutions, such as IRENA, that focus on capacity building in cooperation with existing institutions (e.g., REEEP).
- Involve both public and private sectors to join forces in disseminating information about solar technology.
- Support strategic holistic capacity building on a global level, particularly focusing on countries with a need for solar energy capacity building.
- Develop jointly a global solar atlas with all relevant information to attract cross border investments (i.e., a comprehensive database on country specific economic, legal and administrative investment conditions combined with a global inventory of the potential of solar energy with a high spatial and temporal resolution to allow appropriate global, regional, and national renewable energy modeling).
- Coordinate development of a global solar plan that comprises demonstration and deployment projects, including a global roadmap for solar power projects, the necessary legal, political, and economic frameworks, a strategy for the necessary grid and infrastructure expansion, and identification of financing mechanisms.
- Establish an international technology platform (ITP) to address a deficit of consultation between policy, investors, and stakeholders and to promote an intensive dialogue between governments and industry. Moreover, such a platform can help to match the demand and the supply for specific technologies and to develop new and innovative concepts.

Actions by Individual Countries

To accelerate development and deployment of advanced solar energy technologies, countries should consider adopting some of the actions in each of the categories outlined above, as appropriate to their goals and unique national circumstances.

When choosing these options, MEF countries should in particular take into account the importance of ambitious renewable targets and predictable support schemes. An accelerated global deployment of solar technology could realize economies of scale effects; it could facilitate technology progress and improve technology efficiency. A combined deployment and RD&D strategy could realize synergies for further dynamics of technology progress. Thereby, investment costs as well as electricity generation costs could be driven down along the technology learning curve. All countries could benefit from this technology progress in the long run.

More generally, MEF countries may wish to start by developing a national solar energy roadmap (or updating an existing roadmap) that identifies and appropriately sequences high-impact actions from each category as appropriate to their unique circumstances. These roadmaps may include resource assessments, targets for deployment, reliable support schemes and timelines, and would define the key stages for how solar technologies, associated market changes, and enabling legislation should be implemented in order to meet those targets. Moreover, they might be integrated with roadmaps for other technologies that would enable broader uptake of solar energy (e.g., smart grid).

Periodically, countries should assess progress against their own action plan and correct their course as desired. At the very least, they may want to ensure that they are establishing policies or taking other enabling actions on the schedule envisioned in their road map. Thereby, they may wish to consider, as appropriate, that ambitious minimum renewable targets, reliable support schemes and internalization of external costs appear to be the most significant policies for solar technology deployment and progress.

Similarly, they may establish a matrix of demonstration projects categorized by solution type in order to ensure they are addressing the full range of promising solar energy technology improvements.

These individual actions could then feed into coordinated or cooperative international initiatives, to the extent appropriate or desired, in accordance with national circumstances.

Coordinated or Cooperative Action

Beyond the individual efforts described above, countries should consider the vital role of international coordination and cooperation for the deployment of solar energy technologies. The Global Partnership can play an active role in overcoming common barriers faced by all countries to accelerate development and deployment of advanced solar technologies. Global Partnership initiatives would not replace ongoing work in existing forums but rather enhance cooperation globally.

Several attached proposals for technology coordination and cooperation seek to add value to ongoing discussions in various forums on the contribution of solar energy technologies for mitigation. They offer an outlook of possible technology cooperation and know-how exchange between developing and developed countries on solar energy. Illustrative calculations on potential benefits, based on different studies, are provided. Individual MEF countries may wish to consider participating in one or more of these proposed initiatives.

Establishing a Global Plan for CSP

Proposed Technology Cooperation

Given its capacity to provide firm and dispatchable solar-based electricity, using thermal storage and/or hybridization, CSP represents a very promising technology that could support overall system integration of large shares of renewable energy. However, deployment of CSP on a massive scale is needed in order to impel technology progress and economies of scale.

MEF countries could join forces with developing countries to support the expansion of solar electricity in regions with enormous and largely untapped solar resources. To this end, joint efforts could be made to develop a Global CSP Plan that illustrates a comprehensive strategy for joint, large-scale CSP projects. Such a Global CSP Plan could:

- Include a global roadmap for joint solar power projects around the sunbelt
- Address the necessary legal, political, and economic framework conditions
- Develop a strategy for the necessary grid and infrastructure expansion
- Reflect adequate financing

Specifically, the global solar plan could outline a number of demonstration and deployment projects that can be undertaken at the national, regional, or international level.

Demonstration Projects

In order to overcome high investment-cost barriers—a key hurdle for large-scale solar power plants—countries with expertise in the field of solar power production could team up with countries with greater solar resources in order to facilitate pilot projects.

Demonstration projects play a key role in bridging the "valley of death", i.e., the gap between R&D progress and market entrance. Demonstration projects validate technological feasibility and provide critical feedback on the need for additional R&D.

Deployment Projects

The Global CSP Plan could evaluate and consider a CSP expansion strategy with a total capacity of several gigawatts. A CSP expansion strategy would send a clear signal to the market and attract additional key investments and innovations.

The Global CSP Plan could prove a "win-win" for the following reasons:

- By demonstrating highly innovative technologies, including "first-of-its-kind" power plants and joint R&D activities in suitable areas, the needs of today's technology leaders and tomorrow's technology providers can be met.
- Large-scale CSP projects could cover the growing electricity demand of developing and emerging countries.
- All countries could benefit in the long run from future reduction of CSP investment costs and electricity generation costs, induced by economies of scale and technological progress along the learning curve.

- Demonstration as well as deployment projects could improve storage technology and dispatchability of CSP plants. Improved CSP plants could facilitate system integration of large shares of fluctuating renewables for the benefit of all.
- Exporting CSP generated electricity to neighboring countries could be an additional option to attract investments.
- Large scale projects would have to be accompanied by capacity building initiatives in order to ensure sustainable, comprehensive know-how for the necessary operations and maintenance services.
- A considerable share of investments could be local investments.
- Joining forces for developing and implementing a Global CSP Plan would constitute a unique technology cooperation and know-how exchange and could set free cross-border synergies for the potential benefits of all participating countries.

Background

Today, with an installed capacity of some 500 MW in commercial operation worldwide and more than 1 GW currently under construction (1.1 GW in Spain alone), the CSP market is experiencing dynamic growth. At the end of 2008, more than 7.4 GW was estimated to be in the planning stages worldwide. Less than a year later, estimates suggest that figure has more than doubled (IEA 2009c).

The CTF (Clean Technology Fund) has developed a concept to co-finance 1 GW of CSP in the MENA region over a 6-8 year time frame. This would result in 8-10 commercial-scale power plants. This initiative is currently under review for approval from the CTF Trust Fund Committee.

The proposed Global CSP Plan is targeted to provide further impetus to this scaling-up process. The Global CSP Plan could facilitate the implementation of projects already in the pipeline by addressing the necessary infrastructure, economical and legal framework conditions. Moreover, by inducing new projects, particularly in regions that have not achieved sufficient attention so far, the Global CSP Plan could strengthen dynamics on scaling-up CSP.

Possible benefits could be summarized, roughly, as follows:

- Assuming, as an example, a total new CSP capacity of 20 GW—which could be realized partly by currently planned projects and partly by new projects induced by the Global CSP Plan—would increase the current global CSP capacity by a factor of 40, thus doubling the global CSP capacity more than five times. According to learning curve estimates by the IEA, each doubling of cumulative capacity will decrease the levelized electricity costs by about 10% (IEA 2008b).
- Thus, with 20 GW of new capacity, electricity generation costs for CSP could be reduced by 41%. This additional capacity could also result in annual CO_2 emission savings of about 30 Mt.[23]

[23] Assuming 2,500 full-load hours, i.e. 50 TWh and avoided emissions of 0.6 kg CO_2/kWh electricity per the WEO (IEA 2009k). Exact emission reductions depend on the energy mix of the host country.

- The CTF analysis suggests that the cost for the first gigawatt of newly installed CSP capacity with storage capacity could range between US$5.2–7.8 billion.[24] Moreover, since only few CSP projects have been realized yet, installation costs are likely to decrease with every new GW installed.
- A large share of triggered investments could be local investments. Industry consultations suggest that the local content of CSP projects might amounts to 50% of the total investment and maintenance costs. Local services, particularly local operations and maintenance services, are critical and local production chains could facilitate market presence, assuming adequate legal framework conditions for local production chains are in place. Industry experts from countries in the South have indicated that CSP towers might have a local manufacturing content that is significantly higher than 50%.
- Where appropriate, the export of any electricity that exceeds local demand could constitute an additional incentive to attract investment, especially if the load curves of export and import countries complement each other. This export option could be further incentivized by establishing regional renewable targets for several countries that can partially be fulfilled by imports. However, to avoid overlapping with CDM incentives and facilitate the transition process to a low carbon economy in the importing state, only physically-imported, equivalent amounts of electricity should be taken into account for those regional renewable targets. The new European Directive on the promotion of the use of energy from renewable sources (2009/28/EC) allows for such physical imports from countries outside the EU in order to match Member States' renewable targets.
- The vision for exports currently discussed in the context of the DESERTEC initiative, which plans to install CSP installations in the deserts of the MENA targeted at exporting large amounts of electricity to Europe. However, to achieve this vision, a number of advanced challenges must be addressed including the installation of large high voltage direct current transmission (HVDC) to the receiving country, the establishment of appropriate framework conditions that ensure secure and reliable transmission through transit countries, and the integration of the electricity into the renewable and overall energy strategy of the receiving country. Nevertheless, if managed soundly, energy exports remain a promising option.

Implementation

A comprehensive, holistic approach would be needed to evaluate, verify and address the various aspects and challenges of this Global CSP Plan.

The Global CSP Plan could build on the know-how gathered in the course of the implementation of the recent Solar Plan within the Union of the Mediterranean (MSP). The Solar Plan focuses on establishing the necessary infrastructure and legal framework conditions for large-scale CSP projects in the MENA Region. Close cooperation with the secretariat of the Union for the Mediterranean could be considered as joining forces could add value. The recently founded International Renewable Energy Agency (IRENA) could support the Global Solar Plan as soon as

[24] CTF calculations assume costs of US$4,000–6,000/kW in the MENA region. Moreover, they assume that storage would lead to a 30% increase in costs (CTF 2009). However, these calculations are only a rough estimate as they depend on the specific conditions in the region in question. In addition, they do not cover possible costs for grid infrastructure extension.

IRENA is sufficiently operative and cooperating with other existing institutions. IRENA could add value, particularly regarding capacity building, know-how transfer and policy advice, including project-related technology assessment.

Providing Households with Access to Off-Grid PV Systems in Developing Countries

Proposed Action

Small stand-alone PV systems represent a promising opportunity that could be developed more intensively. MEF countries could evaluate the opportunity to jointly launch a major market enhancement initiative and deployment program for off-grid PV systems in households. The group of countries could include major developing countries such as India and China, as well as industrialized countries, in which off-grid PV systems play (or could play) a more important role, such as Australia and the United States.

This could lead to a win-win situation for the following reasons:

- The considerable potential of small off-grid PV applications would be used to provide access to electricity for households in developing countries
- This initiative would send a clear signal to the market, trigger investment and economies of scale, foster technology efficiency and therefore, reduce investment costs and electricity generation costs along the learning curve. All countries could benefit from this cost reduction in the long run.
- As an illustrative example to indicate possible jobs and CO_2 abatement benefits, based on rough calculations, if this initiative, for instance, provided 40 million households with electricity, it could support approximately 60,000 jobs, most of which would be created locally (e.g., in installation maintenance; Rutovitz and Atherton 2009).[25] If the electricity generated by the PV systems replaces diesel-generated electricity, then it could result in annual CO_2 emission savings of about 8 Mt (IEA 2009k).[26]
- This initiative would need to be accompanied by a capacity building initiative and training for local services as appropriate.
- Such a joint initiative could foster know-how transfer and synergies between developed and developing countries.

Background

Off-grid PV systems can be valuable in remote areas. In China, off-grid PV is assumed to be competitive with electricity from diesel generators[27] (Greentech 2009). Still, off-grid PV systems currently represent less than 10% of the total global PV market. In 2007, the cumulative installed capacity of off-grid PV in member states of the IEA's Photovoltaic Power System program amounted to approximately 660 MW (IEA PVPS 2009). Important off-grid PV markets exist, for example in Canada, the United States, and Australia, where the need for reliable power in remote locations is often met by off-grid PV (IEA 2008c, IEA 2009g).

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[25] Authors' calculation based on PV employment factors of Rutovitz and Atherton (2009).

[26] Assuming 1,000 full-load hours and avoided emissions of 0.9 kg CO_2/kWh electricity generation with diesel generators, per the WEO (IEA 2009k).

[27] Diesel electricity generation prices range between US$0.20–0.30, based on local fuel prices.

Today, 1.5 billion people have no access to electricity. In 2009, the IEA estimated that this figure will only decrease slightly, to 1.4 billion in 2030, if no ambitious countermeasures are taken (IEA 2009k).

In developing countries, more than 2.5 million households receive electricity from off-grid PV known as "solar home systems" (REN21 2008). In many developing countries—particularly in Latin America and Asia—off-grid PV systems are deployed in the context of national rural electrification programs. Some of these initiatives are supported by international organizations. For example, the World Bank is currently involved in two projects in Bangladesh, where the deployment of solar home systems is coupled with off-grid carbon finance under the Clean Development Mechanism (REN21 2008, REN21 2009). Several other PV off-grid programs and initiatives have been launched, such as India's Remote Village Electrification Program, the World Bank's China Renewable Energy Development project, and the German KfW project in Morocco.

Increasing the number of households with access to off-grid PV in developing countries to 40 million by 2020 could also provide an enormous impetus for technology progress for decentralized PV off-grid systems. The initiative would send a clear signal to the market, trigger investment and economies of scale, foster technology efficiency and thereby reducing investment as well as electricity generation costs along the learning curve. In particular, battery systems will benefit from this initiative, since they hold very promising learning rates of 20% (IEA 2008b).

Implementation

Participating countries would need to develop a long-term strategy for this market enhancement initiative and deployment program. This could require a holistic approach. This initiative should therefore, cover government ministries and administrations, as well as planners, installers, and consumers, and should include joint evaluation of possible challenges.

The initiative could accomplish the following:

- Raise public awareness of PV home system at all relevant levels
- Identify access to financing
- Establish appropriate incentives for off-grid PV installations, since current incentives focus on grid-connected application
- Address innovative financing concepts to strengthen demand-pull (e.g., output-based policy instrument of "advance market commitments"; see REEEP 2009 for further detail)
- Provide expert knowledge, and including capacity building and training opportunities for local services where necessary

Expanding Installation of Solar Heating in Developing Countries

Proposed Action

MEF countries could evaluate the opportunity to jointly launch a strategic campaign with the objective to expand installation of solar heating in developing countries that lack a sufficient solar heating market.

This initiative could add value for the following reasons:

- Increasing demand through better-informed consumers will, in the long run, help to develop higher production volumes and gain economies of scale, making the solar heating technology even more competitive.
- As an illustrative example, a total new installed capacity of 300 million m^2 (about 200 GW_{th}) of solar heating could result in annual CO_2 emission reductions of approximately 40 Mt.[28]
- Such a campaign should have a focus on capacity building to ensure that appropriate skills for production as well as for operations and maintenance are developed and available for project implementation.
- Capacity-building and training for professionals, such as planners and installers, would facilitate technology diffusion and know-how transfer.
- Know-how transfer could be strengthened by North-South collaboration. Countries such as China are market leaders for solar heating. China has a solar heating test facility in Beijing, valuable deployment experience, and knowledge about emerging countries. China can, for instance, facilitate further progress in technology and collaboration between developed and developing countries.

Background

Unlike other solar technologies, solar heating is already competitive in many regions today, particularly where solar radiation is high and heating infrastructure for conventional fuels is poorly developed. While some developing and emerging countries, such as China and Turkey, represent leading markets for solar heating technology today, other developing countries have not developed the necessary infrastructure. In many cases, the lack of awareness and training opportunities are problems for the wider deployment of solar heating technologies (IEA 2007, IEA 2008b).

Implementation

The proposed initiative would require a holistic approach, raising public awareness of solar heating at all relevant levels, providing expert knowledge, and including capacity building and training opportunities for local services where necessary. Therefore, it could cover government ministries and administrations, as well as planners, installers, and consumers. It could prioritize the deployment of solar heating in well-proven applications for the tertiary sector (e.g., social services or tourism).

[28] Assuming 500 full-load hours and avoided emissions of 0.37 kg CO_2/kWh heat.

The proposed initiative could be guided by the Solar Water Heating Market Transformation and Strengthening Initiative, which is being implemented by the Global Environment Facility in cooperation with the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP) from 2009 to 2012. The initiative builds up infrastructure for solar water heating, strengthens the supply chain, establishes regulatory environments, and raises awareness in several developing countries (UN 2009). IRENA could contribute to the implementation of this initiative as soon as it becomes operational, particularly with respect to knowledge transfer, policy advice, and capacity building. Moreover, the promising output-based policy instrument of "advance market commitments" could be considered as a potential mechanism for implementing this action (REEEP 2009).

Paving the Road to Grid Parity[29] — Establishing a Grid Parity Circle

MEF countries could consider launching a strategic discourse with industry and international research institutes in a "Grid Parity Circle" to accelerate progress toward grid parity.

Such continuing discourse could add value to the PV technology progress, for the following reasons:

- Political action often differs from market needs
- A continuous discourse with experts having different ideas and being influenced by different policy and market concepts may easier arrive at innovative instruments and novel concepts
- The high-level discourse ensures that novel concepts would have direct access to policymakers

The discourse could accomplish the following:

- Address needed cost reductions for PV to compete with household electricity prices and reflect the way to get there
- Identify necessary progress in complementing technologies (e.g., storage, smart meter, smart grids, etc.)
- Identify possible hurdles for variable tariffs
- Evaluate access to appropriate financing mechanisms; identify innovative financing instruments to attract private investments and to lower up-front investment costs of PV installations (e.g., payments on a monthly basis, such as leasing concepts, or rental agreements included in apartment rental contracts that, for example, allow rents to be above rental indexes when PV is installed on top of the apartment house, etc.)
- Develop joint communication strategies for raising customer awareness of PV installations (e.g., increasing emphasis on economical benefits instead of just environmental ones)

[29] Grid parity refers to the point in time at which PV electricity prices are competitive with household power prices (i.e., the price of power from the grid).

Background

The achievement of grid parity could shift PV to new market deployment strategies if the framework conditions are right. Grid parity will be in reach within the next 5–10 years. The process of reaching grid parity can be accelerated or slowed down, depending on how ambitious the support policies are.

Clear signals from policy support in the past, as well as certain price signals during silicon shortages on the PV market, have led to exponential growth of PV manufacturing capacity. However, corresponding growth on the demand side is strongly influenced by legal and economic framework conditions. A comprehensive, valuable discourse on grid parity strategies, including policymakers, industry, and researchers, could give a clear market signal and provide the necessary stability and reliability for industry to develop strategic business plans, attract innovative investments, and lower investment risks and costs of investment.

Implementation

MEF countries could start such an initiative immediately by launching this Grid Parity Circle. Such a Grid Parity Circle could include representatives of the largest markets, the largest PV companies, research institutes, and other stakeholders, as appropriate. A joint effort between IRENA and the IEA could be entrusted to implement this task on behalf of the Global Partnership.

