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The Heat Exchanger Based Domestic Solar Water Heater

Danish Khan[1], Dr.Vinod Bhaiswar[2], S.C.Sharma[3]

[1] Student, [2] Professor, Department of Mechanical Engineering, G.H.Raisoni College of Engineering, Nagpur
[3]Director (RSI),R.S. Industry, Nagpur, India – 440013

***Abstract** - Solar energy has experienced phenomenal growth in recent years due to both technological improvements resulting in cost reductions and government policies supportive of renewable energy development and utilization. This study analyzes the technical, economic and policy aspects of solar energy development and deployment. While the cost of solar energy has declined rapidly in the recent past, it still remains much higher than the cost of conventional energy technologies. Like other renewable energy technologies, solar energy benefits from fiscal and regulatory incentives and mandates, including tax credits and exemptions, feed in-tariff, preferential interest rates, renewable portfolio standards and voluntary green power programs in many countries. Potential expansion of carbon credit markets also would provide additional incentives to solar energy deployment; however, the scale of incentives provided by the existing carbon market instruments, such as the Clean Development Mechanism of the Kyoto Protocol, is limited. Despite the huge technical potential, development and large-scale, market-driven deployment of solar energy technologies world-wide still has to overcome a number of technical and financial barriers. Unless these barriers are overcome, maintaining and increasing electricity supplies from solar energy will require continuation of potentially costly policy supports.*

Keywords: solar energy; renewable energy economics and policies; climate change

INTRODUCTION

Solar energy has experienced an impressive technological shift. While early solar technologies consisted of small-scale photovoltaic (PV) cells, recent technologies are represented by solar concentrated power (CSP) and also by large-scale PV systems that feed into electricity grids. The costs of solar energy technologies have dropped substantially over the last 30 years.

For example, the cost of high power band solar modules has decreased from about Rs.17,28,000/kW in 1982 to about Rs.2,56,000/kW in 2006; the installed cost of a PV system declined from Rs.10,24,000/kW in 1992 to around Rs.38,4000/kW in 2008 (IEA-PVPS, 2007; Solarbuzz, 2006, Lazard 2009). The rapid expansion of the solar energy market can be attributed to a number of supportive policy instruments, the increased volatility of fossil fuel prices and the environmental externalities of fossil fuels, particularly greenhouse gas (GHG) emissions. Theoretically, solar energy has resource potential that far exceeds the entire global energy demand (Kurokawa et al. 2007; EPIA, 2007). Despite this technical potential and the recent growth of the market, the contribution of solar energy to the global energy supply mix is still negligible (IEA, 2009). This study attempts to address why the role of solar energy in meeting the global energy supply mix continues to be so a small. What are the key barriers that prevented large-scale deployment of solar energy in the national energy systems? What types of policy instruments have been introduced to boost the solar energy markets? Have these policies produced desired results? If not, what type of new policy instruments would be needed? A number of studies, including Arvizu et al. (2011), have addressed various issues related to solar energy. This study presents a synthesis review of existing literature as well as presents economic analysis to examine competitiveness solar energy with fossil energy counterparts. Our study shows that despite a large drop in capital costs and an increase in fossil fuel prices, solar energy technologies are not yet competitive with conventional technologies for electricity production. The economic competitiveness of these technologies does not improve much even when the environmental externalities of fossil fuels are taken into consideration. Besides the economic disadvantage, solar energy technologies face a number of technological, financial and institutional barriers that further constrain their large-scale deployment. Policy instruments introduced to address these barriers include feed in tariffs (FIT), tax credits, capital subsidies and grants, renewable energy portfolio standards (RPS) with specified standards for solar energy, public investments and other financial incentives.

While FIT played an instrumental role in 3 Germany and Spain, a mix of policy portfolios that includes federal tax credits, subsidies and rebates, RPS, net metering and renewable energy certificates (REC) facilitated solar energy market growth in the United States. Although the clean development mechanism (CDM) of the Kyoto Protocol has helped the implementation of some solar energy projects, its role in promoting solar energy is very small as compared to that for other renewable energy technologies because of cost competitiveness. Existing studies we reviewed indicate that the share of solar energy in global energy supply mix could exceed 10% by 2050.

