

A REVIEW OF SOLAR ENERGY

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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.

1. 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 \$27,000/kW in 1982 to about \$4,000/kW in 2006; the installed cost of a PV system declined from \$16,000/kW in 1992 to around \$6,000/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 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 introduced to address these barriers include feed in tariffs (FIT), tax credits, capital economic disadvantage, solar energy technologies face a number of technological, financial and institutional barriers that further constrain their large-scale deployment. Policy instruments 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.

2. CURRENT STATUS OF SOLAR ENERGY TECHNOLOGIES AND MARKETS

2.1. 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; and 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).

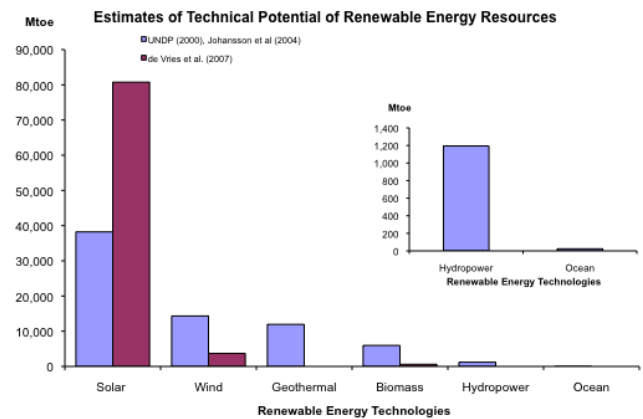
In contrast, active solar energy technology refers to the harnessing of solar energy to store it or convert it for other applications and can be broadly classified into two groups: (i) 4 photovoltaic (PV) and (ii) solar thermal. The PV technology converts radiant energy contained in light quanta into 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: (a) crystalline silicon-based PV cells and (b) thin film technologies made out of a range of different semi-conductor materials, including amorphous silicon, cadmium-telluride and copper indium gallium diselenide¹. Solar thermal technology uses solar heat, which can be used directly for either thermal or heating. Accordingly, it can be divided into two categories (i) photovoltaic (PV) and (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: (a) crystalline silicon-based PV cells and (b) thin film technologies made out of a range of different semi-conductor materials, including amorphous silicon, cadmium-telluride and copper indium gallium diselenide¹. 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 non-electric and (ii) 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

1 While thin film technologies are less efficient than silicon based cells, they are cheaper and more versatile than crystalline silicon based counterparts.
 2 Suitable sites for installing solar thermal collectors should receive at least 2,000 kWh of sunlight radiation per square meter annually and are located within less than 40 degrees of latitude North or South. The most promising areas include the South-Western United States, Central and South America, North and Southern Africa, the Mediterranean countries of Europe, the Near and Middle East, Iran and the desert plains of India, Pakistan, the former Soviet Union, China and Australia (Aringhoff et al., 2005).

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).



2.2. CURRENT MARKET STATUS

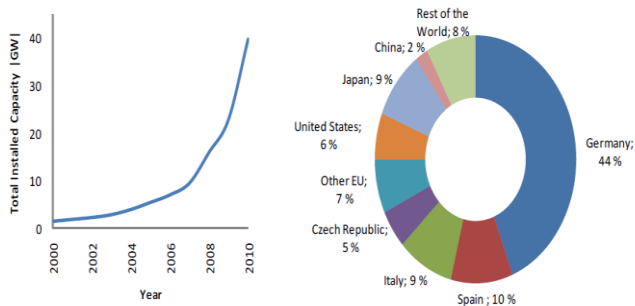
The installation of solar energy technologies has grown exponentially at the global level over the last decade. For example, as illustrated in Figure 2(a), global installed capacity PV (both grid and off-grid) increased from 1.4 GW in 2000 to approximately 40 GW in 2010 with an average annual growth 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 (see Figure 3). 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.

2.2.1 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.

Figure 2: Total Installed Capacity of PV at the Global Level



2.2.3 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). The market for solar cooling systems remains small although it is growing fast. An estimated 11 systems were in operation worldwide by the end of 2009 (REN21, 2011). The use of solar thermal non-electric technologies varies greatly in scale as well as type of technology preferred. For instance, the market in China; Taiwan, China; Japan; and Europe is dominated by glazed flat-plate and evacuated tube water collectors. On the other hand, the North American market is dominated by unglazed water collectors employed for applications such as heating swimming pools.

3. CONCLUSION

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.

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