Triggering Demand-Pull for High-end PV in Niche Markets

Proposed Action

The use of PV should be extended to new applications. Very small PV applications (or “pico PV”) can enter mass markets by providing mobile power supply for electronic off-grid devices.

MEF countries could consider developing a joint strategy to facilitate light-weight, mobile off-grid PV applications.

A joint strategy would send a clear signal to the market, incentivize investment and innovation, and hopefully trigger demand-pull driven market situations.

This strategy could, for instance:

- Identify promising niche markets and market barriers
- Address innovative financing concepts and other incentives to strengthen demand-pull (e.g., the output-based policy instrument of “advanced market commitments”)
- Reflect possible R&D gaps

A promising niche market could be information and communications technology (ITC), which includes, for example, notebook computers and cell phones. Another important niche market includes rooftops of automobiles and other vehicles. Installing PV here may, for example, help save fuels otherwise spent on air conditioning.

Background

Today, more than 2.6 billion cell phones are operated worldwide and approximately 500 million people use laptops. The future holds an almost unlimited increase in the demand for information and communication technologies. In this growing market, emerging countries play an increasingly important role. Since grid access is often limited in such countries, technologies with integrated electricity supply from PV offer better access to information and education. In industrialized countries, on the other hand, integrated PV electricity supply would limit charging procedures.

Since the electricity demand per mobile integrated-circuit (IC) application has been substantially decreasing over recent years, even very small-scale integrated PV systems are already able to grant the required energy without grid connection. Cell phones using PV as their main energy source have just been introduced into the market (for illustration, the deployment of 5 million mobile phones with integrated PV cells would represent a collector area of 30,000 square meters). The additional collector area and associated CO_2 emission savings might be small, but the expected technological development is the real dimension that should be considered in such an effort. Since the average lifetime of cell phones hardly exceeds five years, this new generation of cell phones would penetrate the market very rapidly.

Given the short lifetime of IC technologies in general, the recycling aspects of electrical equipment and PV systems would have to be considered as well in such a development. The linkage between PV technology and the highly innovative IC industry could lead to a technological boost for several other applications, such as standalone systems or public lighting with PV-integrated systems.

Establishing a Global Solar Atlas

Problem

Consultations with industry and experts in the field of solar energy illustrates that insufficient information on investment conditions, potentials, legal and economic conditions, and administrative hurdles in other countries—particularly in developing and emerging countries—often hampers global investments. Moreover, improvement of solar energy modeling is needed in order to further improve comparability of data on global and regional solar energy potential. Currently, existing analyses are hard to compare because they differ with respect to their underlying assumptions. Comprehensive analysis that compares the global and regional potential based on a consistent and integrated methodology is needed

.

Proposed Technology Cooperation

MEF countries could jointly develop a Global Solar Atlas which could comprise:

- A global solar map of solar energy potentials globally with a high spatial and temporal resolution to allow most accurate global, regional and national renewable energy modeling—this model should follow a comprehensive, holistic approach, taking into account all regions and all renewable technologies; in addition, it could be considered to verify satellite data by deploying a sufficient number of pyrheliometers in different regions
- A global solar database on all relevant site-specific investment information, including regional potentials, economic framework conditions, and legal,

technical and administrative information, such as local know-how and needs for capacity building

- A regionally-specific technology assessment indicating which onshore and offshore solar energy projects and what specific solar technology could achieve most valuable benefits under region-specific conditions
- Improved solar modeling based on a comprehensive, holistic approach, which should illustrate future solar technology development based on an enhanced understanding of the basic science and engineering of solar technology and of the complexity of solar resource on many different levels (e.g., temporal, spatial, turbulences, wake effects, forecasting etc.)

By collecting information and analysis on potentials, policies, and strategies, as well as assessments of technology, the global solar atlas will also provide an impetus for knowledge transfer, spillover innovation, new ideas, technology cooperation, and best-practice synergies. By working together to continuously revise the atlas, collaboration between countries could also be enhanced.

Implementation

This initiative could be started immediately, by identifying existing measurement and renanalysis data that could, as appropriate, assist the development of improved solar modeling.

As soon as it is operational, IRENA could help implement this initiative by providing and further developing renewable energy resources data and in developing renewable energy modeling in close cooperation with all relevant institutions in this field, especially the IEA.

Establishing an International Solar Technology Platform

Proposed Technology Cooperation

Industry consultations indicate that information deficits and a lack of constant communication between policymakers, investors, and stakeholders is still a main barrier to the global distribution of solar technologies. Establishing an international technology platform (ITP) could help to systematically address this deficit and promote an intensive dialogue between governments and industry.[30] Moreover, such a platform can help match the demand for and supply of specific technologies.

The ITP would be a valuable tool for constant technology cooperation. Through the platform, information about technology needs could be communicated to interested parties at every level of detail required. The ITP would also serve as a way to bring experienced stakeholders together, effectively creating large cooperative networks that enable the dissemination of information about solar technology and link stakeholders in the North and in the South. As a result of this increased communication and collaboration, the ITP could help bring solar technologies closer to competitiveness and ensure the use of solar energy technologies as a central element of a broad basket of energy technology options to ensure future security.

[30] Discussions held during the course of drafting this *Technology Action Plan* have shown that industry often thinks differently and has different needs than those addressed by policymakers.

The ITP could hold collaborative workshops targeting a range of major R&D and industry-wide issues such as:

- Product quality/reliability (e.g., PV reliability workshops held in 2008/2009 between the U.S. and China)
- Public acceptance, environmental impacts, sustainability of production chains
- New trends and novel concepts
- Support policies and financing instruments
- Long-term strategies for future system and grid integration

Implementation

Existing institutions and initiatives, such as IRENA, the IEA implementing agreements, and the European Technology Platform could join forces and establish a constant dialogue in close cooperation with the Global Partnership.

Joint Capacity Building and Know-How Transfer

Proposed Action

Qualified staff and local know-how is a prerequisite for massive global solar technology deployment. Therefore, MEF countries could foster a comprehensive, long-term strategy for capacity building and know-how transfer on a global level, covering the development of all solar technologies, and permanently gathering, concentrating and updating all relevant information.

Background

Joint efforts for capacity building and knowledge transfer are of the utmost importance to foster investments in solar technologies. Qualified professionals and stakeholders are needed all along the value chain: officials need to be well-skilled as they are responsible for the favorable legal framework conditions, engineers and technicians need to have expertise in proper design, construction, operations and of solar applications; lawyers have to be familiar with the national and international legal implications; and financing institutions need specific background information to adequately evaluate the bankability of solar energy projects.

Training is most effective when accompanied by practical implementation (e.g., applied technology cooperation). However, there are a variety of broad capacity-building needs that should always be adapted to the technology and local conditions, starting earlier than the practical implementation and go beyond them. Therefore, a strategic and long-term approach for capacity-building and know-how transfer on a global level is needed, covering the development of all solar technologies and permanently gathering, concentrating and updating all relevant information in the solar energy sector.

Implementation

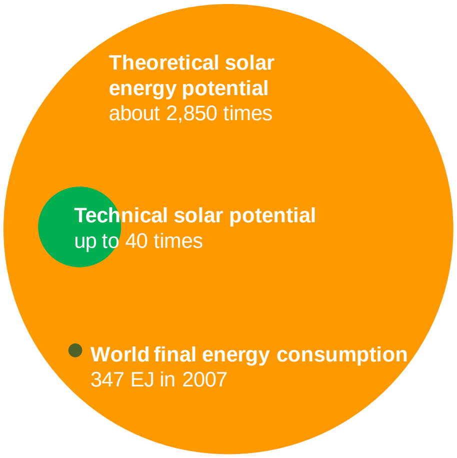
As soon as IRENA is operative, it could add value by implementing this joint capacity-building initiative in cooperation with other existing institutions active in this field such as the Renewable Energy and Energy Efficiency Partnership (REEEP), which applies the reegle search engine (www.reegle.info) for information on renewable energy and efficiency.

APPENDIX A. SOLAR ENERGY TODAY AND TOMORROW

Physical Potential

Solar energy has the highest physical potential of any energy source. The annual solar energy radiation reaching emerged lands exceeds 2,850 times the annual global energy consumption by humans, which was 347 EJ/y in 2007 (Figure 8).[31] The energy reaching our planet during three hours of solar radiation would be sufficient to meet the global energy demand for an entire year. The physical potential remains largely theoretical, however, due to technical and geographic limitations of harnessing solar radiation.

FIGURE 8. THEORETICAL POTENTIAL OF ANNUAL SOLAR ENERGY RESOURCES, COMPARED TO WORLD FINAL ENERGY CONSUMPTION



Source: Adapted from EREC/Greenpeace 2008; IEA 2009; de Vries, van Vuuren, and Hoogwijk 2007
Note: The technical solar potential is based on the technical PV potential described by *Renewable Energy Sources: Their Global Potential for the First-Half of the 21st century at a Global Level: An Integrated Approach* (de Vries, van Vuuren, and Hoogwijk 2007).

Technical Potential

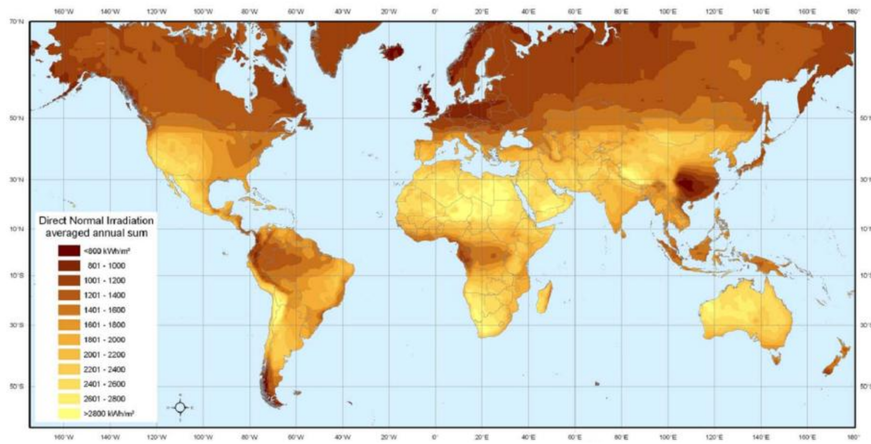
Although much smaller than the physical potential, the estimated global technical potential for solar energy (i.e., the energy that could be effectively harnessed given current technological progress) is estimated to be up to 40 times today's energy consumption (de Vries et al. 2007). Estimates of the exact technical potential vary considerably due to technological specifications, regional differences, environmental conditions, and other underlying assumptions. Nevertheless, the technical potential of solar energy is higher than that of any other energy technology.[32]

[31] Please note that these figures would be lower if the global primary energy demand was the reference case (503 EJ in 2007). The global primary energy demand depends on the future energy mix and the development of conversion losses for different technologies.

[32] Even according to the most conservative estimates, the technical potential is about 4 times higher than global demand (Hoogwijk 2004).

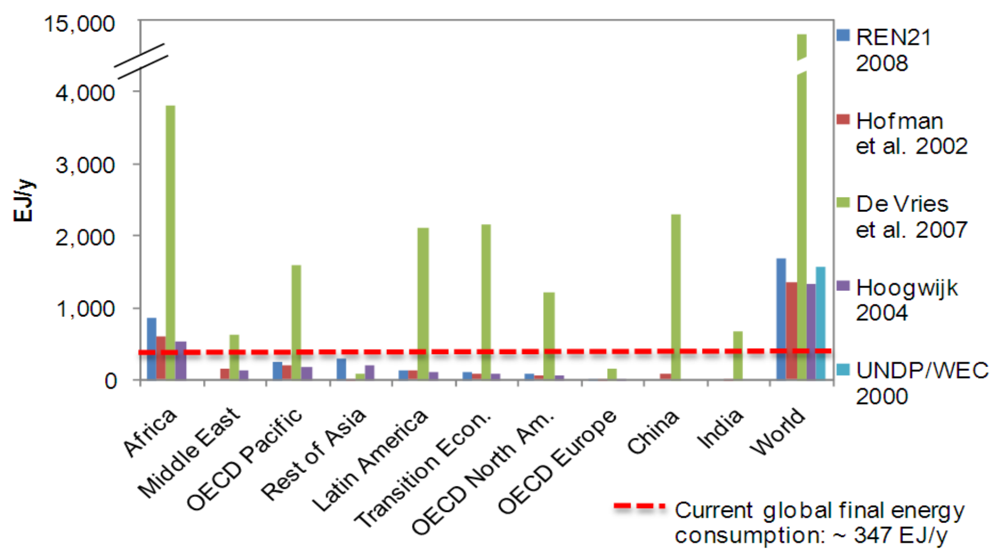
The highest PV potential is estimated to be in Africa and in the Middle East—the "sunbelt"—where large available land area coincides with high average irradiation (Figure 9). The technical PV potential in each of these two regions alone exceeds today's global final energy consumption (Figure 10). In all regions of the world, however, considerable PV technical potential can be found.

FIGURE 9. WORLDWIDE ANNUAL DIRECT NORMAL IRRADIATION (BRIGHTER AREAS INDICATE HIGHER IRRADIATION)



Units: kWh/(m²*y)
Source: DLR 2009, which was derived from NASA SSE 6.0 dataset (NASA 2009)

FIGURE 10. PV: REGIONAL DISTRIBUTION OF THE TECHNICAL POTENTIAL OF PV FOR THE YEAR 2050

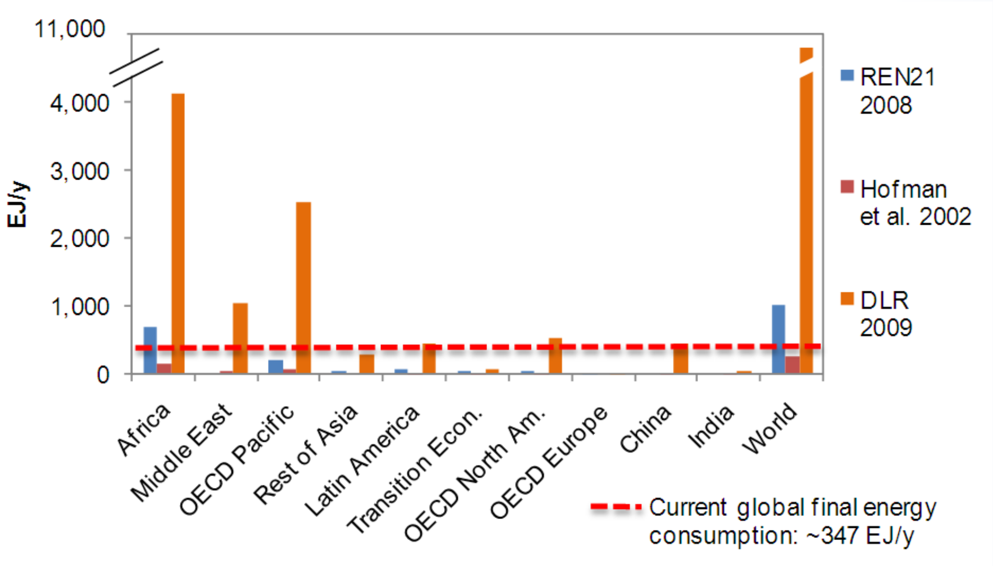


Note: The estimates of Hofman et al refer to the year 2020.
Source: Hofman et al 2002

The technical potential of CSP largely overlaps with that of PV, because both require regions with a sufficient level of solar radiation. However, while most PV technologies can also convert indirect solar radiation into electricity, CSP needs direct solar radiation, slightly restricting its technical potential.[33]

The regional distribution of the technical potential for CSP in 2050 shows the highest CSP potential in Africa, which could alone provide more energy than is needed worldwide (Figure 11). To put this into perspective, even the much smaller technical CSP potential of Europe, which amounts to about 9 EJ (DLR 2009), is sufficient to supply almost 75% of the European power in 2008.

FIGURE 11. CSP: REGIONAL DISTRIBUTION OF THE TECHNICAL POTENTIAL OF CSP FOR THE YEAR 2050



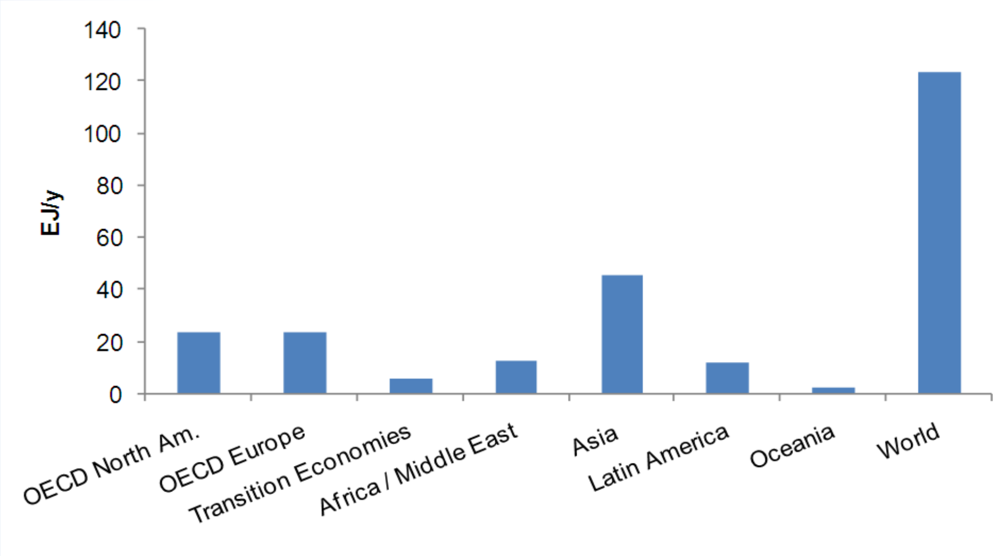
Source: Hofman et al. 2002
Note: The estimates of Hofman et al. refer to the year 2020.

Regions most suitable for CSP are the Middle East and North Africa (MENA countries); South Africa; Australia; the Southwest of the United States; parts of South America; central Asian countries from Turkey to parts of India and China; and southern regions in Europe, such as Spain, Portugal, and Greece (IEA 2008d).

The absolute technical potential for solar heating has not been analyzed by world region. However, a recent analysis conducted by the Renewable Energy Policy Network for the 21st Century (REN21) links demand for heating in different regions to the technical potential of solar heating (i.e., heating demand-adjusted technical potential) (REN21 2008). The analysis found that this heating demand-adjusted technical potential is limited since southern countries have less of a need for space heating. The possibility of inter-regional heat transport is also restricted in this demand-adjusted context. Therefore, the highest technical solar heating potential is estimated to be in Asia, OECD-North America, and Europe (Figure 12).

33 The efficient implementation of CSP technology requires an annual direct radiation of at least 2,000 kWh/m². Where CSP is feasible, it is likely to be preferred for bulk power production given its capacity to provide firm and dispatchable electricity, while PV will likely be preferred for decentralized (on- or off-grid) power production.

FIGURE 12. SOLAR HEATING: REGIONAL DISTRIBUTION OF THE TECHNICAL POTENTIAL OF SOLAR HEATING FOR THE YEAR 2050



Source: REN21 2008

Solar Technologies in Brief

The market development and technological progress for solar technology has experienced vibrant growth over the last years. This progress can be linked to ambitious support policies in several leading markets.