This would still be a small share of total energy supply and a small share of renewable supply if the carbon intensity of the global energy system were reduced by something on the order of 75%, as many have argued is necessary to stem the threat of global warming. The paper is organized as follows. Section 2 presents the current status of solar energy technologies, resource potential and market development. This is followed by economic analysis of solar energy technologies, including sensitivities on capital cost reductions and environmental benefits in Section 3. Section 4 identifies the technical, economic, and institutional barriers to the development and utilization of solar energy technologies, followed by a review of existing fiscal and regulatory policy approaches to increase solar energy development in Sections 5 and 6, including potential impacts of greenhouse gas mitigation policies on the deployment of solar energy technologies. Finally, key conclusions are drawn in Section 7.

CURRENT STATUS OF SOLAR ENERGY TECHNOLOGIES AND MARKETS

Technologies and resources Solar energy refers to sources of energy that can be directly attributed to the light of the sun or the heat that sunlight generates (Bradford, 2006). Solar energy technologies can be classified along the following continuum:

[1] Passive And Active
[2] Thermal And Photovoltaic
[3] Concentrating And Non-Concentrating.

Passive solar energy technology merely collects the energy without converting the heat or light into other forms. It includes, for example, maximizing the use of day light or heat through building design (Bradford, 2006; Chiras, 2002). In contrast, active solar energy technology refers to the harnessing of solar energy to store it or convert it for other applications and can be broadly classified into two groups: **(i)** 4 photovoltaic (PV)

[II] SOLAR THERMAL.

The PV technology converts radiant energy contained in light quanta into electrical energy when light falls upon a semiconductor material, causing electron excitation and strongly enhancing conductivity (Sorensen, 2000). Two types of PV technology are currently available in the market:

CRYSTALLINE SILICON-BASED PV CELLS

[A] Thin film technologies made out of a range of different semi-conductor materials, including amorphous silicon, cadmium-telluride and copper indium gallium diselenide

[1] Solar thermal technology uses solar heat, which can be used directly for either thermal or heating application or electricity generation. Accordingly, it can be divided into two categories:

[I] Solar thermal nonelectric

Solar thermal electric.

The former includes applications as agricultural drying, solar water heaters, solar air heaters, solar cooling systems and solar cookers2 (e.g. Weiss et al., 2007); the latter refers to use of solar heat to produce steam for electricity generation, also known as concentrated solar power (CSP). Four types of CSP technologies are currently available in the market: Parabolic Trough, Fresnel Mirror, Power Tower and Solar Dish Collector (Muller-Steinhagen and Trieb, 2004; Taggart 2008a and b; Wolff et al., 2008). Solar energy technologies have a long history. Between 1860 and the

First World War, a range of technologies were developed to generate steam, by capturing the sun‟s heat, to run engines and irrigation pumps (Smith, 1995). Solar PV cells were invented at Bell Labs in the United States in 1954, and they have been used in space satellites for electricity generation since the late 1950s (Hoogwijk, 2004).

The years immediately following the oil-shock in the seventies saw much interest in the development and commercialization of solar energy technologies. However, this incipient solar energy industry of the 1970s and early 80s collapsed due to the sharp decline in oil prices and a lack of sustained policy support (Bradford, 2006). Solar energy markets have regained momentum since early 2000, exhibiting phenomenal growth recently. The total installed capacity of solar based electricity generation capacity has increased to more than 40 GW by the end of 2010 from almost negligible capacity in the early nineties (REN21, 2011).

Solar energy represents our largest source of renewable energy supply. Effective solar irradiance reaching the earth‟s surface ranges from about 0.06kW/m2 at the highest latitudes to 0.25kW/m2 at low latitudes. Figure 1 compares the technically feasible potential of different renewable energy options using the present conversion efficiencies of available technologies. Even when evaluated on a regional basis, the technical potential of solar energy in most regions of the world is many times greater than current total primary energy consumption in those regions (de Vries et al. 2007).