Various solar technologies are deployed in a very broad range of applications, covering two main areas: electricity generation on the one hand and heating and cooling on the other. Photovoltaic (PV) and Concentrating Solar Power (CSP)[34] are the main technologies for solar electricity generation. Solar heating and cooling includes hot water, space heating, and cooling via solar thermal collectors, and process heat. The various technologies have to be distinguished and are in different stages of development. Therefore, they are addressed separately below.

Photovoltaics

Photovoltaic (PV) technology allows for direct conversion of light into electricity by virtue of the photoelectric effect through the use of semiconductor materials. The huge advantage of PV systems is that they have become a well-proven and reliable mainstream technology that is highly modular. Thus, they can be installed in nearly every region of the world and in various sizes. Photovoltaics can be deployed as small scale rooftop applications with an installed capacity of just a few watts (W_p) or as large-scale free-field applications with an installed capacity of hundreds of megawatts (MW_p) (IEA 2009g). Projects can start on a small scale and later be enlarged step-wise.

[34] Concentrating Solar Power is the common term for a range of technologies producing electricity in a thermal cycle using solar energy to heat a fluid. Some authors refer to CSP as Solar Thermal Electricity (STE).

PV systems can function with grid connections or as off-grid systems. In industrialized countries today, grid-connected systems are dominating the market to a great extent. Conversely, off-grid PV systems are common in areas lacking a suitable power grid. As a consequence, PV off-grid systems could play a major role for rural electrification in developing countries.

Concentrating Solar Power

Concentrating Solar Power (CSP) uses direct sunlight (Direct Normal Irradiation, DNI) to produce heat or electricity. An array of hundreds of mirrors collect and concentrate sunlight thereby heating a mostly liquid transfer medium to a temperature between 400°C and 1000°C. This heated transfer medium is then used to drive a conventional power cycle for electricity generation, such as a steam or gas turbine or a Stirling engine. CSP has the potential to become a large-scale, commercially viable option for generating electricity from solar energy. This technology has expanded rapidly and is now on the verge of becoming a mass-produced, main stream energy generation solution. Individual CSP plants today typically have a size of 50 to 280 MW, but can even be larger (SolarPACES 2009). Given their size, CSP plants must be integrated into transmission grids.

Solar Heating

Solar heating refers to technologies for the generation of solar heating and cooling, specifically for the use of solar energy in buildings (water and/or space heating/cooling) as well as for industrial processes (heating as well as cooling purposes). Some applications, such as solar water heating, are already well established and may only require modest technological development.

Solar heating is one of the most well-established technologies in the renewable heat sector. It is of high standards, is tried and tested, and features a high level of efficiency and reliability. Today, there are several different applications for using solar heat, the most common of which are space and water heating. Other applications are process heating and solar cooling. Solar heating systems can be used in stand-alone or grid-connected configurations (IEA 2008b).

Solar cooling meets cooling demands almost perfectly. Today, technical cooling demands are increasing and will continue to rise into the future. Electrically powered compressor cooling units provide the standard solution. Solar cooling and air-conditioning systems offer a unique alternative, especially as the demand for cooling generally coincides with the supply of solar irradiation. Solar air conditioning is not only an attractive prospect for southern countries; systems that combine heating and cooling are also capable of significantly reducing CO_2 emissions in colder countries such as Germany. Solar cooling applications suffer from considerably high costs and therefore need further technological development to bring down costs.

The potential applications for solar process heat are found predominantly in the food and beverage industry, the metal-processing and chemical industry, agriculture, and washing and cleaning processes. Process analyses as well as energy-saving and thermal recovery measures are particularly relevant to their efficient use. In Germany, for example, around one-third of demand for process heat is in the temperature range up to 250°C, while around 10% is in the range up to 100°C. High-efficiency flat-plate solar thermal collectors, vacuum tube collectors and concentrating systems such as parabolic trough and Fresnel collectors can make significant contributions towards saving fossil fuels in these lower temperature ranges.

Relationship between Solar Technologies

The specific relationship between the different solar technologies demands a closer look in order to understand the integration of these technologies into the energy market.

PV and CSP

PV and CSP are the main solar electricity technologies. As such, they compete with and complement each other.

Competitive applications

Both technologies convert direct light into electricity; PV does this by direct conversion through semiconductor materials and CSP does this through an array of mirrors that heat a transfer medium, in turn driving a conventional power cycle for electricity generation.

Thus, large scale, ground-mounted and grid-integrated PV and CSP installations compete with each other in areas with high direct solar irradiation. This is particularly the case for Concentrator-PV technology, since Concentrator-PV, as well as CSP, operate effectively in areas of high direct solar irradiation.

On the other hand, small scale off-grid PV applications may compete with the parabolic dish technology. Parabolic dishes are individual systems and, like PV, they are modular power units. They could provide a significant solution for off-grid stand alone applications for rural electrification in the future. Though they are quite complex and thus far not well-proven, their high solar-to-electricity conversion rates are promising.

Complementary applications

On the other hand, PV and CSP technology complement each other. PV can be applied in areas where CSP cannot, for two reasons. Firstly most PV technologies are able to convert diffuse, indirect solar radiation into electricity. Second, PV is highly modular. It can easily be enlarged to large scale ground-mounted application similar to CSP. Incremental enlargement allows for additional investment. In sum, both technologies together cover a broader range of applications for using solar energy for electricity generation.

WHY IS CSP SO IMPORTANT?

Concentrating Solar Power:

- Allows for highly efficient thermal storage
- Offers firm and dispatchable power production
- Could help to integrate more PV and wind into the energy system
- Will provide base-load electricity in the long run

Unlike CSP, however, PV's modular character allows also for very small applications with small capacity of only a few Watts to be used for instance for building-integrated PV systems (e.g., rooftop applications) or for small stand-alone off-grid electrification in rural areas. Additional key aspects marking the relation between CSP and PV are seen in the capacity of CSP installations to provide firm, reliable and dispatchable electricity on demand due to their ability to integrate thermal storage (stored heat) or fuel driven balancing power cycle (hybridization).

CSP can therefore cover energy demand at times when PV cannot due to low solar radiation (darkness, cloudy skies) and at costs which will be able to compete with peak-load and intermediate-load probably in the short run in some regions and even with base-load electricity in the long run, provided there is an appropriate storage capacity used.

As shown in the CSP section above, the dispatchability of CSP-generated electricity also considerably increases the amount of PV or wind capacity that can be integrated into the power system. For one, it reduces differential costs that need to be covered by support schemes due to CSP's capacity to compete with peak load and intermediate-load electricity. Furthermore, CSP can balance fluctuating electricity generation from other renewables sources, such as solar PV or wind energy installations by balancing their periods of low electricity generation.

This balancing capacity is of enormous importance for grid stability and system integration in order to increase shares of fluctuating electricity generation from renewables.

PV and Solar Heating Systems

Solar heating systems compete in the residential and service sectors with rooftop mounted PV installations for appropriate roof area since not all areas of a roof receive adequate irradiation to operate a solar installation efficiently. Therefore customers usually must decide on one technology or the other. However, the future development of combined systems will likely limit this competition between PV and solar heat systems. Moreover, competition will be limited by increasing PV and heat collector efficiency rates, resulting in a broader range of suitable application areas, as well as by increasing efficiency rates of building technologies, reducing overall energy demand.

PV and solar heating systems may complement each other when distinguishing roof areas from building façades. Roofs are often more appropriate for PV, delivering more energy in summer (in particular when air-conditioning systems drive peak electricity loads), while façades might be more appropriate for solar heating panels as the heat is more valuable in winter, when the sun is low and vertical façades collect more solar energy than horizontal surfaces.

Outlook

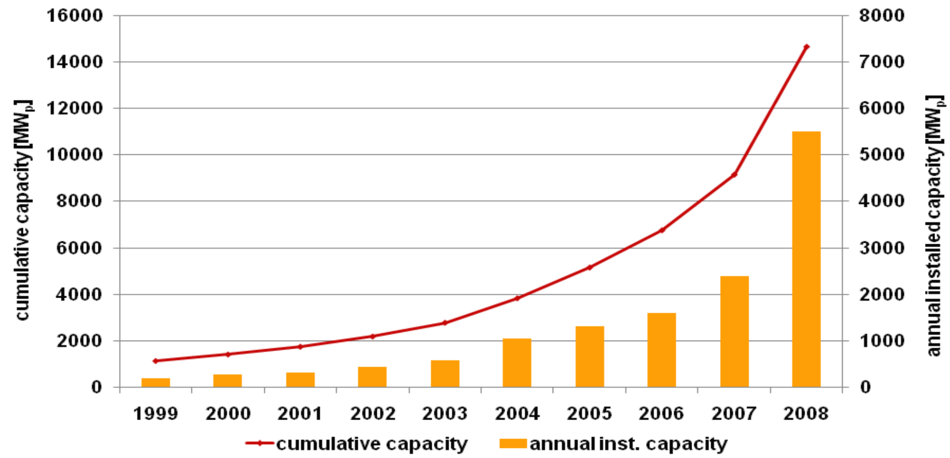
The different PV and CSP technologies are developing in rapid and innovative ways, each offering promising future prospects. It is important to increase efforts in developing both PV and CSP and all their various sub technologies in order to provide for a larger basket of energy technology options for future energy supply.

Market Development

PV Market Development

PV currently produces about 15 TWh per year of electricity; the world's total installed PV capacity has reached nearly 15 $GW_{p.}$ For more than a decade, the global PV market has been characterized by a significant average growth rate of 40% per year. From 1999 until 2008, the installed capacity increased more than tenfold (Figure 13).

FIGURE 13. GLOBAL CUMULATIVE AND ANNUAL INSTALLED PV CAPACITY FROM 1999 TO 2008



Source: IWR 2009, Data: EPIA Greenpeace2009, IWR 2009

While its share in global electricity generation is still small (about 0.1%), the current installed PV capacity can supply about 5 million households with electricity[35], thereby saving nearly 10 Mt of CO_2 annually. Given the dynamic development in 2008—a record year for the international PV industry—the global PV market will likely experience considerable growth in the future.

Rapid growth experienced in the global PV market has been driven primarily by three leading PV markets: Germany (5.3 GW), Spain (3.4 GW) and Japan (2.1 GW) (Figure 14). By relying on ambitious support policies, with feed-in tariffs as the major policy element, these three countries make up approximately 75% of the world's total installed PV capacity.

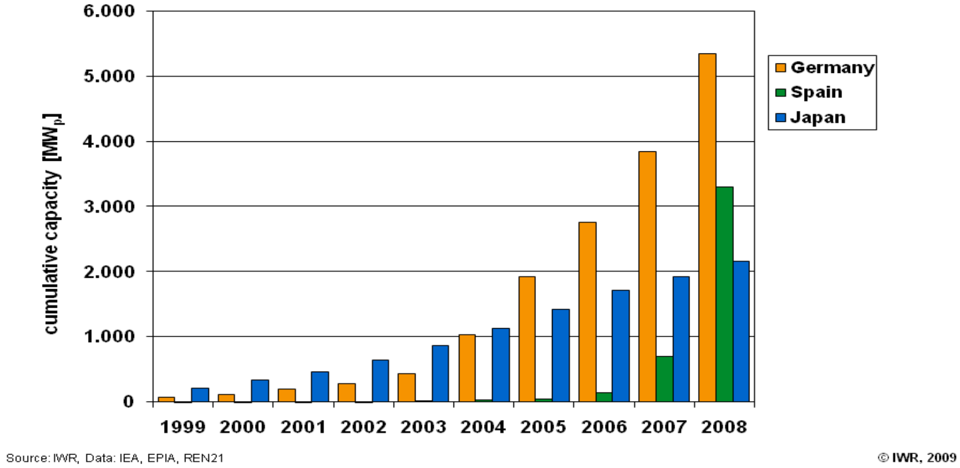
By taking into account that many southern countries have higher solar radiation, it is evident that the largest potential for PV electricity generation in Africa, Asia and America has yet to be tapped.

The solar PV market showed clear trends in the last few years. The attention for building-integrated PV has been growing and utility-scale installations have grown in scale (REN21 2009).

Current global installed PV capacity amounts to about 15 GW, saving 10 Mt of CO_2 annually. Only three leading markets, Germany, Spain and Japan, account for approximately 75% of the global installed PV capacity due to their ambitious support policies.

[35] Based on the assumption that each household consumes about 3,000 kWh.

FIGURE 14. CUMULATIVE PV CAPACITY IN GERMANY, JAPAN, AND SPAIN FROM 1999 TO 2008



Source: IWR, Data: IEA, EPIA, REN21

Regional Markets Today

Germany

Today, Germany is the largest PV market worldwide in terms of cumulative installed capacity with 5.3 GW_p. This development of the German PV market was mainly influenced by the Renewable Energy Sources Act (EEG), which includes fixed feed-in-tariffs guaranteed for 20 years. The Renewable Energy Source Act was introduced in 2000 and optimized since then several times. In 2003/2004, tariffs were adjusted, and covered for the first time the full costs of the system without any additional subsidies, thus providing a boost to PV market development. Given its installed PV capacity, Germany was able to generate about 4.0 TWh of electricity from PV in 2008. Compared to 2007, electricity generation from PV increased by about 29%. According to a scenario for the year 2020, the share of PV in total electricity generation may amount to about 4% (BMU 2009b).

Most of Germany's PV capacity is installed on rooftops. In 2008, investments into PV installations amounted to about 6.2 billion Euros, and approximately 57,000 jobs depended on PV (BMU 2009a, O'Sullivan et al. 2009).

Spain

With a new installed capacity of 2.6 GW, the PV market in Spain was the fastest growing market worldwide in 2008, reaching a cumulative capacity of 3.4 GW at the end of the year.

The Spanish feed-in system was introduced in 1998, the year when the Spanish electricity sector was liberalized. An adjustment to this system in 2004, which, among other things, guaranteed the feed-in tariff for 25 years, coincided with the beginning of dynamic growth in the Spanish market. A second system improvement in 2007 boosted the market even further; in 2008, electricity generation from PV increased by about 400% compared to 2007. Given that the target for 2010 was attained in 2008, the support mechanism was modified again as previously envisaged. In order to ensure a sustainable and steady growth of solar PV, the modified mechanism limits annual growth rates by establishing an annual quota of 500 MW_p beginning in 2009 and increasing by 10% each year, provided that the annual quota is fulfilled. Consequently, Spain is likely to reach an estimated total capacity of more than 11,000 MW in 2020.

Japan

Japan was the first PV market in the nineties which displayed growth. The Japanese government installed implementation programs such as the "Residential PV Dissemination Program" that granted subsidies to private purchasers of PV installations. Growth rates did not reach the level of growth experienced in Spain or Germany, but the annually installed market volume for PV installations has remained at a constant level of 100 to 300 MW_p since 2000. At the end of 2008 the installed cumulative capacity achieved about 2,100 MW_p.

Other markets

The United States is the fourth largest market after Japan, at 1.1 GW cumulatively through 2008 and an 8% share of global PV capacity. Other markets are gaining momentum thanks to new or improved support schemes (e.g. France, Greece, Korea, and Portugal). Italy optimized its feed-in tariff in 2007, which has led to a boost in new PV installations. The cumulative capacity raised from 2007 to 2008 by about 400%, amounting to a total installed capacity of 670 MW.

In the future, PV markets in China and the United States are anticipated to exhibit significant growth attributed to recently adopted support schemes. In addition, data on new PV installations indicate an accelerated market deployment that can be ascribed to improved support schemes. China, for example, is expected to reach an annual PV installation of 1 GW in 2010 and 2 GW in 2011 (Hughes 2009).

Developing countries

Market development in developing countries is disproportionate to the vast renewable energy potential of these regions. One challenge is the lack of appropriate grid capacity and infrastructure required for renewable energy integration. But there are several other aspects which can be concluded from the fact that the high potential for rural electrification through off-grid technology has not been tapped significantly. Currently, off-grid PV-systems constitute less than 10% of the global PV market.

Another key issue impeding solar technologies' growth in developing countries is that PV must compete against subsidised fossil fuel prices. In addition, external costs of fossil fuel energy generation have not been internalized for several reasons. In this environment, appropriate support schemes are difficult to establish and consequently rarely exist (IEA 2009a). Another key issue is the lack of awareness and expertise.

Particularly in the context of rural electrification, PV installations compete with diesel generators and could soon reach a competitive advantage due to comparatively lower costs. The cost of diesel generators is based on local fuel prices and can only produce power at levelized generation costs of US$0.20-0.30/kWh due to their low efficiency.[36] Furthermore, diesel generators contribute to noise and air pollution. There are several issues to be tackled, such as storage technology or balancing PV electricity. Nevertheless, the outlook of PV driven rural electrification appears promising.

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[36] Estimation by Prognos AG; www.prognos.com, based on current Chinese diesel prices according to the IEA on behalf of the German Federal Ministry of Environment.

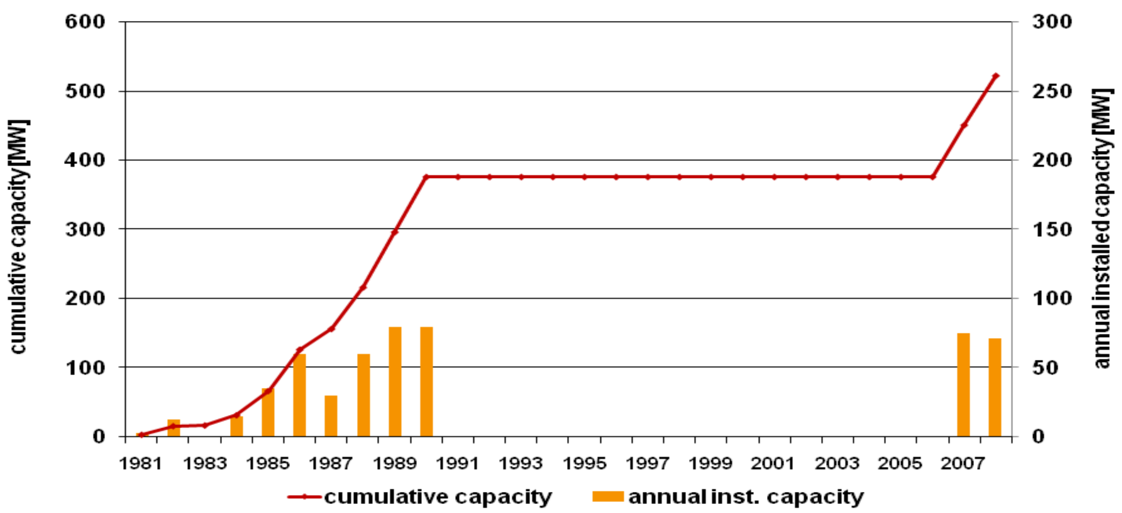
The situation in developing countries is complex and requires an integrated policy strategy with appropriate support by industrialised countries through technology cooperation, funding and capacity building.

CSP Market Development

Overall Market Development Today

The development of the CSP market shows that the implementation of reliable support schemes is essential for making market growth sustainable. After initial commercial CSP employment in the United States in the 1980s, a total global capacity of 354 MW had been installed (IEA 2008b). As a result of decreasing energy prices during the 90s, the deployment process of CSP lost momentum completely until 2006. At this time, the implementation of support schemes in the United States and Spain – coupled with rising energy prices – led to a renaissance of the CSP market. To date three additional plants with a total capacity of 125 MW have been installed in Spain and the United States. The overall global capacity in 2008 has reached about 500 MW (DLR 2009) (Figure 15). Even though CSP's share in global electricity generation is still small (0.01%), today, CSP produces about 1 TWh per year to supply about 500,000 households with electricity (each consuming about 3,000 kWh), thereby saving nearly 1 Mt of CO_2 annually.