Current market status The installation of solar energy technologies has grown exponentially at the global level over the last decade. For example, as illustrated in Figure 2.A**,** global installed capacity PV (both grid and off-grid) increased from 1.4 GW in 2000 to approximately 40 GW in 2010 with an average annual growth rate of around 49% (REN21, 2011).

Similarly, the installed capacity of CSP more than doubled over the last decade to reach 1,095MW by the end of 2010. Non-electric solar thermal technology increased almost 5 times from 40 GWth in 2000 to 185 GWth in 2010 .The impetus behind the recent growth of solar technologies is attributed to sustained policy support in countries such as Germany, Italy United States, Japan and China.

Solar PV By December 2010, global installed capacity for PV had reached around 40 GW4 of which 85% grid connected and remaining 15% off-grid (REN21, 2010). This market is currently dominated by crystalline silicon-based PV cells, which accounted for more than 80% of the market in 2010. The remainder of the market almost entirely consists of thin film technologies that use cells made by directly depositing a photovoltaic layer on a supporting substrate.

As illustrated in Figure 2b, a handful of countries dominate the market for PV. However, a number of countries are experiencing a significant market growth. Notably, Czech Republic had installed nearly 2 GW of solar PV by December 2010 (REN21, 2011), up from almost zero in 2008. India had a cumulative installed PV capacity of 102 MW (EPIA, 2011) and China had a cumulative capacity of 893 MW at the end of 2010. Two types of PV systems exist in the markets: grid connected or centralized systems and off-grid or decentralized systems. The recent trend is strong growth in centralized PV development with installations that are over 200 kW, operating as centralized power plants. The leading markets for these applications include Germany, Italy, Spain and the United States. After exhibiting poor growth for a number of years, annual installations in the Spanish market have grown from about 4.8 MW in 2000 to approximately 950 MW at the end of 2007 (PVRES 2007) before dropping to 17 MW in 2009 and bouncing back to around 370 MW in 2010 (EPIA, 2011). The off-grid

Concentrated Solar Power (CSP) The CSP market first emerged in the early 1980s but lost pace in the absence of government support in the United States. However, a recent strong revival of this market is evident with 14.5 GW in various stages of development across 20 countries and 740 MW of added CSP capacity between 2007 and 2010 While many regions of the world, for instance, Southwestern United States, Spain, Algeria, Morocco, South Africa, Israel, India and China, provide suitable conditions for the deployment of CSP, market activity is mainly concentrated in Southwestern United States and Spain, both of which are supported with favorable policies, investment tax credits and feed-in tariffs (Wolff et al. 2008). Currently, several projects around the world are either under construction, in the planning stages, or undergoing feasibility studies6 and the market is expected to keep growing at a significant pace (REN21, 2011).

Solar thermal for heating and cooling The total area of installed solar collectors (i.e., non-electric solar thermal) amounted to 185 GWth by early 2010 (REN21, 2011). Of which China, Germany, Turkey and India accounted for 80.3%, 3.1%, 1.8% and 1.1% respectively. The remaining

13.7% was accounted for other 40 plus countries including the USA, Mexico, India, Brazil, Thailand, South Korea, Israel, Cyprus, Ethiopia, Kenya, South Africa, Tunisia, and Zimbabwe. Three types of solar collectors (i.e., unglazed, glazed flat-plate and evacuated tube) are found in the market. By the end of 2009, of the total installed capacity of 172.4 GWth, 32% was glazed flat-plate collectors; 56% was evacuated tube collectors; 11% was unglazed collectors; and the remaining 1% was glazed and unglazed air collectors (Weiss et al., 2011)..

Therefore, we have taken the maximum and minimum values of overnight construction costs for each technology considered here from the existing studies to reflect the variations in overnight construction costs, along with the corresponding O&M and fuel costs, and applied a uniform 10% discount rate and 2.5% fuel price and O&M costs escalation rate to cost data from all the studies. Since our focus is on economic analysis, taxes, subsidies or any types of capacity credits are excluded. Please see Table 2 for key data used in the economic analysis.

The difference between the minimum and maximum values for the levelized costs of solar energy technologies (and also other energy technologies) are wide due mainly to large variations in overnight construction costs and to different capacity factors. For example, the overnight construction costs of grid connected solar PV system vary from US$2,878/kW to US$7,381/kW (NEA/IEA, 2010). Similarly, the overnight construction costs of CSP vary from US$4,347/kW (NEA/IEA, 2010) to US$5,800/kW (Lazard, 2009). The capacity utilization factor of simple cycle gas turbine varies from 10% (Lazard, 2009) to 85% (NEA/IEA, 2010). Furthermore, very different economic lives are assumed for hydro, coal and nuclear plants.

It is also interesting to observe the contributions of various cost components (e.g., capital, O&M and fuel costs) to estimated future growth of solar energy and barriers to realizing growth Advocates of solar energy claim that it will play a crucial role in meeting future energy demand through clean energy resources. Existing projections of long-term growth (e.g., until 2050) of solar energy vary widely based on a large number of assumptions. For example, Arvizu et al. (2011) argue that expansion of solar energy depends on global climate change mitigation scenarios. In the baseline scenario (i.e., in the absence of climate change mitigation policies), the deployment of solar energy in 2050 would vary from 1 to 12 EJ/yr.

In the most ambitious scenario for climate change mitigation, where CO2 concentrations remain below 440 ppm by 2100, the contribution of solar energy to primary energy supply could reach 39 EJ/yr by 2050. EPIA/Greenpeace (2011) produces the most ambitious projections of future PV installation. IEA (2008) projects that CSP capacity could reach 380 GW to 630 GW, depending on global targets for GHG mitigation14.In the case of solar thermal energy, the global market could expand by tenfold to approximately 60 million tons of oil equivalent (Mtoe) by 2030 (IEA World Energy Outlook 2006). A more optimistic scenario from the European Renewable Energy Council (2004) projects that solar thermal will grow to over 60 Mtoe by 2020, and that the market will continue to expand to 244 Mtoe by 2030 and to 480 Mtoe, or approximately 4% of total global energy demand, by 2040.It would be also relevant to envisage the contribution of solar energy to the global energy supply mix. According to EREC (2004), renewable energy is expected to supply nearly 50% of total global energy demand by 2040. Solar energy alone is projected to meet approximately 11% of total final energy consumption, with PV supplying 6%, solar heating and cooling supplying 4% and CSP supplying 1% of the total. Shell (2008) shows that if actions begin to address the challenges posed by energy security and environmental pollution, sources of energy other than fossil fuels account for over 60% of global electricity consumption, of which one third comes from solar energy. In terms of global primary energy mix, solar energy could occupy up to 11% by 2050. Notwithstanding these optimistic projections, the existing literature identifies a range of barriers that constrains the deployment of solar energy technologies for electricity generation and thermal purposes. These barriers can be classified as technical, economic, and institutional and are presented Technical barriers vary across the type of technology. For example, in the case of PV, the main technical barriers include low conversion efficiencies of PV modules15; performance limitations of system components such as batteries and inverters; and inadequate supply of raw materials such as silicon. In the case of stand-alone PV systems, storage is an important concern, as is the shorter battery life compared to that of the module. Furthermore, safe disposal of batteries becomes difficult in the absence of a structured disposal/recycling process. With regard to solar thermal applications, there are two main technical barriers. They are limits to the heat carrying capacity of the heat transfer fluids and thermal losses from storage systems (Herrmann et al. 2004; IEA 2006a). In addition, as seen in Table 3, there are constraints with regard to system design and integration as well as operating experience for system optimization. For example, lack of integration with typical building materials, designs, codes and standards make widespread application of solar space and water heating applications difficult. In the case of CSP, technologies such as the molten salt-in-tube receiver technology and the volumetric air receiver technology, both with energy storage systems, need more experience to be put forward for large-scale application (Becker et al., 2000). Moreover, solar energy still has to operate and compete on the terms of an energy infrastructure designed around conventional energy technologies .