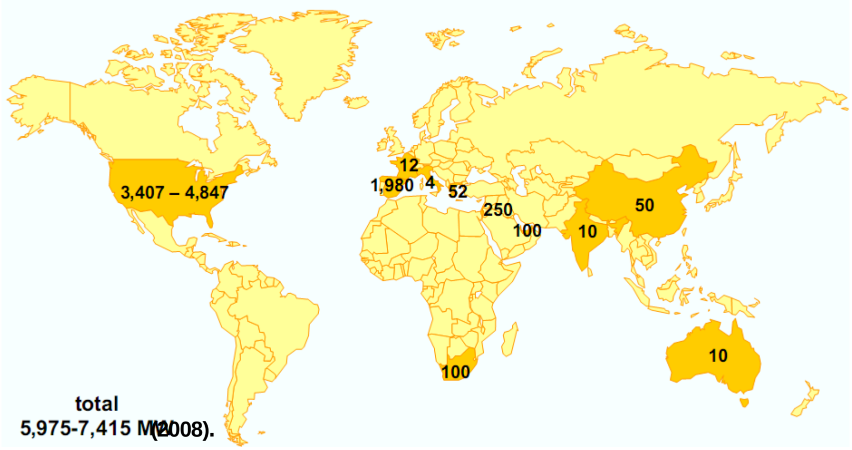
FIGURE 15. GLOBAL CUMULATIVE AND ANNUAL INSTALLED CSP CAPACITY UNTIL 2008



Source: IWR, Data: SolarPACES 2009

Implemented support schemes in Spain, the United States and in several countries of the MENA region (Middle East and North Africa) have led to increasing momentum in the market. As a consequence, projects with a total capacity of more than 1 GW are currently under construction (1.1 GW in Spain alone). At the end of 2008, more than 7.4 GW were in the planning stage (Figure 16). Currently, 15 GW are estimated to be in the planning stage worldwide (IEA 2009c).

FIGURE 16. PLANNED CSP CAPACITIES WORLDWIDE AT THE END OF 2008



Source: Adapted from DLR 2009

> **Current global installed CSP capacities amount to about 500 MW, saving 1 Mt CO_2 annually. The leading markets are Spain and the United States. Due to ambitious CSP support policies, Spain represents the most dynamic CSP market today. Many projects are also planned in the United States, the Middle East and Africa. The projects already under construction will triple global capacity; the projects already in planning stage will increase it more than fifteen-fold.**

Regional Markets Today

United States

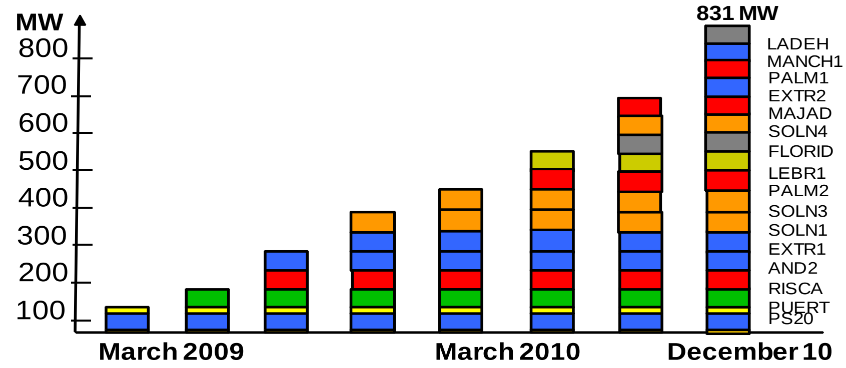
CSP markets developed first in the United States with the first installation of parabolic trough technology in the U.S. Mojave desert in 1984 (SEGS project). Today, more than 420 MW are in operation in the United States and more than 3,200 MW of capacity are planned, making the U.S. market for CSP very dynamic (IEA 2009i). The Department of Energy's goal to install 1,000 MW of CSP power in the southwestern United States by 2010 (NREL 2008), should be reached given current development.

With the installation of the Martin Next Generation Solar Energy Center in Florida, the first CSP plant in the world that is connected to an existing combined-cycle power plant is being realized in the United States. Construction of the parabolic trough plant with a capacity of 75 MW began in December 2008 and completion is scheduled for the end of 2010 (FPL 2009).

Spain

Although it established test and research facilities in the mid-eighties, the Spanish solar market emerged in 2004 following the implementation of a feed-in tariff. This tariff either guarantees a fixed electricity price or a premium paid on top of the wholesale market price to operators of CSP plants. In 2008, Andasol 1 came online– the first commercially operated plant with a total peak output of 50 MW and a heat storage system to enlarge plant utilization. By the end of 2008, the total capacity of all commercial plants in operation in Spain was about 63 MW, with many additional plants under construction (389 MW) or in an advanced planning stage (1,980 MW) (DLR 2009). Several more are in an early planning stage. By the end of 2010 alone, more than 800 MW of new plants will start operation in Spain (Figure 17).

FIGURE 17. CONNECTION SCHEDULE FOR CSP PLANTS IN SPAIN UNTIL DECEMBER 2010



Source: Adapted from Protermosolar

Outlook

Looking forward, projects in the United States and Spain will soon be complemented by activities in emerging CSP markets to harvest the enormous global CSP potential. **Israel**, for instance, established a feed-in-tariff system differentiated by plant size in 2006 (US$0.24 for plants smaller than 20 MW and US$0.164 for larger facilities). The tendering process for two CSP plants with a total capacity of 220 MW is expected to be finished at the end of 2009. **Turkey** is also in the process of enacting a CSP feed-in law. It is likely to include a special bonus if a certain percentage of the plant components are manufactured domestically. **Italy** is funding a CSP development and demonstration program with €50 million and introduced a feed-in tariff for CSP in 2008 providing between €0.22 and €0.28 per kWh for 25 years. Australia recently announced a 20% renewable target by 2020 based on a quota support mechanism. **France** applies a feed-in tariff for CSP. **Germany**, which has only limited CSP potential, nevertheless hosts a very successful demonstration project, the Solar Tower Jülich. The Solar Tower Jülich tests a prototype of a new receiver technology (volumetric air receiver) and will further support research and development as well as demonstration in suitable areas.

Developing and emerging countries

As for the development of PV, market development of CSP in **developing countries** lags far behind its vast potential due to a complex set of factors (see further above regarding PV). Today, the CSP market is primarily concentrated in industrialized countries. Nevertheless, very promising new initiatives have begun in developing and emerging markets.

India, for instance, has put forward the National Action Plan on Climate Change stating that base-load prices and dispatchable CSP power should be available at competitive prices within the next 20-25 years and has enacted a CSP feed-in tariff of US$0.19 for a duration of 10 years with a capacity cap of 10 MW for each state. India's solar plan sets the objective to reach 20 GW of total solar generation capacity by 2020.

China has included the installation of 200MW of commercial CSP capacity in the 2006-2010 five year plan of the National Development and Reform Commission and is promoting research in the field of CSP tower technology (SolarPACES 2009).

Algeria and **South Africa** apply feed-in tariffs for CSP.

The Mediterranean Solar Plan **-** the energy project of the Union for the Mediterranean **-** is focusing on facilitating the exploration of the renewable energy potential around the Mediterranean sea for electricity generation, especially CSP in the MENA region (Middle East and North Africa) by establishing appropriate framework conditions and providing for capacity building.

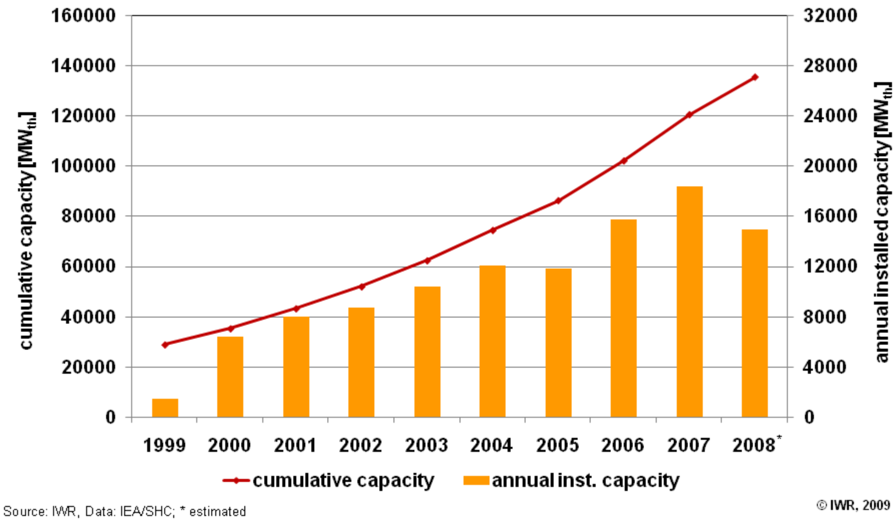
The DESERTEC Industrial Initiative aims to install CSP installations in the deserts of the MENA region by following a combined approach of covering the growing electricity demand of that region with the opportunity to export excess production by large high voltage direct current transmission (HVDC) to Europe. Though a number of issues must be addressed step by step – including the installation of appropriate HVDC transmission grids, establishing appropriate framework conditions for transmission as well as integrating the exported electricity into the renewables strategy of importing countries—this vision remains very promising. The European industry association ESTELA forecasts an installed capacity of 20,000 MW in the Mediterranean region alone and estimates the total investment of up to €80 billion (ESTELA 2009).

Solar Heating Market Development

Solar heating, particularly for hot water, looks back on a tremendous technological and market development in the past 25 years. Efficiency has improved considerably, and system costs have continuously decreased. Due to these advancements, solar heating systems are competitive in many regions already today – especially where solar radiation is high and heating infrastructure for conventional fuels is underdeveloped. While emerging countries, such as China and Turkey, represent leading markets for solar heating technology, many developing countries have not established the necessary infrastructure yet. In such cases, raising awareness and providing training opportunities will be critical for the wider deployment of solar heating technologies. Moreover, an adequate policy framework is needed. The success of support schemes has been proven in the German and Austrian solar heating markets, in which solar heating has to compete against conventional energy supply infrastructure. In industrialized countries, increasing prices for fossil fuels would help to improve solar heating’s competitive position in the future.

Worldwide solar heating markets have been growing for years, with average annual growth rates of about 20% in China and Europe, and about 16% worldwide in 2007 (IEA/SHC 2009c; Sarasin 2008). In the last decade, the total solar heating capacity has increased nearly fivefold. At the end of 2008, a total of about 165 GW_{th} were estimated to be installed worldwide, of which 135 GW_{th} are flat plate and vacuum tube collectors (Figure 18). Not shown in the figure are approximately 24 GW_{th} of unglazed plastic collectors and 1.5 GW_{th} of unglazed air collectors.

FIGURE 18. GLOBAL CUMULATIVE AND ANNUAL INSTALLED SOLAR HEATING CAPACITY FOR FLAT PLATE AND VACUUM COLLECTORS (1999 - 2008)



Source: IWR, Data: IEA/SHC

Current global installed solar heating capacity amounts to about 165 GW_{th}, led by installations in China, Germany, Turkey and Japan. These four countries represent more than two thirds of the installed solar heating capacity worldwide.

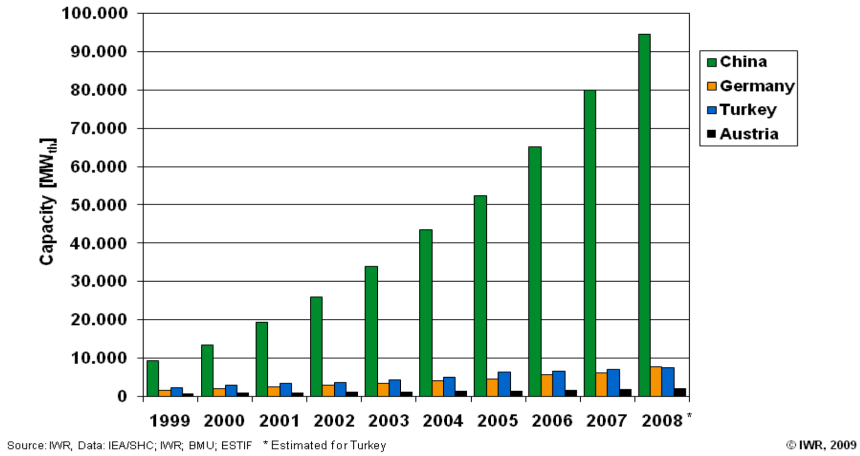
Solar heating currently produces about 83 TWh per year of heat. Its share in global heat demand is still small (about 0.2%). But already today, the installed solar heating capacity can supply about 6 million households with heat for warm water and space heating (each consuming about 15 MWh), thereby saving about 30 Mt of CO_2 annually.

Most of the total capacity is installed in industrialized or emerging countries like China, Germany, Turkey or Japan. Less than 1% of the worldwide solar heating capacity is located in developing countries like Namibia, Jordan or Tunisia (IEA/SHC 2009c; OECD 2009). The market is dominated by systems for solar water heating in single-family homes, while combined space and water heating has only modest market shares in Europe and Japan (IEA/SHC 2009c; OECD 2009).

Regional Markets Today

Major markets include those in China, Turkey, Germany, and Austria (Figure 19).

FIGURE 19. CUMULATIVE SOLAR HEATING CAPACITY IN THE MAJOR COUNTRIES FOR FLAT PLATE AND VACUUM COLLECTORS (1999 TO 2008)



Source: IWR, Data: IEA/SHC; IWR; BMU; ESTIF 2009

The solar heating market in **China** is the largest in the world where, in 2007, more than 75% of the global newly installed capacity was created (IEA/SHC 2009c). The growth of the market is driven by lower system prices relative to Europe (IEA 2008c). In 2008, a cumulative capacity of 94.5 GW_{th} was installed (CREIA 2009). The significant increase in China results from the high level of solar radiation and the low system prices so that solar heat energy is commercially feasible, even when compared to electric and gas heating. In contrast to the photovoltaic market, solar heating systems made in China are also sold domestically. Only a small fraction of 10% is exported (Sarasin 2007).

The **Turkish** solar heat market used to be the biggest in Europe until 2007. In 2008, the cumulative installed capacity[37] was around 7.3 to 7.6 GW_{th} (IEA/SHC 2009c, Epp 2009b). The solar market has grown because of the high level of sun radiation in this country and due to the fact that solar heating systems are also commercially viable. According to experts, growth has declined in recent years because of new natural gas pipelines and lack of assistance from the government (Epp 2009b).

Although solar radiation in **Germany** is less intensive than in China or Turkey, the German solar heating market is estimated to have exceeded the Turkish market in 2008. The cumulative installed capacity in 2008 amounted to 7.7 GW_{th} (BMU 2009a). In 2008 solar hot water set record growth with over 200,000 systems installed for an increase in total capacity of 1.5 GW_{th}. The market has been established with the assistance of several government programs: the market incentive program, which offers investment grants for solar radiation systems and information campaigns, and currently through the new Renewable Energies Heat Act, which contains an obligation to use renewable heating in new buildings (IEA/SHC 2009c). In 2008, investments into solar heating systems totaled nearly 1.5 billion Euros, and

[37] Estimated from 2006/2007 data.

about 17,400 people were employed in the German solar heating industry (BMU 2009a; O'Sullivan et al. 2009).

The solar heat market in **Austria** was one of the first with a more dynamic development. It took off in 1980 with an initial boom and grew until 1996. Since 2003, there has been another boom in the Austrian solar heat market. The cumulative installed capacity in 2008 was 2.3 GW_{th}. The market development in Austria was a product of the oil crisis in the late 1970s and the self-made collector production from the 1980s to the end of the 1990s (Hackstock 2007, ESTIF 2009). Today, there is strong development resulting from support schemes and increasing energy prices.

Technology Development

PV Technology Development

PV Technologies Today

Today, crystalline silicon PV cells and thin-film PV cells are standard PV technologies. However, concentrator PV cells are on the verge of entering the PV market (IEA 2009g).

Crystalline silicon PV
Crystalline silicon PV cells have the largest market share in today's global PV market. It uses silicon as a semi-conductor. Their main advantage is that they are the most well proven standard PV technology. Commercial modules based on crystalline silicon PV cells have solar-to-electricity conversion rates of 13% to 18%. This is the highest efficiency rate of all PV technology lines commercially available today (IEA 2009g). In the laboratory, an efficiency rate of 20.3% has already been achieved by the German Fraunhofer ISE Institute.

The key cost determining factor of PV cell production, the lack of sufficient capacity for producing silicon, has been overcome. Increased global production capacity for silicon has reduced production costs considerably. A competitive disadvantage of crystalline silicon PV cells, however, is the various production steps needed along the value chain, including the production of silicon, cells, wafers, and modules. Although this increases investment costs, the high efficiency rates of crystalline silicon PV cells can compensate for the higher investments costs, resulting in comparable levelized electricity generation costs with thin-film PV cells.

Thin-film PV cells
Thin-film PV cells or modules are constructed by depositing thin layers of photo-sensitive materials on low-cost substrates like glass or plastic. The main advantages of thin film technologies are their resource-efficiency, since relatively small amounts of raw materials are needed, and the low-cost, highly automated production process, which needs only few production steps. The current main drawbacks of this technology are lower conversion efficiency rates, ranging from 6% to 12%, and limited experience with lifetime performance. Nevertheless, thin-film technology has gained a greater market share in the last years (IEA 2009g; Sarasin 2008).

Concentrator PV cells
In contrast to thin-film technology, concentrator PV cells suffer from higher production costs compared to crystalline silicon PV cells, but achieve considerably higher conversion efficiency rates. Concentrator PV cells use mirrors or lenses to

focus light on an area equipped with small, high-efficient PV cells. The advantage of this technology is that the required active area of PV cells is reduced to only a small fraction. As a result, it is viable to use high-quality solar cells with higher efficiency rates of 30% to 40%. Several research groups have already achieved an efficiency rate of more than 41% in the laboratory. [38] Concentrator PV cells are starting to become commercially available. With more than 12 MW installed capacity, the Spanish Guascor leads the European market. This technology may play a larger role in the future due to its efficiency advantage (IEA 2009g; EPIA/Greenpeace 2009). One comparative disadvantage, however, is the need for direct solar radiation to achieve high conversion efficiency rates. This is particularly the case for large scale applications of concentrator PV cells. These large scale applications compete with the CSP technology.

Trends and Emerging Technologies

Organic PV cells

One future trend for PV technology is to use organic electronic materials (organic PV cells). The advantages of this kind of PV cells are low-cost production methods and a broad variety of possible applications. Under the current status of development, however, efficiency rates are only 5% to 6% and the life cycle of these cell types is limited. Given their lower production costs, this PV technology may play a more important role in the future. However, organic PV cells are not expected to be commercially available before 2014 (IEA 2009g; IWR 2009).

Increased efficiency rates

The overall PV technology trend is to increase solar-to-electricity conversion rates. The current efficiency rates from about 6% to 18% are estimated to increase considerably in the future. The IEA expects that they reach up to 32% by 2020 and up to 40% by 2030/2050 (Table 4).