The economic barriers mainly pertain to initial system costs. Cost comparisons for solar energy technologies by suppliers and users are made against established conventional technologies with accumulated industry experience, economies of scale and uncounted externality costs. Solar energy technologies thus face an “uneven playing field,” even as its energy security, social, environmental and health benefits are not internalized in cost calculations (Jacobson & Johnson, 2000). Financing is another critical barrier. Financial institutions consider solar energy technologies to have unusually high risks while assessing their creditworthiness. This is because solar energy projects have a shorter history, lengthy payback

However, these potential constraints can become binding only when other policies in place induce or require use of solar energy in order to overcome its higher cost. Even if interconnection were to be simplified, grid based electricity suppliers would still have to address challenges of integrating significant quantities of episodic, non-dispatchable solar power into the grid (or the high cost of current storage options).

[5] Potential policy instruments to increase solar energy development As illustrated earlier, by and large solar energy technologies are not yet cost-competitive with conventional energy commodities at either the wholesale or retail levels. Therefore, any significant deployment of solar energy under current technological and energy price conditions 24 will not occur without major policy incentives. A large number of governments have decided to increase solar energy development, using a range of fiscal, regulatory, market and other instruments 16 . In fact, the strong growth in solar energy markets, notably those for gridconnected solar PV and solar thermal water heating, has been driven by the sustained implementation of policy instruments in Europe, the United States and some developing countries to induce or require increased use of solar power. This section briefly presents key characteristics of policy instruments that support solar energy for both electric and direct heating applications. A large number of policy instruments have been implemented to increase power supplies from solar PV and CSP. The key instruments we highlight here include feed-in-tariffs, investment tax credits, direct subsidies, favorable financing, mandatory access and purchase, renewable energy portfolio standards and public investment. Three rationales are commonly offered for utilizing these policies. One is to encourage the use of low-carbon technology in the absence of a more comprehensive policy for greenhouse gas mitigation, like a carbon tax. The disadvantage of this approach for greenhouse gas mitigation is that it does not create incentives for cost-effective mitigation choices.

Investment tax credits Different types of investment tax credits have been implemented in several jurisdictions around the world to support solar energy. In the United States, for example, the federal government provides an energy investment tax credit for solar energy investments by businesses equal to 30% of expenditures on equipment to generate electricity, to heat or cool and on hybrid solar lighting systems.

Besides the investment tax credit, the US federal government provides and accelerated cost-recovery system through depreciation deductions: solar energy technologies are classified as five-year property. In addition, the federal Economic Stimulus Act of 2008, enacted in February 2008, and the American Recovery and Reinvestment Act of 2009, enacted in February 200919, provide a 50% bonus depreciation to solar energy technologies implemented between 2008 and September 2010 and 100% bonus depreciation to solar energy technologies placed in service after September 2010. Residential tax payers may claim a credit of 30% on qualified expenditures on solar energy equipment (e.g., labor costs for onsite preparation, assembly or original system installation). If the federal tax credit exceeds tax liability, the excess amount may be carried forward to the succeeding taxable year until 2016. The 30% federal tax credits have provided significant leverage to solar energy development in the United Sates, where state governments have further supplemented federal tax incentives with their own programs. For example, the one megawatt CSP project (Sugarno project) installed by Arizona Public Service (APS) in 2006, and the 64 MW Nevada Solar One parabolic trough CSP installed in Boulder City, Nevada in 2007 have largely benefited from the federal tax credit scheme (Canada et al., 2005).

In Bangladesh, the primary driver of the PV market is microcredit finance that led to the substantial growth of privately owned Solar Home Systems (SHS) (IDCOL 2008). Investment tax credits schemes are criticized for their impacts on government revenues. For example, the investment tax credits in the United States would cost approximately US $907 million over 10 years (Renewable Energy World, July 31, 2008). The tax rebate system in New Jersey would cost $500 million annually to reach the goal; to avoid such high costs, the State Government decided that only systems 10 kW and smaller would qualify for rebates, and systems larger than 10 kW would have to compete in a tradable solar renewable energy credit (SREC) market (Winka, 2006).