TABLE 4. PRESENT AND FUTURE PV EFFICIENCIES (COMMERCIAL MODULE EFFICIENCY)

	Crystalline silicon	Thin films	Concen-trator PV	Organic PV
Present efficiencies	13-18%	6-12%	13-18%	5-6%
Efficiency targets 2015-2020	18-23%	12-15%	27-32%	~8%
Efficiency targets 2020-2030/2050	21-27%	15-18%	35-40%	~10%

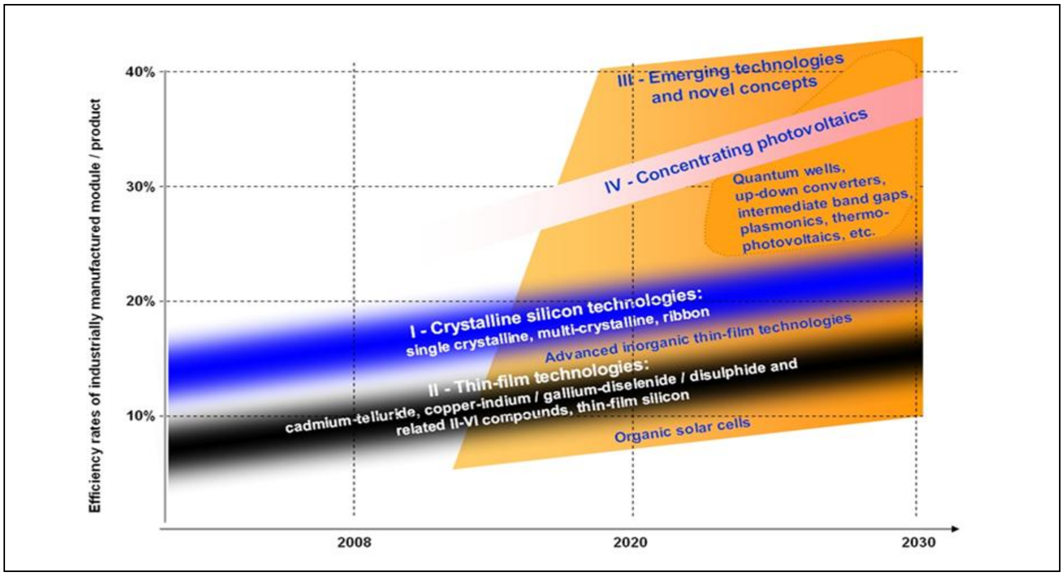
Source: IEA 2009g, Sarasin 2008, IWR 2009

Emerging technologies and novel concepts

Emerging technologies and novel concepts are expected to lead to a significant increase in performance and a significant decrease in costs (Figure 20). Those concepts build on progress in nanotechnology and nano materials (e.g. quantum wells, wires and dots), the collection of excited charge carriers, and the formation of intermediate band gaps (IEA 2009g).

[38] For example, the Fraunhofer ISE Institute in Germany (ISE 2009), and the University of New South Wales together with two U.S. groups (UNSW 2009).

FIGURE 20. PROSPECTS OF PHOTOVOLTAIC CELL TECHNOLOGIES (EFFICIENCY RATES OF INDUSTRIALLY MANUFACTURED MODULES / PRODUCTS)



Source: IEA 2009g

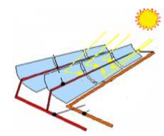
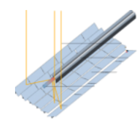
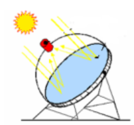
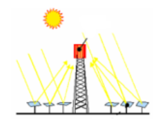
> **The portfolio of PV technologies offers a broad range of well-proven technology applications and various promising options for competitive electricity production in the near future.**

CSP Technology Development

CSP Technologies Today

Four main technologies for CSP plants are commercially used or currently under development. They are at different stages of development and demonstration, but all follow the same principle: using mirrors that track the sun's position to reflect and concentrate sunbeams. There are line focusing systems and point focusing systems. Line focusing systems (parabolic troughs and linear Fresnel systems) concentrate the radiation about 100 times and achieve temperatures of up to 550°C. Point focusing systems (parabolic dishes and central receiver, so called solar towers) concentrate radiation about 1,000 times and achieve temperatures of up to 1000°C. The different technologies can be further subdivided by the type of their receiver station (i.e., fixed or mobile).

FIGURE 21. CLASSIFICATION OF CSP TECHNOLOGIES

CSP Technologies	Receiver		Optical Properties
	Sun Tracking	Fixed	
Parabolic Trough Linear Fresnel			Line focusing one-axis tracking
Solar Tower Parabolic Dish			Point focusing two-axis tracking

Source: Christmann 2009

Parabolic trough

In the parabolic trough system, trough-shaped mirrors focus and concentrate solar radiation on long receiver tubes placed in the trough's focal line. The troughs are usually arranged along a north-south axis and track the sun from East to West. A fluid pumped through the tubes is heated to a temperature of approximately 400°C. A system of heat exchangers then produces superheated steam that is converted to electricity by a conventional steam turbine generator.

Parabolic trough projects are currently in operation at installed capacity between 14 and 80 MW. Typical electric capacity of parabolic trough applications is currently around 50 MW, although 350 MW is feasible. The maximum peak solar-to-electric efficiency is close to 20%. The maximum mean annual value is estimated to be around 15% (IEA 2009i). Examples for commercially realized trough projects are Andasol 1 in Andalusia (Spain, 50 MW, storage capacity of 7.5 hrs at 50 MW) and the SEGS I-IX plants in the Mojave Desert in southern California (United States).

The advantage of the parabolic trough system is that it is the most implemented and commercially proven CSP technology with up to 25 years of commercial experience. Already in 1984, the SEGS project in the U.S. Mojave desert provided the first major installation of CSP technology. As a result, parabolic trough systems provide for the bulk of current CSP projects. Hybrid and storage concepts in parabolic trough applications are already commercially proven. Parabolic trough technology has relatively low material demand and its field installation and components, such as collector elements, are highly modular. However the use of oil as a transfer medium restricts the operation temperature to 400°C, resulting in only moderate steam production (SolarPACES 2009).

Linear Fresnel system

In a linear Fresnel system a set of flat mirrors is used to reflect and focus solar radiation onto a receiver line fixed above the parallel array of mirrors. While obtainable steam temperatures are below those of trough systems, the usage of flat mirrors requires lower installation costs. As a consequence, the overall efficiency along the day is considerably lower. These systems have the potential for large scale installations; however, most currently installed commercial linear Fresnel systems have a limited capacity below 5 MW.

The first commercial Fresnel plant to reach a capacity of 5 MW is the Kimberlina facility in Bakersfield, United States. Another pilot plant with a capacity of 1.4 MW is located in Murcia, Spain.

Solar tower systems
In solar tower systems, a number of flat mirrors (heliostats) with two-axis sun-tracking concentrate the solar radiation on a tower-mounted central receiver. Solar tower systems concentrate the sunlight 600-1000 times and can reach 1,000° C and above. These high temperatures allow for very high solar-to-electricity conversion ratios and effective storage at higher temperatures. Tower systems have the potential to achieve solar-to-electricity efficiency rates of up to 35% peak and 25% annual when coupled to a combined power plant. Moreover, central receiver systems, such as the solar tower, offer a more ideal application in areas with a varied terrain.

Even though the temperatures achieved by the use of water as the current transfer medium has been increased (e.g. a demonstration plant in Israel already produces steam at 525°C) the full potential of tower systems will only be reached once heat transfer media such as air or molten salt become more common (IEA 2009c). Plant sizes of 200 up to 350 MW are possible; systems ranging from 10 to 20 MW are already operational. The first commercial solar tower installations PS10 and PS20 have been realized in Sanlucar la Mayor (Spain). PS10 generates 2 GWh per year and supplies 5,500 households. PS20 could supply electricity for another 12,000 households (SolarPACES 2009).

Further advancements have been presented by state-of-the-art demonstration projects, such as the Julich Tower in Germany, which have integrated innovative receiver technologies and high temperature storage in a complete solar power plant. The Solar Two project in Daggett, California, demonstrated solar-only production around the clock already in the 1990s.

Parabolic dish
Parabolic dish systems are individual units that concentrate the solar radiation on a receiver at the focal point of the dish as the dish tracks the sun on two axes. As the sun moves, both the parabolic dish system and the receiver shift to an optimal constellation in relation to the sun. In contrast to other CSP systems, either heated fluid or air drives an individual motor-generator, usually a Stirling engine or small gas turbine, which is attached to the receiver at the focal point of the dish.

These comparatively small systems have a power output of 3–25 kW, but are modular and can be connected to a large scale application. Parabolic dish systems show very high solar-to-electricity conversion rates, which peak at over 30%.

Examples of current parabolic dish installations include the Plataforma Solar de Alméria in Andalusia (Spain) and Odeillo (France). The EURO-Dish project, a consortium with partners from industry and research, has developed a cost-effective 10 kW Dish-Stirling engine for decentralized electric power generation. A 1 MW plant is under construction in Cuenca, Spain; another project of 50 MW in the development phase in Ciudad Real, Spain; and hundreds of MW are announced in several locations of the United States.

In comparison to the other CSP technologies, dish systems have the competitive advantage that they do not need water to cool the system. The disadvantage, on the other hand, is their low compatibility with heat storage and hybridization. Due to a lack of large scale commercial applications, the costs of dish systems are currently unknown. The industry claims that mass production will allow parabolic dish systems to compete with large-scale CSP technology (IEA 2009c).

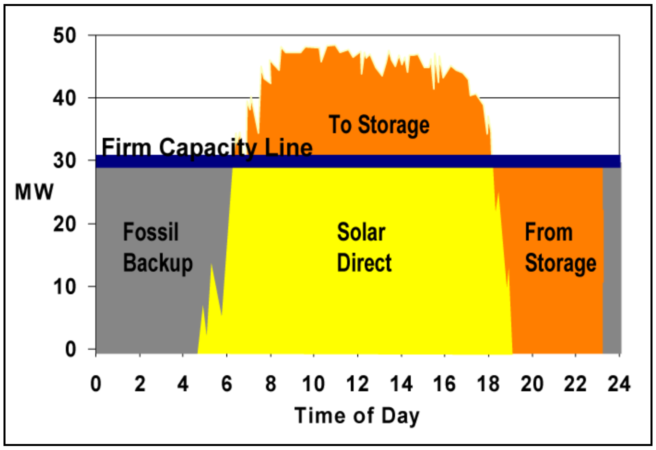
As individual, modular power units, parabolic dishes may offer a significant solution for off-grid stand-alone applications in rural electrification. As a consequence, parabolic dish technology, more than all other forms of CSP technology, compete with small-scale PV applications.

Heat storage and hybridization
By producing heat to drive a conventional power cycle grid-connected, large scale CSP installations benefit from two key advantages: (1) the produced heat can be stored, and (2) the solar-driven conventional power cycle can be backed-up by burning fuels, fossil or renewables (hybrid plant or integrated solar combined cycle, ISCC).

Heat storage increases the utilization factor of a CSP plant significantly compared to those facilities without storage thereby increasing the value of CSP-generated electricity, as it firms the capacity of CSP installations and expands solar-only production. The heat can be stored in a storage media, such as molten salt and can be extracted from the storage medium in order to run the power block in times of low solar radiation (at nights, cloudy skies).

The fuel back up of CSP plants works as an alternative option or a complementation to heat storage, thereby allowing CSP to operate in tandem with burning fuels, fossil or renewable, in a hybrid plant using the same steam generator and turbine to produce electricity. Fuel back-up further extends the load factor of the steam cycle and the power block, which can be of particular importance where full back-up by thermal storage is not possible or too costly.

FIGURE 22. COMBINATION OF STORAGE AND HYBRIDIZATION IN A SOLAR PLANT



Source: IEA 2009c

Heat storage and hybridization are two complementary ways for contribution to the same value of CSP, which constitutes a considerable comparative advantage: the capability to provide firm, reliable and dispatchable electricity on demand.

Given the expected learning rates, this could allow CSP to compete with peak-load and intermediate-load electricity probably in the short term in some regions, and in the long run also with base-load electricity if combined with an appropriate storage.

The dispatchability of CSP-generated electricity also considerably increases the amount of PV or wind capacity that can be integrated into the power system. For one, it reduces differential costs that need to be covered by support schemes due to CSP's capacity to compete with peak load and intermediate-load electricity. Furthermore, CSP can balance fluctuating electricity generation from other renewables sources, such as solar PV or wind energy installations by backing-up their periods of low electricity generation.

This balancing capacity is of enormous importance for grid stability and system integration in order to increase shares of fluctuating electricity generation from renewables. Both heat storage and hybridization have already been commercially proven in parabolic trough-driven CSP plants.

Trends and Emerging Technologies

Improving efficiency

Current annual solar-to-electricity efficiency rates of different available CSP technologies range from approximately 10 to 18%. Due to intensified deployment and economies of scale, they are estimated to increase considerably in the future and may reach 25% and more (Table 5).

TABLE 5. CAPACITY RANGES & EFFICIENCIES OF CSP TECHNOLOGIES IN COMMERCIAL OPERATION

	Parabolic Trough	Linear Fresnel	Solar Tower	Dish/ Stirling
Capacity unit	30 – 350 MW	6 – 150 MW	10 – 350 MW	< 0.05 MW
Current efficiencies (annual solar-to-electricity efficiency; projects commissioned)	15%	-	10%	18%
Future efficiencies (annual solar-to-electricity efficiency; future projects expected)	>15%	11%	>25%	23%

Source: DLR 2009, IEA 2009i, IEA 2009c

Higher temperatures

In order to improve efficiency rates, efforts must be concentrated primarily on achieving higher temperatures. To this end, the following options are currently being considered and tested:

- Using new high temperature heat transfer fluids, (e.g., pressurized gas) as currently tested at the Plataforma Solar de Almeria; molten salts (problem: freezes above 200º C) nanofluids; atmospheric air, as currently experienced in the German Jülich project;
- Using Direct Steam Generation (DSG) for parabolic trough technology; thereby cost could be decreased and efficiency could be improved by using

water instead of transfer fluids, thus making heat exchange equipment superfluous; on the other hand storage would be more difficult (IEA 2008b and IEA 2009c);

- Improving the shape and material of dishes (precision in pointing form, resistance to wind).

Improvement for cost reduction

Higher temperatures would also allow for much more effective and cost-efficient storage.

In order to drive down costs, future R&D projects should concentrate on the continuous improvement of components, the development of new materials and on optimizing production processes, quality control and system integration.

Another approach could be to use CSP generated heat to increase efficiency of a fuel firing power cycle instead of direct steam-based electricity generation. CSP would operate as preheating support application which would allow for lower temperatures and costs.

In the case of trough or linear Fresnel systems, this might include, for instance, replacing the costly silver coating covering the glass mirrors with cheaper materials. Another improvement for heat collector elements would be the replacement of the glass-to-metal welding of evacuated tubes with a mechanical seal.

Storage capacity

The integration of large storage systems in CSP installations, as the major innovation of CSP today, needs further optimization in order to allow large storage integration in both point and line focusing systems.

Solar fuels and desalination

Another area of CSP application with a unique future potential is the generation of solar fuels, such as hydrogen, which could then be used in several ways, for example as hot synthetic gas, which would be immediately sent to a gas turbine. Moreover, solar hydrogen could be used in fuel cells in the transport sector, or it could be blended in existing natural gas grids to be ultimately burnt by households and industry. CSP-generated syngas could serve as a basis for producing liquid, storable fuels with lower upstream emissions than other processes. Finally, metals and metal oxides could serve as solar energy carriers, possibly CO_2 free. Overall, these options enhance the possibilities for exporting clean fuels from sunny regions to all customers in the world. Their application will increase the solar fraction of the global energy mix beyond solar electricity (SolarPACES 2009; IEA 2009c, Philibert 2005).

Finally, given the strong demand for fresh water, particularly in semi-arid regions, an important field of further research is the advancement of the desalination process by means of CSP (IEA 2008b).

Both applications play an important role in the context of load management. The responsible transmission system operator (TSO) could use these applications to balance peak electricity supply.

The portfolio of CSP technologies offers a broad range of various promising options for competitive electricity production in the near future and for providing firm and dispatchable electricity as well as for backing up integration of renewables into the power system.

Solar Heating Technology Development

Technologies Today

Solar heating systems can be operated as stand-alone systems or in connection with local heating networks, which allows for the installation of large-scale systems. Depending on the field of application, three different solar heating systems can be distinguished.

Solar hot-water heating systems have the potential to provide 60 to 70% of domestic hot-water demand and about 50% of the service sector demand (IEA 2008b). Due to their simple technology and lower costs, the most common solar water heating systems worldwide are thermosiphons.

More innovative than solar-hot-water heating systems are solar combi-systems for hot water and space heating (IEA 2008b). Depending on the collector size, the storage capacity as well as insulation and the climatic conditions, these systems can provide for a significant portion of a building's heating demand (Weiss 2004).

Another field of solar heating application is the generation of process heat that can be used for industrial processes (IEA 2008b). With the collector types already introduced into the market, temperatures for process heat of less than 80°C can be reached. Advancements in collector technology and components will likely increase temperatures up to 250°C. At those temperature levels, a major share of the heat demand for industrial production could be covered in the future (IEA/SHC 2008).

Generally, two primary classifications of solar heating collectors can be distinguished: flat plate collectors and vacuum collectors.

In flat plate collectors, the solar radiation hits the top of the collector from where it diffuses to the absorber. The medium that carries the heat from the collector to the usage point is a specialized liquid. The overall efficiency of the flat plate collector is about 50% to 80%, depending on the specific system and the location. The size always depends on the field of application, so most of the systems sold for space and water heating have an average size from 2 to 5 m^2, which is sufficient for a single-family house. The solar heating system also comprises a tank and a pump for the circulation of the used heat transfer medium (IEA 2008b/Purkarthofer 2005).

Vacuum collectors use a different method of converting solar radiation to heat. The system is mostly built using glass tubes. A vacuum in the tube system ensures that the generated heat is kept inside, resulting in a higher efficiency rate compared to a flat collector (by 20% to 30%). The typical size is usually identical to the size of a flat collector. Apart from China, where vacuum collectors are the most popular technology, due to their higher costs, vacuum collectors are not as popular as flat collectors, especially in industrialized countries (IEA 2008b/Purkarthofer 2005). The efficiencies of different available collector types range from about 50% to more than 80% (Table 6).

Table 6. Efficiencies of Existing Collector Types for Solar Heating Systems

	Flat Plate Collectors	Vacuum Collectors
Efficiencies	50-80%	> 80%

Source: IEA 2008b, Purkarthofer 2005

Overall, the different types of solar heating systems available vary with respect to their efficiencies and system costs. Further cost reductions can be achieved through continuous deployment, increasing mass production and associated economies of scale.

Trends

Future trends in technology development will be seen particularly in the areas of materials and components, as well as advanced systems.

Regarding materials and components, effective optical coatings and anti-reflective and self-cleaning materials are likely to play an important role. Innovative plastic materials with such characteristics could decrease costs and improve efficiencies. Furthermore, an innovative task is the development of combined photovoltaic-thermal systems which could generate both electricity and heat.

Advanced systems will need to be scaled up to broaden the market for solar heat systems, including hotels, schools, etc. for providing both hot water and space heating. In the case of demand for process heat in the industrial sector and the usage of solar heat in district heating, future R&D efforts should focus particularly on the development of large-scale solar heat systems at higher temperature levels.

Moreover, compact heat storage will presumably be a key technology for the market extension of solar heating systems, even in regions closer to the poles, if it provides for affordable inter-seasonal storage (IEA 2008b).

Concentrating solar systems such as parabolic trough and Fresnel collectors can also have an increased impact in the heat sector, especially for advanced cooling applications with refrigerating machines using heat on a medium temperature level (up to 250 °C) or other process heat applications.

In the field of solar cooling ambitious research has been conducted in the main solar research centers in recent years. Spain is a leading country in terms of demonstration projects with over 120 installations. Still, there is a need for research and demonstration to drive costs down, particularly with solar-assisted systems using absorption and adsorption technology in the small output range, as well as with re-cooling.

Costs and Competitiveness

PV Costs and Competitiveness

PV Costs Today

Due to increasing PV deployment and R&D efforts of recent years, cost-efficiency of PV technology was improved tremendously making most solar technologies widely available and applicable today.

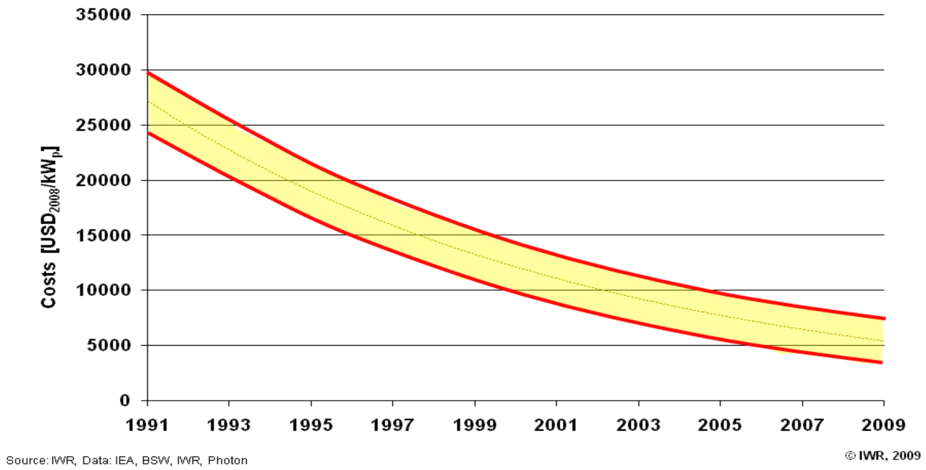
While details of technology progress vary depending on the particular technology efficiency, the size of the installation, and the regional differences in solar radiation, the general development has been towards dramatic cost reductions.

Investment costs

The cost of PV electricity generation is primarily determined by up-front investment costs. This is similar to other renewables since variable operating costs are very low due to the lack of fuel needed for operation.

The expansion of production capacity in the PV industry reduced prices for PV systems by approximately 84% from an estimated US$27,000 per installed kW_p in 1991 to an estimated US$4,400 per installed kW_p in 2009, as shown in Figure 21 below (Photon 2009).

FIGURE 23. DEVELOPMENT OF INSTALLATION COSTS FOR RESIDENTIAL PV SYSTEMS (1991 - 2009)



Source: IWR, Data: IEA, BSW, IWR, Photon

The investment costs for PV systems depend on the type of solar cells, the type and scale of installation (small scale building integrated PV or large-scale free-field applications; with or without tracking system) and local labor costs (IEA 2008c). For residential PV systems (up to 20 kW_p) typical turnkey-system prices are approximately US$6,000 per kW_p today. For utility-scale systems, prices of approximately US$4,000 per kW_p can be assumed (IEA 2009g).

Enormous price reductions were also obtained by progress in PV system technology. For instance, prices for PV inverters have been reduced from €1 per Watt to €0.33 per Watt since 1990

PV investment costs have declined dramatically since the 1990s. Similarly, prices of important PV system technology (e.g., inverters) have decreased considerably.

Electricity generation costs

At the same time, mass production, intensified competition and increased R&D (from US$250 million in the year 2000 to about US$500 million in the year 2007, according to IEA PV Roadmap) have increased PV efficiency rates considerably. Since 2000, the efficiency rate of standard multi-crystalline silicone PV has been increased by about 25%, from 13% in 2000 to 18% in 2009 (see above). This progress was accompanied by important improvements in the PV engineering and installation construction sector.

As a consequence, PV electricity generation costs decreased by more than 50% compared to the year 2000. Today, the lowest electricity generation costs for PV amount to US$0.24 per kWh for utility-scale systems beyond the MW-Scale; at best locations[39]). Costs range up to US$0.72 per kWh for small scale residential systems up to 20 kW_p at low solar radiation locations[40] (IEA 2009g).

Tomorrow's Cost Reductions

PV costs are anticipated to decrease further and rapidly due to very promising learning rates.[41] Learning rates for PV modules (particular for crystalline silicon cells) ranged from 20% to 23% in the past and were approximately 22% for PV systems (IEA 2008b). This means when the cumulative PV production doubled, the investment costs were reduced by 20-23%.

According to an analysis carried out by the Department of Engineering and Public Policy in Carnegie Mellon University in 2003, the future learning rate for PV could achieve 30%. That is, higher deployment rates would reduce cost faster thereby leading to a faster market penetration of PV modules.

To put these figures in perspective, future learning rates for fossil power systems such as IGCC (integrated gasification combined cycle) or CCS technologies are so far assumed to equal about 3% (IEA 2008b)

Based on these promising learning rates, the IEA expects that ambitious deployment policies combined with further R&D efforts can reduce today's generation costs by one-half by 2020. In such regions, utility-scale systems could then generate a kWh of electricity at just about US$0.12. At the end of 2030, generation costs of US$0.07/kWh are expected in regions with sufficient solar radiation.

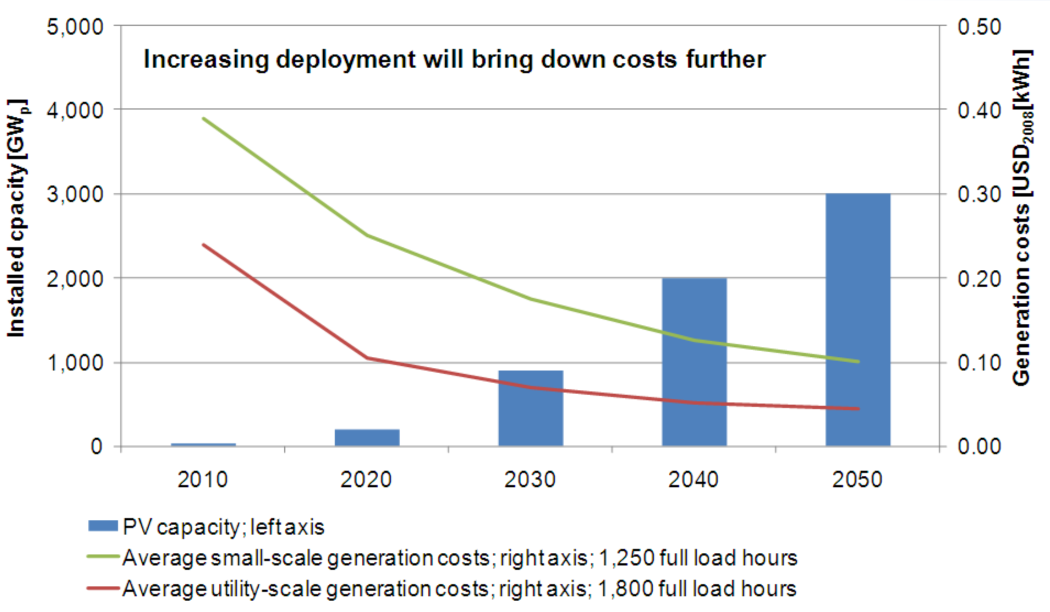
Until 2050, utility-scale generation costs could further decrease to US$0.045 per kWh, cutting current prices by a factor of 5 relative to 2010. Small-scale generation costs are projected to come down to about US$0.10/kWh (IEA 2009g, Figure 24).

[39] Where 2,000 kWh per kW_p can be generated per year.

[40] Where 1,000 kWh per kW_p can be generated per year.

[41] A learning rate reflects the cost reduction for each doubling of globally installed capacity. A learning rate of 10% means that doubling the cumulative production is associated with a reduction in investment costs by 10 %.

FIGURE 24. PROJECTION OF GLOBAL PV CAPACITY AND GENERATION COSTS UNTIL 2050



Source: IEA 2009a

Competitiveness

Whereas PV electricity generation costs are declining, fossil fuel prices may rise due to the limitation of fossil fuels as well as to increasing climate policy-driven internalization of climate change costs (e.g., cap and trade schemes).

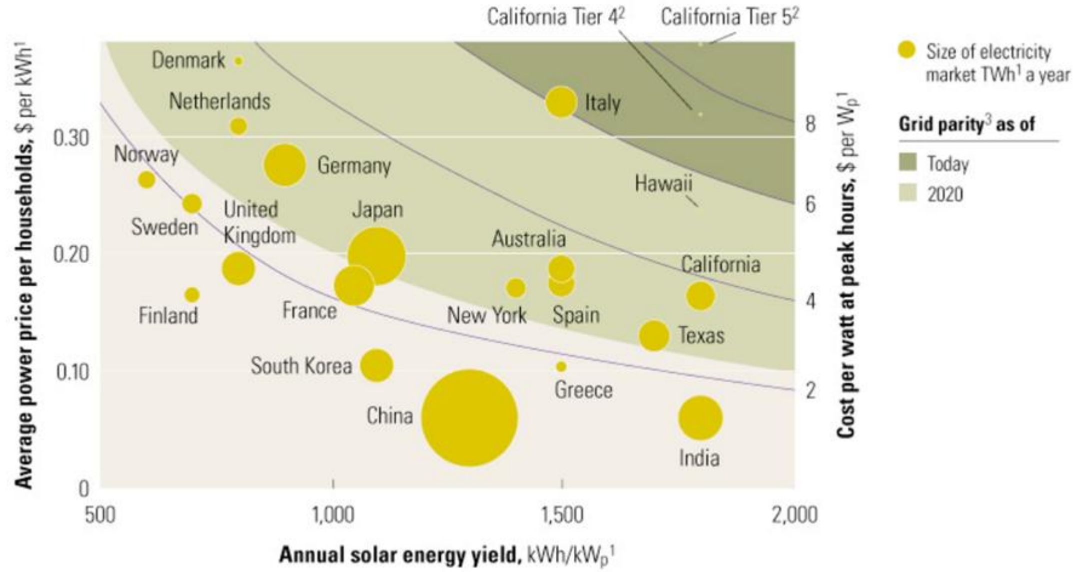
Moreover, in the context of rural electrification, PV applications have competitive advantages compared to diesel motors not only in terms of costs (US$0.20–0.30 based on local fuel prices) but also since diesel motors contribute to noise and air pollution.

Grid Parity

Once grid parity is achieved, it might even further boost market dynamics thereby further driving down PV installation and electricity generation costs along the learning curves. Grid parity refers to the point in time when PV electricity generation costs fall below the electricity price for private households. This opens a new scope for PV applications through self consumption of PV generated electricity by consumers since PV electricity would be competitive with household power prices. For instance, in Germany, where current household power prices are about US$0.28 (EU €0.20), grid parity may be achieved by 2013-2015. After 2020, photovoltaics are expected to reach grid parity conditions in a rapidly increasing number of countries covering more than half of the world by 2030, as shown in Figure 25 below (IEA 2009g).

However, grid parity needs to be flanked by establishing appropriate framework conditions, including flexible tariffs, smart metering, intelligent household devices and development of storage capacity.

FIGURE 25. COUNTRIES IN WHICH GRID-PARITY CAN BE REACHED BY 2020



¹kWh = kilowatt hour; kWp = kilowatt peak; TWh = terawatt hour; Wp = watt peak; the annual solar yield is the amount of electricity generated by a south-facing 1 kW peak-rated module in 1 year, or the equivalent number of hours that the module operates at peak rating.
²Tier 4 and 5 are names of regulated forms of electricity generation and usage.
³Unsubsidized cost to end users of solar energy equals cost of conventional electricity.

Source: CIA country files; European Photovoltaic Policy Group; Eurostat; Pacific Gas & Electric (PG&E); Public Policy Institute of New York State; McKinsey Global Institute analysis

Source: Lorenz et al. 2008

Grid parity can accomplish the following:

- Accelerate PV deployment
- Relieve the power grid
- Foster the opportunity to introduce minimum requirements for PV in buildings, since the consumer benefits from these installations
- Give further impetus on developing horizontal technologies such as storage technology and smart grid technologies, which will play an important role in the context of system integration of renewables

Prospect of very low variable costs

Moreover, there is the prospect of PV electricity generation from re-financed PV installations at considerably lower costs than conventional electricity generation. Since PV electricity generation does not require fuel or produce by-products in its operation, it incurs very low variable costs. This advantage is fully realized after the installation costs are financed (and only operation and maintenance cost remain). Although not all technology life cycles are currently well proven, PV installations typically have an operational life span that considerably exceeds the re-financing period.

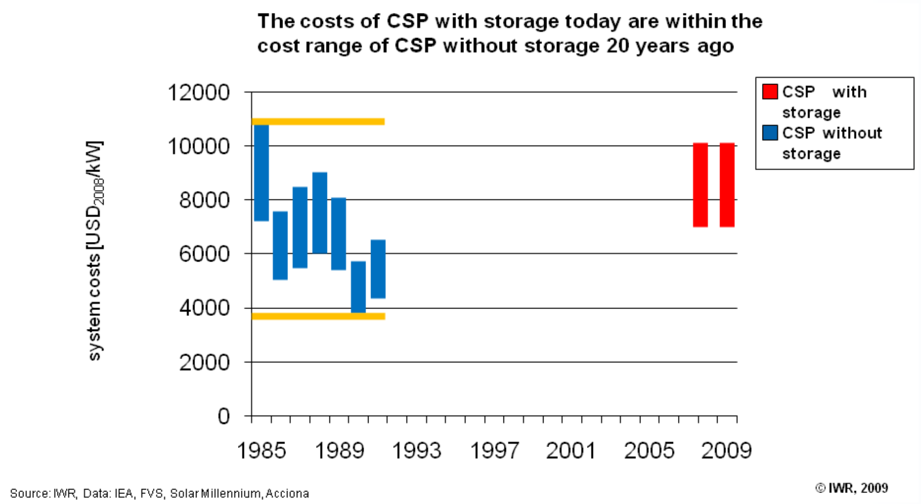
The costs of electricity generation from PV have been cut by half since 2000, and they are expected to be halved again until 2020 driven by economies of scale. The outlook of grid parity will boost PV deployment and bring about further cost reductions along the learning curve.

CSP Costs and Competitiveness

CSP Costs Today

Triggered by the re-emerging market, CSP installation costs are falling. Between 1984 and 1991, when the first commercial parabolic trough plants were installed in the United States, investment costs were reduced by more than half, from above US$10,000 per kW_p to an amount between US$3,000 and US$5,500 per kW_p (Figure 26). Today, installation costs for a CSP installation with a heat storage system like Andasol 1 are in the range of CSP installation costs without storage 20 years ago. This is a consequence of the storage capacity increasing the utilization factor of the CSP plant twofold. Therefore levelized electricity generation costs are likely to be considerably lower for a CSP plant with integrated storage capacity compared to systems without storage. Recently constructed plants generate electricity at a cost of US$0.13–$0.23/kWh depending on the location (IEA 2008b).

FIGURE 26. DEVELOPMENT OF SPECIFIC COSTS FOR DIFFERENT CSP PLANTS WITHOUT AND WITH STORAGE (1985 – 2009)



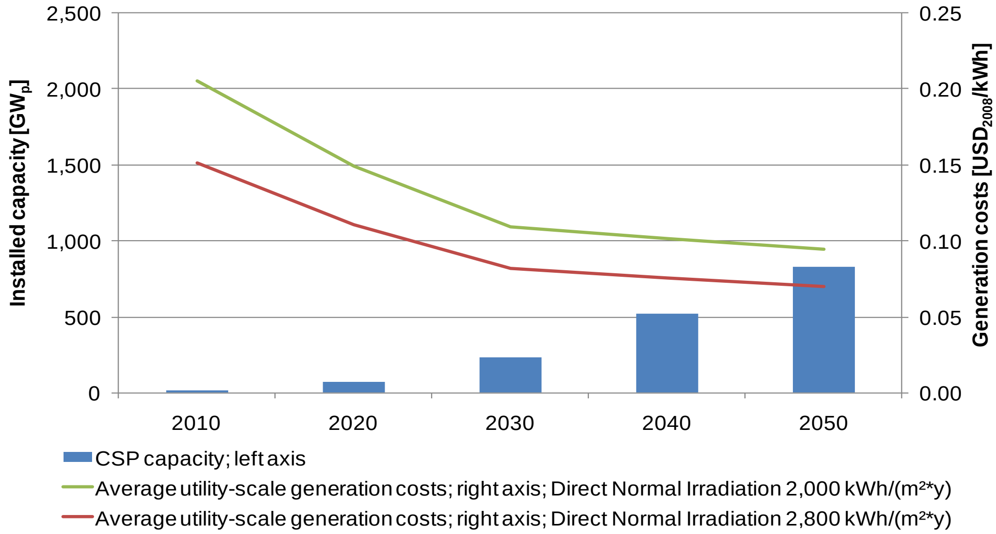
Source: IEA, FVS, Solar Millennium, Acciona

Tomorrow's Cost Reductions

By increasing CSP capacity, investment and generation costs could be further reduced. Cost reductions are driven by technological learning. Future technical learning rates are expected to amount to 10% (IEA 2008b). Further cost reduction can be expected as a result of scaling up the size of CSP plants (IEA 2009c).

Based on the expected increase in CSP capacity by 2020, power generation costs are estimated to decrease to a range of US$0.10–0.13 per kWh (IEA 2009i). By 2030, more than 200 GW could be installed, resulting in electricity generation costs of about US$0.11 per kWh in regions with less solar radiation and only US$0.08 per kWh in regions with high solar radiation. By 2050, further learning could decrease the generation costs from CSP to almost less than US$0.07 per kWh (Figure 27).[42]

FIGURE 27. PROJECTION OF GLOBAL CSP CAPACITIES AND GENERATION COSTS UNTIL 2050



Note: A CSP plant with a large solar field, large storage system and one power block with the potential to be used for base load power generation.[43]
Source: SolarPACES 2009, DLR 2009.

Competitiveness

While CSP electricity generation costs will presumably fall, fossil fuel prices may rise due to the increasingly limited supply of fossil fuels as well as by the increasing internalization of climate change costs by cap and trade schemes and other political measures.

Furthermore, the storage and hybridization capacity of CSP technologies allows for the unique advantage of providing firm and dispatchable electricity on demand, by which CSP can compete with peak-load or intermediate-load electricity in some regions, and even with base-load electricity in the long run, if combined with appropriate storage (see above).

Prospect of nearly zero variable costs
Since CSP technology, like most renewables, does not require fuel nor produces waste, it benefits from the competitive advantage of nearly zero variable costs, which will fully realize once the installation costs are re-financed (at which point only operation and maintenance cost remain). Assuming the first large scale CSP installation launched in the California Mojave Desert in 1980 will have a life cycle of 30-40 years and considering that this was achieved based on the state of technology in 1980, one can assume a very promising outlook of operating re-financed large-scale CSP plants. Such projects will likely operate for more than 20 years at very low costs

[42] In an analysis carried out before the recent jump in raw material prices, the U.S. Department of Energy even expected levelized electricity generation costs from CSP to reach about US$0.05 to US$0.06 per kWh by 2015 (DOE 2007).