Subsidies Direct subsidies (versus tax credits) are a primary instrument to support solar energy development in most countries. The subsidy could be investment grants or capacity payments, soft loans (e.g., interest subsidies), or output or production based payments. The Spanish government launched a program to provide grants of between €240.40/m2 and €310.35/m2 in 2000 to solar thermal technologies. In India, capital subsidies initially used, were funded either through donor or government funds. Solar hot water systems, solar cooking systems and concentrating solar cookers receive capital subsidies of, respectively, Rs. 1,500, Rs.1,250 and Rs.2000 per square meter. The primary reliance on capital subsidies was criticized because it incentivized capacity and not necessarily production (Sharma, 2007). In response to these changes, government policy for PV in India has recently been revised. Currently, a production based subsidy offered by the government has been supplemented by a combined feed-in-tariff of about Rs. 15/kWh for solar PV and solar thermal projects commissioned after March 31st, 2011, for up to 25 years (CERC, 2010).

Remote village electrification programs receive even higher levels of subsidies. One such program that aims to establish a single light solar PV system in all non-electrified villages in India by 2012 has 90% of the system cost covered by the government subsidy. In the case of below poverty line (BPL) families, 100% of the system cost will be underwritten by the state governments (MNRE, 2006). The rebate program for solar PV in California under the California Solar Initiative (CSI) is another example of a subsidy scheme for solar energy. The goal of the $3.3 billion CSI program is to support the development of 3,000 MW of PV in California by 2017 using rebates, also known as Expected Performance-Based Buy-Down (EPBB) based on performance-based incentives (PBI).

Public investment One of the main drivers of solar energy development in developing countries continues to be direct public investment. Many developing countries host a number of government and/or donor-funded projects to support solar energy under their rural electrification programs. The rapid development of the PV industry and market in China is mainly due to government support, implemented through a number of rural electrification programs. National and local levels programs for rural electrification were the major driving force for solar PV market expansion in China in the late 1990s and early 2000s. The major programs supporting PV programs are Brightness Program Pilot Project, Township Electrification Programs, and China Renewable 31 Energy Development Project. The Brightness Program Pilot Project, launched in 2000, plans to provide electricity to 23 million people in remote areas by 2010, using 2,300 MW of wind, solar PV, wind/PV hybrid and wind/PV/diesel hybrid systems. Inner Mongolia, Gansu and Tibet were selected as pilot provinces, and a RMB 40 million grant was allocated for the project (Ma, 2004). The Township Electrification Programs, launched in 2002, installed 268 small hydro stations and 721 PV, or PV/wind hybrid systems by 2005 (PMO, 2008). The overall investment was RMB 2.7 billion, and 15.3 MWp of PV systems were installed during the life of the program. The China Renewable Energy Development Project (REDP), also launched in 2002 and supported by a GEF grant, provided a direct subsidy of US$1.5 per Wp to PV companies to help them market, sell and maintain 10 MWp of PV systems in Qinghai, Gansu, Inner Mongolia, Xinjiang, Tibet and Sichuan. Developing countries initiated programs with the help of bilateral and multilateral donor agencies are mainly facilitating solar energy development in developing countries.

Net metering Net metering is the system where households and commercial establishments are allowed to sell excess electricity they generate from their solar systems to the grid. It has been implemented in Australia, Canada, United States and some European countries including Denmark, Italy and Spain. In the US, for example, most net metering programs are limited to renewable energy facilities up to 10 kW. In California it could reach up to 1 MW. In Canada, it goes up to 100 kW in Prince Edward Island and 500 kW in Ontario.

Most programs only require purchases up to the customer's total annual consumption, and no payment is offered for any electricity generated above this amount. They receive the retail tariff for their output.