[43] The electricity learning curve was calculated for a CSP plant that is equipped with four solar fields, three storage systems, and one power block.

that will be limited to service and maintenance. Operating costs are estimated to be about only US$0.03 per kWh (SolarPACES 2009).

This outlook is underpinned by a nearly constant level of CSP installation performance. In the SEGS project it has been proven that the annual plant availability constantly exceeds 99% and the plant performance level has dropped by about 3% in 20 years.

Exports as additional option

Moreover, the prospect of investing in CSP installations in southern regions of the world might be improved by the prospect of exports to northern countries. The huge solar power potential in the sunbelt of the world far exceeds their demand. Though a number of advanced challenges must be overcome, such as the installation of large High Voltage Direct Current Transmission (HVDC) to the import country, establishing appropriate framework conditions which allow for secure and reliable transmission and the integration into the renewable strategy of the import country, this remains a promising additional option.

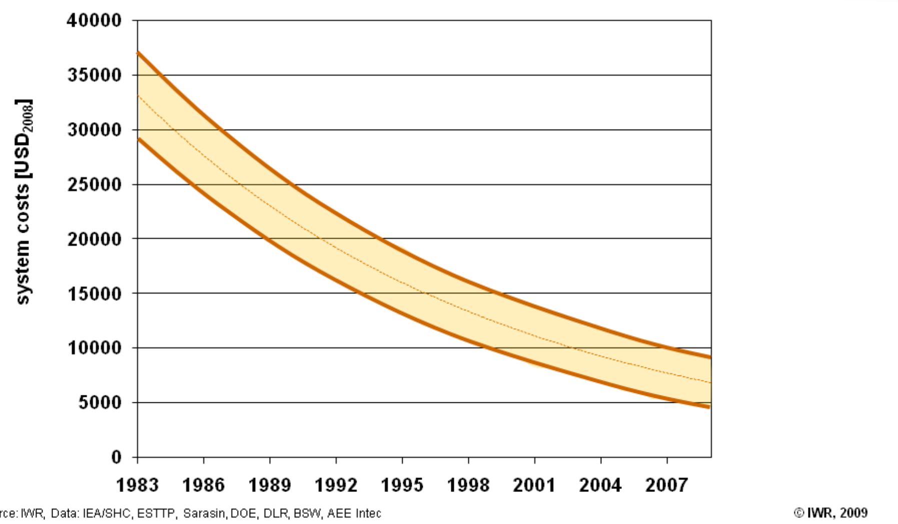
The costs of electricity generation from CSP could decrease rapidly within the next decade. Until 2030, they are expected to be cut by 50%, making CSP even more competitive.

Solar Heating Costs

Cost Reductions of the Past

With rising efficiency rates and increasing market penetration, the average costs of solar heating systems have fallen by 50% and more since 1980. Currently, the overall system costs for solar heating systems average around US$310 to US$1400 per m^2, depending on size and technology (IEA 2007). Figure 28 shows the range of cost development from 1983 until today for an average solar heating system in Central Europe, illustrated in US$ based on prices of 2008.

FIGURE 28. DEVELOPMENT OF SPECIFIC COSTS FOR AN AVERAGE SOLAR HEATING SYSTEM (2-5 M^2 COLLECTOR AREA) IN CENTRAL EUROPE (1983–2008)



Source: IWR, Data: IEA/SHC, ESTTP, Sarasin, DOE, DLR, BSW, AEE Intec

The costs of heat production depend on solar heating technology, the location and the level of solar radiation, and can vary widely by region. Consequently, the costs of solar heat production in central Europe differ from those in southern Europe. In southern Europe costs range from US$0.07–0.16/kWh; meanwhile the average costs in central Europe vary from US$0.09–0.21/kWh due to lower insulation levels (ESTTP 2009b).

Future Cost Reductions

The costs of heat production are expected to decrease even further. The current learning rate for solar heating systems equals about 10%. That is, production costs shrink by about 10% each time the cumulative production of solar heating systems doubles (IEA 2000). Given the capacity increase projected in the IEA's ETP BLUE Map scenario, overall system costs may drop by about 30% or more until 2050, especially for large-scale solar heat systems. In conjunction with efficiency improvements in different system components (stand-by losses, etc.), the costs of heat supply can be expected to decrease even more to improve the competitiveness of solar heat systems.

Solar heating systems are competitive in many regions already today, and their heat generation costs are shrinking further.

Benefits of Investing in Renewables

Economic Growth and New Markets

Renewable support policies attract considerable private investments. In the EU for example, in 2005 the total value added by investment in renewable projects was worth more than US$80 billion (€58 billion). The continually prospering European renewable market driven by complying with the EU 2020 renewable energy targets will likely induce investments amounting to around €130 billion of gross value added, which would induce a net increase in the EU GDP of up to 0.25% by 2020 (Ragwitz et al. 2009).

The global financial investments in solar technologies in 2008 reached US$33.5 billion (second renewable technology after wind that reached US$51.8 billion). This corresponds to an increase of 49% compared to 2007 and marks an equivalent average annual growth of 172% in the period 2004-2008 (UNEP 2009).

New Jobs

Investments in renewables are investments in jobs in leading future markets with high growth rates. There is a need for qualified staff all along the value chain.

- In the PV technology sector, about 170,000 people worldwide were employed in 2006 (UNEP 2008a). Given the dynamic market development for PV since then, this number is likely higher today. Until 2030, 1.6 million jobs can be reached in an ambitious PV growth scenario (Rutovitz and Atherton 2009).
- In the CSP market, 200,000 jobs worldwide in 2020 and 1.2 million jobs in 2050 are expected by the CSP industry (SolarPACES2009).

- In the solar heating and cooling sector already today, the solar heating industry employs more than 600,000 people worldwide (UNEP 2008a) and up to 5 million jobs worldwide appear realizable in the long run[44].

In Germany, for instance 280,000 people are employed in the whole renewable sector already today.

Local Investments

Investments in solar technologies generate local value added. For one, existing component suppliers tend to set up production lines where markets exist since this enhances market presence and reduces market entrance barriers such as for instance logistical or legal obstacles. Consultation with industry indicates, however, that the decision to set up local production chains depends on appropriate framework conditions for investments such as legal certainty, protection of intellectual property rights and the availability of qualified staff.

Even without local production, local jobs created to install PV systems and local services required for the operation and maintenance of PV installations are equally important. Other services such as local equipment manufacturing, planning, logistics, financing and craft services play an important role as well. Industry estimates indicate that up to about 60% of an investment in a solar energy project is likely to consist of local investment and services (McCrone 2009).

Save Greenhouse Gas Mitigation Costs and Other External Costs

As shown above, renewables will presumably be available at lower energy costs in the future. If one takes into account the relative costs, they could be already more competitive today. Taking into account long-term macroeconomic factors, it becomes clear that the most relevant cost is the comparative cost of inaction.

Solar technologies save greenhouse gas mitigation costs, costs for energy imports and other external costs, such as environmental costs or long-term health-care costs from pollution.

The Stern Report impressively demonstrated that the costs of inaction by far exceed the costs of action. Unchecked climate change will cost between 5 and 20% of global GDP, active climate policy, on the other hand, only around 1% (Stern 2006).

Energy Security

Investments in solar technologies provide for energy security in the long run by enhancing independence from energy imports and by providing stable and predictable solar energy prices.

Avoided fossil fuel imports will improve a state's balance of trade considerably, depending on the amount avoided and the price for fossil fuels. Solar energy replaces energy produced through fossil fuels. For the EU, it is estimated that renewables will help save a total of about €100 billion in 2020 by avoiding fossil fuels imports (Ragwitz et al. 2009). In Spain, the Renewable Energy Plan 2005-2010 aims to avoid fossil fuel imports amounting to €3,500 million (assuming US$50 per barrel oil).

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[44] Estimates by Prognos for the German Federal Ministry of Environment.

Future Competitiveness

Investing in clean energy technologies already today is a question of long-term competitiveness. The transition towards a low-carbon economy is of utmost complexity for the energy system. New challenges will only become clear in practice. For example, the aspect of balancing fluctuating energy supply from renewables requires a comprehensive energy policy providing for instance for larger balancing areas, smart grids, flexible and easily controllable power plants and storage technologies. Power-system operating strategies need to be optimised and adapted, resulting in a learning process which needs several years.

Spillover Effects and Synergies

Investment in renewable technologies accelerate market dynamics, facilitate a high level of innovations and synergy effects and accumulate knowledge, which could have spillover effects in the renewables sector (e.g., storage technology, system integration) as well as the broader economy (e.g., electric vehicles, smart grids, smart domestic appliances, new technology concepts).

Knowledge Transfer

Implementing solar projects requires capacity building since qualified service and technology-specific knowledge is needed. This may initiate a North-South transfer of knowledge, investments and technologies by employing the vast, untapped solar potential in the south through technology cooperation and capacity building.

Window of Opportunity

The current global and financial crisis has lead to particularly lower investment costs for renewable energy projects. This coincides with the current need to stimulate the economy and create recovery programs. Currently, a unique window of opportunity has opened for low cost investments in green technology today for tomorrow’s energy security and sustainable growth. Green recovery” programs in many countries reflect this opportunity to a considerable content.

Furthermore, countries that begin investing in renewables today can benefit from the technological progress and the enhanced cost-efficiency that has already been achieved over the last years and by doing so, they will contribute to further technology progress and costs reductions.

APPENDIX B. FURTHER DETAIL ON BEST PRACTICE POLICIES AND GAPS

Increasing Demand for Solar Power

Green power purchase agreements, labeling of additionality, and improving customer awareness

According to global evaluations, green power markets grew strongly over the last few years in several countries. The worldwide number of green power consumers grew to 5 million households and businesses. In Germany, more than 1 million households purchased 2.8 TWh of green electricity. In the United States, 850,000 green power consumers purchased 18 TWh. In Australia, almost 950,000 green power consumers purchased 1.8 TWh. In Switzerland, 600,000 green power consumers purchased about 4.7 GWh (REN21 2009).

Nevertheless, the market pull for new renewables deployment remains inadequate. One major hurdle is the lack of transparent consumer information on the origin of the energy mix (disclosure). The EU has made some progress with the electricity labeling directive it launched to tackle this issue. However, the system does not yet work at full effectiveness due to the complexity of disclosure-related issues. Since renewable electricity, once fed into the grid, cannot be tracked physically, a certificate needs to be used as proof of electricity origin (guarantees of origin). Since the amount of electricity produced by old and previously re-financed hydropower installations exceeds the overall consumer demand for renewables, these guarantees of origin can be achieved today at very low costs (in the EU, a guarantee of origin currently costs significantly less than €0.01). This leads to a considerable drawback for marketing renewables because consumers pay higher prices for renewable contracts with the intent to support further renewables deployment but, counter to this intent, their renewable energy purchase does not set off additional deployment effects. This hinders market pull and could considerably affect consumer confidence.

Private eco-labeling initiatives attempt to overcome this gap by requiring that suppliers that want to sell an eco-labeled renewable contract to invest a set amount of their margins into new renewable installations. In addition, the full marketing potential of solar PV should be tapped (see text box).

HOW TO MARKET SOLAR PV SUCCESSFULLY

- Emphasize stronger economic benefits of PV investments rather than only environmental benefits, e.g. by:
  - Stressing the affordability of monthly installments rather than total cost of a PV sale, and
  - Stressing the increasing property value of the home due to the PV installation.
- Reinforce the reliability of solar by:
  - Creating strategic partnerships with sports teams, local celebrities, media,
  - Involving the real estate industry (as done in some U.S. states), and
  - Reducing the complexity of PV by involving trusted advisors (installers, solar ambassadors such as existing PV customers, energy advisors)
- Reach new customer markets. For example, San Francisco has decided to support PV on the largest buildings (for other examples in the U.S., see Sinclair 2009).

Grid Access and System Integration

New Transmission Infrastructure and Connecting Power Systems

High voltage direct current
High voltage direct current (HVDC) transmission is a promising solution particularly for bulk power transport of wind power over long distances. It reduces transmission losses and undesired load flows. For example, a feasibility study of the German Aerospace Centre (DLR 2009) has shown that for a HVDC transmission line from Africa to Europe only 10% loss would likely occur. In addition, HVDC transmission has a smaller land print than the alternating current system (AC) because it only needs two power lines instead of three. For example, a pylon constructed for transferring 10 GW of electric capacity needs about 60% less space with HVDC than with AC (DLR 2009). However, this system is more complex than the alternating current system (AC) and requires more advanced communication between all terminals and power flow has to be actively regulated. Good examples for HVDC connections that have been or are being built can be found in China, India, the U.S., Brazil, and Europe, e.g., the HVDC connection between the Netherlands and Norway.

Underground transmission cabling
The use of underground transmission cabling can enhance public acceptance of grid installations and therefore speed-up the permitting process. Even though they are rather costly at the moment, prices have come down over the last few years and further cost reductions are envisaged through economies of scale. In the German grid expansion act, four demonstration projects for ground cabling on the transmission level have been provided for.

Power electronic devices for load flow control
Power electronic devices for load flow control, so-called FACTS (Flexible AC Transmission Systems) enhance the grid performance by responding to fast-changing network conditions by influencing the AC transmission parameters. The first installation was put into service 20 years ago. Nevertheless, the full potential of this innovative technology can only be realized when a coordinated control scheme is implemented.

Improving Existing Grid Infrastructure

Dynamic line rating (vs. fixed line rating)
Today, the power carrying capacity of overhead lines is determined by their sag. The line sag depends on the conductor temperature and therefore on the ambient weather conditions such as air temperature and irradiation. The responsible transmission system operator (TSO) normally bases its calculations of the maximum power capacity according to international standards (IEC /CENELEC) on fixed weather conditions which reflect the worst case scenario.

A dynamic line rating, which takes into account the current weather terms, such as wind cooling, could increase the transmission capacity by up to 50%. For instance, due to its storage capacity, CSP could deliver dispatchable electricity at night when significantly lower temperatures cool down the temperature of overhead lines.

Rewiring with low sag, high temperature wires
Another approach to overcoming the line sag problem is to rewire existing overhead transmission lines with low sag, high temperature wires. This is an easy and simplified approach since rewiring does not require complicated spatial planning

procedures and therefore allow for quick permitting. The exchange of wires has already been approved, e.g., in Canada, U.S., Switzerland and Italy.

Sufficient, Affordable Financing

Incentives for Private Investments

Private investments in large-scale projects are the most important driver for PV and CSP scale-up. Equipment prices for PV have been reduced to unprecedented levels because of investment in the PV manufacturing industry. Currently, investment in PV is attractive to investors because the prices for PV modules have come down because of global overcapacity. On the other hand, the financial crisis has considerably weakened global financing. To bolster investor confidence in solar energy, broader public awareness of the benefits of PV and CSP investments is needed, especially in areas where PV and CSP power are competitive with conventional generation. A public discourse with mainstream financiers is needed regarding opportunities, technical risks and mitigation mechanisms specific to solar energy. Recent large-scale initiatives, such as the DESERTEC industrial initiative, could help put solar energy back in the spotlight.

Risk-averse, large-scale, long-term financiers such as pension funds could be attractive partners for solar investments. In addition, specialized renewable energy financiers—developers of closed funds, for example—can access private investors who want to put small amounts of money into ethical investments, and might be open for facilitation of global cooperation.

Financial commitments made by the public sector can bring down market barriers, bridge gaps, and share risk with the private sector. It has been estimated that US$1 of public investment spent through a well-designed PFM can leverage US$3–15 of private capital (UNEP 2008). However, availability of public funding is just one part of the challenge; getting financial institutions and private investors to make use of public funds is another. UNEP has been working on bringing the public and private sectors closer on how best to spend public monies in order to catalyze private investment through Public Finance Mechanisms (PFMs) (UNEP 2008). It will be critical for any potential new climate financial architecture that the financial institutions in developing countries have the capacity to use public funding to mobilize private investments. Additional capacity building might be valuable here.

Another key aspect is transparency and information on existing financing mechanism. The Sustainable Energy Finance Initiative (SEFI) and, in the future, IRENA can add value in this area.

Utility-scale Project Financing

A large number of mechanisms have been used for utility-scale on a national and international scale, including funding by the World Bank Climate Investment Funds (CIF), European Investment Bank (EIB), Development Bank of the Federal Republic and federal states (KfW), Global Energy Efficiency and Renewable Energy Fund (GEEREF), Global Environment Facility (GEF) / International Finance Cooperation (IFC), and Overseas Private Investment Corporation (OPIC). The CIF, in particular, provides an effective and promising model. Under this scheme, established in 2008, a total of US$6 billion was pledged by ten donor countries. The money is to be spent on soft loans for large-scale sustainable energy programs in emerging economies.

The CIF program addresses a number of important financing aspects with the potential to serve as a best practice. First, it is being implemented on an unprecedented scale, ensuring a real impact on technology deployment. Second, it intends to take on a strategic focus such that funds are to be spent on strategic programs for specific countries or technologies that are large enough to have a sustainable impact. Third, the Funds have a "sunset clause." They will be closed at a specific point in time, avoiding the build-up of excessive administrative structures and use of valuable resources on institutional survival strategies. Finally, in most cases, the funds require the World Bank to cooperate directly with the Regional Development Banks (World Bank 2009a). This supports the dissemination of experience to other key players. It can also place renewable energy firmly in the minds of a larger number of lending institutions.

Pilot Projects Financing

An alternative approach can be to set up funds for supporting pilot projects. These funds, by their very nature, have a limited impact in terms of replication and multiplication. A number of initiatives such as GEEREF and U.S. OPIC are based on equity funds. They operate in regions where there is a lack of equity investment available to the market for these types of projects. In this way, they create a finance platform to accelerate the transfer, development and deployment of environmental technologies. The "closed fund model", originally conceived in the 1990s for the German solar industry, is now being applied in the German solar industry. Indeed, it has helped raise money for some of the largest solar PV installations—not only in Germany, but also in Spain and Italy. Innovative public-private partnerships can also be used to raise the financial resources needed. One example is the partnership between the State of California (U.S.) and a solar company to install 8 MW of solar capacity at 15 state universities campuses. Such efforts to support pilot projects can also be linked to the expanding global carbon markets. The German Climate Protection Initiative (CPI) uses parts of the revenues generated through the auctioning of emission allowances to support the development of innovative project approaches.

Risk Mitigation

In order to mobilize more commercial financing for developing or emerging countries, several instruments rely on mechanisms with flow back guarantees or other risk mitigation tools. A public funded portion covers higher risks that may impede commercial credit or asset financing. Such financial instruments can be designed in order to transfer specific risks from project sponsors and lenders to, for example, insurance companies and other special parties.

The public sector loan guarantee is one form of risk mitigation mechanism. A guarantee given for a specific project can motivate banks to invest, although the project might be perceived as risky. These innovative financing instruments may provide global risk capital through private investment. In contrast to end-user lump-sum investments or tax subsidies, these instruments result in less significant market distortion. Continued investment subsidies have in the past helped some markets develop, but have destroyed others. If not applied properly they can lead to higher margins in the supply chain and less efficient delivery of solar technology to the consumer.