Other government regulatory provisions In many countries, governments have introduced laws mandating transmission companies and electricity utilities to provide transmission or purchase electricity generated from renewable energy technologies, including solar. In January 2006, China, for example, issued the Renewable Energy Law, mandating utility companies to purchase "in full amounts" renewable energy generated electricity within their domains at a price that includes production cost plus a reasonable profit. The extra cost incurred by the utility will be shared throughout the overall power grid (GOC, 2005). Similarly, in Germany, all renewable energy generators are guaranteed to have priority access to the grid. Electric utilities are mandated to purchase 100% of a grid connected PV system output, regardless of whether the system is customer-sited or not. Government regulations mandating installation of solar thermal systems is the main policy driver for the development of solar thermal applications in many countries (e.g., Spain, Israel). The growing role of private finance has reduced the role of fiscal policy drivers in the overall financing mix for solar power, and capital subsidies have been ratcheted down substantially, except in exceptional cases such as „remote villages and hamlets". India now relies on a mix of mechanisms including various tax and generation-based incentives, renewable purchase obligations, capital subsidies and accelerated depreciation. Yet, the accumulation of incentive programs and the failure to coordinate them is thought to hinder the development of renewable energy resources in India as it results in unnecessary delays and conflicts (ESMAP, 2011a). In the Philippines, the portfolio of policy instruments includes duty-free importation of equipment, tax credits on domestic capital equipment and services, special realty tax rates, income tax holidays, net operating loss carry-over, accelerated depreciation and exemption from the universal charge and wheeling charges (WWF, 2008)

Implementation challenges Sensitivity to policy costs is more significant in developing country markets such as India, China, Brazil, Philippines and Bangladesh than in more developed economies. Thus, a common approach toward renewable energy technologies, seen in developing countries, is to "rationalize development and deployment strategy" (MNRE 2006) of renewable energy technologies. For instance, India planned in its eleventh Five-Year plan (2007-2012) to install 15,000 MW of grid-connected renewable energy and it was widely believed that this market expansion would be driven by wind, micro-hydro and biomass, as the plan recognized that solar PV would be an option only if the prices come down to levels comparable to micro-hydro. More recently, the National Solar Mission promoting solar power in India has been launched. The first phase (2009-2013) targets increases in the utility grid power from solar sources, including CSP, by over a 1 GW (ESMAP, 2011a). By 2022, 20 GW of solar capacity is to be added in India. The approach to the renewable energy mix in China, Philippines and Bangladesh represents similar priorities of rationalizing the policy costs.

In Brazil, as in other developing countries, the minimal policy cost is ensured via technology-specific and reserve energy auctions (ESMAP, 2011b) as the cheapest renewable energy projects are implemented first. Solar PV is recognized as serving a niche market that is very important in developing countries – electrification of rural and peri-urban areas that do not yet have access to the electric grid. There are vigorous efforts to expand the market for Solar Home Systems (SHS) as a means toward rural electrification. However, rural and peri-urban areas are characterized by low income households that may not be able to afford solar energy technologies unless they are substantially subsidized. Until now, the approach is to provide subsidies either via government funds or through international donors. However, a subsidy is a short-term support, not a long-term solution. CSP and solar water heating are comparatively cheaper than solar PVs. These could be cost competitive with conventional fuels if existing subsidies to the latter are reduced or removed. However, fossil fuel subsidies are politically sensitive in many countries and their removal might take time. Thus far, CSP has not found much success in a developing country context. Unlike Solar PV, CSP is limited to utility scale applications and as such is often out of consideration in the traditional utility generation market due to current prices. Thus, developing country governments have adopted a cautious policy approach to this market, focusing more on pilot scale projects, as with grid-connected solar PV. Through its National Solar Mission, India is the first developing country to take a step towards the installation of CSP capacity. Unlike in electric applications, solar heating applications enjoy limited policy support as instruments like FITs and RPS are not applicable for heating applications. Moreover, it is more difficult to measure and verify solar water heating performance, and so performance-based incentives are harder to enact.

Solar energy development under policies for climate change mitigation Greenhouse gas mitigation policies and activities help support renewable energy development, including solar energy. Various incentives and mandates designed to trigger GHG mitigation have helped promote solar energy in industrialized countries. In the case of developing countries, the Clean Development Mechanism (CDM) under the Kyoto Protocol has been the main vehicle to promote solar energy under the climate change regime. The CDM allows industrialized countries to purchase GHG reductions achieved from projects in developing countries, where reducing GHG emissions is normally cheaper than in industrialized countries. As of July 2011, there are 6,416 projects already registered or in the process of registration under the CDM. Of these, 109 projects are solar energy projects with annual emission reduction of 3,570,000 tons of CO2. Out of these 109 projects, 89 are located in China, South Korea and India. However, the solar energy projects account for a very small fraction (< 1%) of total emission reductions from the total CDM projects already registered or placed in registration process (UNEP Risoe, 2011).

One reason for the small share of solar energy projects in the global CDM market is cost. As noted, solar energy technologies remain costly, and at present they are not economically competitive with other CDM candidates such as wind power, small hydro, landfill gas, and biomass cogeneration. The high upfront capital investment cannot be recovered even if the revenue generated from sales of emission mitigation at standard (non-subsidized) rates is included along with revenue from electricity sales. In addition, solar energy projects to date come in smaller sizes than other CDM options; transaction costs incurred in various steps during the CDM process (e.g., validation and registration of projects and monitoring, verification and certification of emission reductions) do not vary that much with project size and are often prohibitive for solar energy projects that are already less attractive compared to their competitors.

CONCLUSIONS

Physically, solar energy constitutes the most abundant renewable energy resource available and, in most regions of the world, its theoretical potential is far in excess of the current total primary energy supply in those regions. Solar energy technologies could help address energy access to rural and remote communities, help improve long-term energy security and help greenhouse gas mitigation. The market for technologies to harness solar energy has seen dramatic expansion over the past decade – in particular the expansion of the market for grid-connected distributed PV systems and solar hot water systems have been remarkable. Notably, centralized utility scale PV applications have grown strongly in the recent years; off-grid applications are now dominant only in developing markets. Moreover, the market for larger solar thermal technologies that first emerged in the early 1980s is now gathering momentum with a number of new installations as well as projects in the planning stages. While the costs of solar energy technologies have exhibited rapid declines in the recent past and the potential for significant declines in the near future, the minimum values of levelized cost of any solar technologies, including tower type CSP, which is currently the least costly solar technology, would be higher than the maximum values of levelized costs of conventional technologies for power generation (e.g., nuclear, coal IGCC, coal supercritical, hydro, gas CC) even if capital costs of solar energy technologies were reduced by 25%. Currently, this is the primary barrier to the large-scale deployment of solar energy technologies. Moreover, the scaling-up of solar energy technologies is also constrained by financial, technical and institutional barriers. Various fiscal and regulatory instruments have been used to increase output of solar energy. These instruments include tax incentives, preferential interest rates, direct incentives, loan programs, construction mandates, renewable portfolio standards, voluntary green power programs, net metering, interconnection standards and demonstration projects.

However, the level of incentives provided through these instruments has not been enough to substantially increase the penetration of solar energy in the global energy supply mix. Moreover, these policy instruments can create market inefficiencies in addition to the direct costs of requiring more- costly electricity supplies to be used. While not discussed in this paper, these indirect impacts need to be considered in assessing the full opportunity cost of policies to expand solar power production. Carbon finance mechanisms, in particular the CDM, could potentially support expansion of the solar energy market. While some changes in the operation of the CDM could increase solar investment, the price of carbon credits required to make solar energy technologies economically competitive with other technologies to reduce GHG emissions would be high. The fundamental barrier to increasing market-driven utilization of solar technologies continues to be their cost. The current growth of solar energy is mainly driven by policy supports. Continuation and expansion of costly existing supports would be necessary for several decades to enhance the further deployment of solar energy in both developed and developing countries, given current technologies and projections of their further improvements over the near to medium term. Overcoming current technical and economic barriers will require substantial further outlays to finance applied research and development, and to cover anticipated costs of initial investments in commercial-scale improved-technology production capacity.

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