Several examples of small to medium-sized guarantee instruments include the French FOGIME, the Canadian GMIF and the RE and EE Program of the United States Department of Agriculture (USDA) (UNEP 2005). In developing countries, the

World Bank offers some guaranteeing facilities for specific project and risk types. In the UK, the Euler Hermes Guarantee provides a full range of bonds and guarantees to every size of company.

Incentives for the User Side

On the user side, such as residential installations, the financing mechanisms currently being applied are more diverse. Options include contracting and leasing models, government loan programs, government subsidy-to-banks programs, and tax rebates. Most consider output-based aid a better practice than investment subsidies.

In the case of solar retail technologies, the biggest impact can be achieved by programs that help retail banks supply their commercial and residential customers with loans at terms that make solar energy a profitable investment. This can be achieved by a variety of means. Projects such as the GEF, which supported cooperation between IFC and private-sector banks in Eastern Europe for energy efficiency investments, could be viable for solar technologies (ASE 2009). This would involve the IFC educating retail banks on how to assess investments in solar energy. If the policy framework then sends out the right signals (e.g., through feed-in tariffs), banks should be willing to lend against the resulting revenue streams.

Micro-Financing

Supplying solar energy to rural areas that are economically depressed and other marginalized impoverished areas is a technical, logistical and economic challenge. These areas do not have a labor force with technical expertise, are financially disadvantaged and often, are geographically remote. One of the first successful PV off-grid models, both in terms of deployment and poverty reduction, is the Bangladesh Grameen Shakti program. This program used a combined approach of micro-financing and technical expertise delivered by the same supplier. By installing more than 210,000 solar home systems throughout the country, the program led to more than 38,000 villages being equipped with electricity (Barua 2007). In 2008, two new World Bank projects in Bangladesh were approved to develop 1.3 million solar home systems. The World Bank’s China Renewable Energy Development project was completed in mid-2008 with solar PV systems for more than 400,000 households (11 MW total). A German KfW project in Morocco, also completed in 2008, provides electricity through PV off-grid installations to 40,000 households (REN21 2009).

Clean Development Mechanism (CDM)

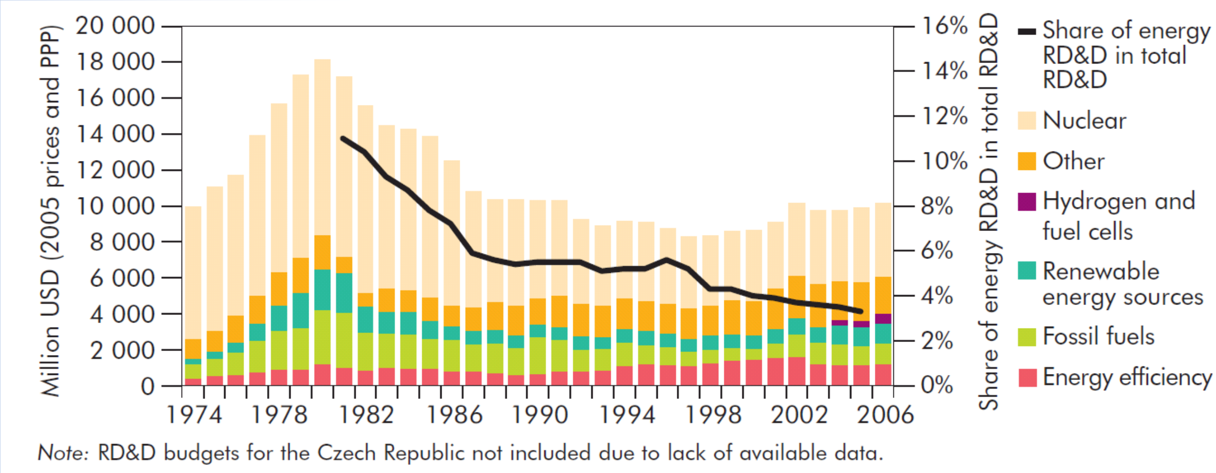
Implemented under the United Nations Framework Convention on Climate Change, Clean Development Mechanism (CDM) projects are, in principal, a useful approach to contribute to sustainable development and technology cooperation with developing countries. The CDM is one of the flexible mechanisms under the Kyoto Protocol that allows Annex-I countries to receive emission reduction credits from GHG abatement projects in developing countries. However, currently just 1% of CDM projects are solar projects, and the majority of these are PV. As part of the international climate negotiations, a dynamic debate is ongoing about reforming the mechanism. A reformed CDM may offer further incentives for financing solar energy projects.

Research, Development & Demonstration Projects

RD&D Investment Trends

Overall government expenditures on energy research, development & demonstration (RD&D) have steadily declined compared to the levels achieved in the late 1970s and early 1980s (Figure 29).

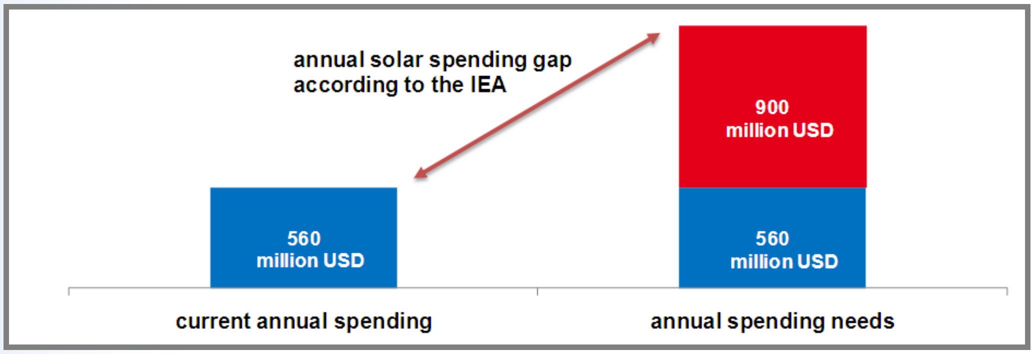
FIGURE 29. GOVERNMENT BUDGETS FOR ENERGY RESEARCH, DEVELOPMENT & DEMONSTRATION IN IEA COUNTRIES



Source: IEA 2008b

According to the IEA's findings in its recent analysis of Global Gaps in Clean Energy Research, Development, and Demonstration (IEA 2009f), completed for the Major Economies Forum, current global R&D investments are insufficient to achieve needed advancements in solar energy technologies. Per the IEA's BLUE Map scenario, overall investment needs for solar energy in the MEF countries are between US$75–89 billion by 2050 in order to achieve the 2050 solar energy targets. However, the IEA analysis found that only a relatively small amount of US$560 million is currently being spent annually on R&D for solar energy globally. Thus, according to this finding, the annual spending gap on solar R&D is approximately US$900 million (Figure 30) (IEA 2009f).

FIGURE 30. ANNUAL MEF-WIDE SPENDING NEEDS FOR SOLAR ENERGY TECHNOLOGIES



Source: IEA 2009i

Joint international research efforts hold promise to promote critical synergies and accelerated research dynamics. However, industry-based research cooperation has proven to be rather complex and is continually hindered by a number of legal uncertainties, such as policies on intellectual property rights. In the future, new approaches to joint research and development programs by public institutes, such as laboratories or universities should be considered.

Demonstration and Test Facilities

The gap between R&D success and market entrance for new technical solutions, sometimes called the "valley of death," can be bridged, at least partially, by demonstration projects and test facilities. Test facilities and demonstration projects help accelerate technology development, bring about cost reductions and spur technology deployment. They provide prototype and component testing, supporting future R&D and serving as starting points for further technology refinement (e.g., improved materials, quality management, increased efficiency and reliability, extended service life). Furthermore, large-scale demonstration projects improve public awareness and publicity of various solar technologies.

PV sector test facilities

In the PV sector, lead facilities for PV technology, production, and manufacturing processes perform research on critical future technology developments. In the case of individual PV components, the primary test facilities for PV cells are installed at the National Renewable Energy Laboratory (NREL) in Golden (United States), the Fraunhofer ISE in Freiburg (Germany) and at the Research Center for Photovoltaic at the National Institute of Advanced Industrial Science and Technology (AIST) in Ibaraki (Japan).

Though the PV industry is increasingly setting up its own test facilities worldwide, it remains important to ensure that appropriate test facilities are provided for also in the future, particularly for future technologies and novel concepts.

Solar heating test facilities

A key barrier for testing solar heating technology is the cost of system tests. As a consequence, testing is less profitable for operators in this area and thus, most of the known test facilities in the solar heating sector can be found at universities or other independent institutions. In contrast to the PV sector, there is currently a definitive lack of competition between test facilities. Assuming continual market growth, this might result in deficient testing capacities.

The major players in the solar heating sector at the international level are, for example, the Institute for Solar technology (SPF) in Rapperswil (Switzerland) and the "Testzentrum Solarthermie" (TZS) in Stuttgart (Germany). Other major test facilities for solar thermal systems are located at CRES in Athens (Greece) and at the National Centre for Quality Supervision and Testing of Solar Water Heating Systems in Beijing (China).

CSP test facilities

In the field of concentrating solar power technologies, test facilities produced a flood of new testing installations in the 1980s. Despite this, only a handful remains in operation today and very few have been recently established. Compounding this trend have been major gaps in the implementation of other CSP demonstration projects due to inappropriate project funding. Moreover, high installation costs for demonstration projects often overstrain national research funds even when industry stakeholders are involved.

Worldwide, several test facilities and large-scale demonstration projects in the CSP sector are currently in operation, for instance:

- One of the main research and test centers for CSP is the Plataforma Solar de Almería (PSA) in Spain. With participation from nine IEA countries under the leadership of the German Aerospace Center (DLR), several small CSP-plants were initially installed in Andalusia in 1980. Since 1999, the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) has maintained sole management responsibility for PSA by continuing its close and successful cooperation with DLR. The PSA continues its success due to the unique and constant growth of its facilities, constant funding and the great demand for its capacity.
- In the United States, the Sandia National Laboratories operate the National Solar Thermal Test Facility (NSTTF) near Albuquerque in New Mexico with an installed 5 MW solar power tower for component testing.
- Other solar tower test facilities include the Weizmann Institute in Rehovot, Israel, the former THEMIS plant in the French Pyrenees, which is planned to be revived as a research platform, and in Australia, at CSIRO’s Energy Centre. Australia has recently announced an AUD$1.5 billion initiative "Solar Flagships" to support the construction and demonstration of up to four large-scale solar power plants in Australia, using both CSP and PV technologies.
- The solar tower plant in Jülich, Germany, is a best practice example for a CSP test facility established through a public-private partnership. It was co-funded by three different ministries in Germany and realized through the collaboration of the research institutes DLR and Solar Institute Jülich, the municipal energy supplier Stadtwerke Jülich and the construction company Kraftanlagen München.
- To investigate key properties of CSP plant components including efficiency, durability and verifiable usability, the German Aerospace Center (DLR) has recently constructed a unique qualification and evaluation center for solar thermal power plant technology (QUARZ) in Cologne (Germany). In addition to CSP component testing, the center focuses its work on the development of certifiable standards and testing techniques for technical performance capabilities.

Appendix C. Further Specification of Options for Fostering Solar Energy

Goals and Support Schemes for Solar Energy Technologies	
Barrier / Gap	**Options**
Lack of confidence for investments	• Set ambitious targets to provide long-term investment security for solar energy. Targets should be formulated as minimum targets to achieve sustainable market development without "stop-and-go" cycles.
Lack of predictable and reliable demand	Establish a predictable and reliable support scheme, which should ideally comprise the following characteristics, as appropriate to unique national circumstances: • Provide predictable, reliable and transparent support over period sufficient for re-financing of investment costs. • Promote technology-specific support that aims at a broad renewable energy technology basket for future energy security. • Provide transitional incentives that decrease over time in order to further drive innovation. • Provide incentives for electricity fed into the grid rather than installed capacity therefore promoting efficient production over the project lifetime. • Recognize the increasing need for grid and market integration to ensure system reliability and overall cost efficiency due to the growing market share and increased technological maturity of renewables. • Promote ease of application and enforcement to attract as many private investors as possible. • Ensure efficient interactions with other schemes and other national policy frameworks.
Additional stimulus	• Consider the use of tax and investment incentives, particularly during the early stages of market development. Soft loans can offer an additional incentive.
Solar heating and cooling	• Consider the benefits of mixing different support mechanisms such as investment and tax incentives, taking also into consideration the benefits of obligatory minimum requirements.

Improving Marketing Conditions	
Barrier / Gap	**Options**
Lack of consumer information	• Take into account the benefits of labeling and consider ensuring transparent and cost-effective disclosure for consumers on origin of purchased renewable energy origin (e.g., labeling). • Support transparent information for consumers on the effect that their green power purchase agreements have on the deployment of additional renewables installations.
Lack of awareness	• Improve consumer awareness of the benefits from electricity generation from renewables through appropriate public information campaigns and all other appropriate marketing options.

Grid Access and System Integration	
Barrier / Gap	**Options**
Grid access	• Enact policies that provide for guaranteed connection and guaranteed or priority access to the grid for solar energy.
Grid capacity	• Ensure sufficient grid capacity either through extending and upgrading the grid and/or through optimized grid operation. • Make appropriate use of novel concepts and new technologies in the field of grid infrastructure and grid operation.
Lack of predictability of grid access and capacity	• Ensure early start of grid infrastructure planning. • Follow an integrated spatial planning approach which balances different land-use interests and prevents third-party claims during the permission or construction period. • Develop comprehensive grid studies which reflect a long term strategy for improving grid infrastructure.
System integration	Follow a holistic approach to integrate renewable energy into the system, which should cover, in particular: • A flexible power plants mix and advanced storage capacity. • Advanced demand-side management. • Improved congestion management that only rarely negatively affects renewables integration. • Connecting, as appropriate, different power systems and markets in order to enhance flexibility of the power system, leading to increased adaptability to fluctuating electricity generated from renewable sources. • Improved weather forecasts models and wide-area monitoring. • Facilitation of new concepts, intelligent applications and devices (e.g., smart meters) to intelligently interconnect supply and demand side in a way that allows online-based real-time system management in a smart grid.

Sufficient, Affordable Financing	
Barrier / Gap	**Options**
Utility-scale financing	• Implement, as appropriate, large-scale strategic financing programs with a sustainable impact.
Investment risks	• Consider leveraging more commercial financing through guarantee elements.
Knowledge gap	• Support capacity building for retail banks on how to assess solar energy investments. • Consider promoting micro-financing in combination with technical assistance to reach rural populations and alleviate poverty, especially in developing countries.
Untapped sources	• Promote strategic dialogue with investors to access untapped financing sources and establish public private partnerships to activate investment in developing and emerging countries.
Financing gaps	• Promote increase transparency of international funding schemes.

Research, Development and Demonstration Projects	
Barrier / Gap	**Options**
Funding	• Increase and coordinate public sector investments in RD&D in line with the L'Aquila declaration, while recognizing the importance of private investment, public-private partnerships, and international cooperation, including regional innovation centers.
RD&D framework conditions	• Establish appropriate RD&D framework conditions and environments, covering also legal certainty and intellectual property rights.
Lack of synergies and RD&D dynamics	• Follow a combined approach of RD&D and consequent deployment policy benefiting from economies of scale and spillover effects between research and mass scale testing.
Lack of forecast of technology development	• Employ a balanced set of instruments that ensures support of new and innovative concepts as well as all promising renewables technologies for a broad technology basket for future energy security.
International cooperation	• Consider the benefits of possible joint RD&D projects between public institutions (e.g., laboratories, universities).
Gap between R&D progress and market entrance for new and emerging technologies	• Provide, as appropriate, for sufficient test facilities and demonstration projects, particularly to address specific needs of new and emerging technologies. • Promote large scale demonstration projects
Readily available test facilities and demonstration projects	• Ensure that test sites for prototypes are available to allow flexible testing of new technologies with low requirements for approval and appropriate infrastructure; support international large-scale demonstration projects to improve the public image of solar technologies
PV test facilities	• Support test facilities especially for new emerging technologies for acceleration of market penetration.
CSP facilities worldwide	• Facilitate an increase in the number of test facilities and large-scale demonstration projects in different regions of the world, but especially in sunbelt countries.
Test facilities for solar heating	• Support the establishment of commercial test facilities necessary for expected market growth.

Greater Legal Certainty	
Barrier / Gap	**Options**
Frequent change in support schemes/ weak judicial system	• Establish stable and predictable legal frameworks.

Improved Planning and Reduced Administrative Burden	
Barrier / Gap	**Options**
Large number of required procedures and authorities involved	• Provide streamlined and concentrated administrative procedures; consider the benefits of a "one-stop-shop" approval system. • Introduce simplified approval procedures for small plants.
Different requirements in different regions	• Provide for an appropriate harmonization of requirements and procedures in order to facilitate investments
Huddle of techno-administrative requirements	• Provide for "better regulation", i.e., a clear, transparent, harmonized and sufficient set of regulations
Lengthy permitting process	• Accelerate appropriately permitting procedures and give clear time horizons to facilitate project planning
Unclear planning requirements	• Provide planning standards and guidelines to facilitate the planning process of homeowners and investors
Lack of planning predictability	• Use an integrated planning approach with a holistic approach that settles rival claims and balances land use interests and possible environmental impacts. • Start as soon as possible with the planning procedure and provide for early involvement of stakeholders. • Provide legal claim for permission if requirements are fulfilled. • Ensure that permission requirements are transparent and do not discriminate against solar energy installations. • Provide that solar energy installations are privileged, as appropriate, when balancing interests in the permitting process.
Lack of transparency and lack of information	• Develop transparent and easily accessible information on requirements and procedures. • Facilitate best practice guidelines.

Human Resources: Training and Capacity Building	
Barrier / Gap	**Options**
Knowledge gap	• Build up solar expertise in governments and the private sector and keep decision makers informed.
Lack of junior education	• Develop specific curricula in engineering disciplines at colleges and universities. • Set up technical schools to provide practical and theoretical training for mechanics, electricians, etc. in solar energy.
Lack of information exchange	• Involve both the public and private sectors to join forces in disseminating information about solar technology. • Create databases to make information easy to access. • Facilitate know-how transfer, e.g., through workshops and training.
Lack of project specific know-how	• Facilitate capacity building as one key element of solar energy projects.
Unsupportive policy and legal frameworks	• Consider creating an enabling environment by offering tax incentives and create renewable energy enterprise zones (REEZ) to promote the use of solar heating and PV systems.
Failure to share information	• Involve both the public and private sectors to join forces in disseminating information about solar technology. Make information accessible by training, workshops and Internet libraries (databases).
Lack of effectiveness due to lack of coordinated approach	• Support strategic, holistic capacity building on a global level, particularly focusing on countries with a need for solar energy capacity building. • Support international institutions, such as IRENA, that focus on capacity building in cooperation with existing institutions (e.g., REEEP).

Technology Cooperation	
Barrier / Gap	**Options**
Involvement of developing countries	• Strengthen North-South collaboration and mutual exchange, and enhance South-South technology cooperation; also address the issue of rural electrification.
Deployment gap	• Focus on technology cooperation in the deployment phase
International cooperation over RD&D	• Strengthen cooperative networks of solar energy research centers and other important players
Private sector participation	• Strengthen the role of the private sector in technology cooperation
International collaboration	• Support international institutions aiming at facilitating technology cooperation in the field of renewables

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