A Brief Comparative Study 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, feedin-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.

Key words: Solar Energy; Renewable Energy Economics and Policies; Climate Change

I. Introduction

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever evolving technologies such as solar heating, photovoltaic, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power.[1] Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy[2]. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air. The large magnitude of solar energy available makes it a highly appealing source of electricity[3]. The United Nations Development Programme in its 2000 World Energy Assessment found that the annual potential of solar energy was 1,575–49,837 exa joules (EJ). This is several times larger than the total world energy consumption, which was 559.8 EJ in 2012. In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits[4]. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared"[5].

A. Advantages of Solar Power

- Solar energy is a clean and renewable energy source.
- Once a solar panel is installed, solar energy can be produced free of charge.
- Solar energy will last forever whereas it is estimated that the world's oil reserves will last for 30 to 40 years.
- Solar energy causes no pollution.
- Solar cells make absolutely no noise at all. On the other hand, the giant machines utilized for pumping oil are extremely noisy and therefore very impractical.
- Very little maintenance is needed to keep solar cells running. There are no moving parts in a solar cell which makes it impossible to really damage them.
- In the long term, there can be a high return on investment due to the amount of free energy a solar panel can produce, it is estimated that the average household will see 50% of their energy coming in from solar panels.

B. Disadvantages of Solar Power

- Solar panels can be expensive to install resulting in a time-lag of many years for savings on energy bills to match initial investments.
- Electricity generation depends entirely on a countries exposure to sunlight; this could be limited by a countries climate.
- Solar power stations do not match the power output of similar sized conventional power stations; they can also be very expensive to build.
- Solar power is used to charge batteries so that solar powered devices can be used at night. The batteries can often be large and heavy, taking up space and needing to be replaced from time to time.

C. Some of Applications of Solar Energy

Power plants: In conventional power plants non-renewable energy sources are used to boil water and form stream so that turbines can rotate and water to produce electricity. But with application of solar energy heat of sun can boil that water to create steam and rotate turbines. To convert sunlight into electricity solar panels, photoelectric technologies and thermoelectric technologies etc. are used.

1) Homes:

Use of solar energy is increasing in homes as well. Residential appliances can easily use electricity generated through solar power. Besides this solar energy is running solar heater to supply hot water in homes. Through photovoltaic cell installed on the roof of the house energy is captured and stored on batteries to use throughout the day at homes for different purposes. In this ways expenditure on energy is cutting down by home users.

2) Commercial Use:

On roofs of different buildings we can find glass PV modules or any other kind of solar panel. These panels are used there to supply electricity to different offices or other parts of building in a reliable manner. These panels collect solar energy from sun, convert it into electricity and allow offices to use their own electrical power for different purposes.

3) Ventilation System:

At many places solar energy is used for ventilation purposes. It helps in running bath fans, floor fans, and ceiling fans in buildings. Fans run almost every time in a building to control moisture, and smell and in homes to take heat out of the kitchen. It can add heavy amount on the utility bills, to cut down these bills solar energy is used for ventilation purposes.

4) Power Pump:

solar power not just help in improving ventilation system at your homes but with that it can also help in circulating water in any building. You can connect power pump with solar power supply unit but you must run it on DC current so that water circulate throughout your home.

5) Swimming Pools:

Swimming pools are great joy for kids and adults in all seasons. But during winters it is tough to keep water hot in these pools with minimum power usage. Solar energy can help many in this matter as well. You can add a solar blanket in the pool that will keep the water hot with energy generated from sunlight. Besides this you can install a solar hot water heating system with solar hot water heating panels.

6) Solar Lighting:

these lights are also known as day lighting, and work with help of solar power. These lights store natural energy of sun in day time and then convert this energy into electricity to light up in night time. Use of this system is reducing load form local power plants.

7) Solar Cars:

it is an electrical vehicle which is recharged form solar energy or sunlight. Solar panels are used on this car that absorb light and then convert it into electrical energy. This electrical energy is stored in batteries used with the car, so that in night time as well we can drive these vehicles.

8) Remote Applications:

Remote buildings are taking benefit of solar energy at vast scale. Remote schools, community halls, and clinics can take solar panel and batteries with them anywhere to produce and use electric power.

These are most common *applications of solar energy* that we get to see in our daily lives. As solar industry grows more diversified applications are expected to be seen in future.

D. History of Solar Energy

Solar technology isn't new. Its history spans from the 7th Century B.C. to today. We started out concentrating the sun's heat with glass and mirrors to light fires[6]. Today, we have everything from solar-powered buildings to solar powered vehicles. Here you can learn more about the milestones in the historical development of solar technology, century by century, and year by year. You can also glimpse the future.

- This timeline lists the milestones in the historical development of solar technology from the 7th Century B.C. to the 1200s A.D.
- 7th Century B.C. Magnifying glass used to concentrate sun's rays to make fire and to burn ants.
- 3rd Century B.C. Greeks and Romans use burning mirrors to light torches for religious purposes.
- 2nd Century B.C. As early as 212 BC, the Greek scientist, Archimedes, used the reflective properties of bronze shields to focus sunlight and to set fire to wooden ships from the Roman Empire which were besieging Syracuse. (Although no proof of such a feat exists, the Greek navy recreated the experiment in 1973 and successfully set fire to a wooden boat at a distance of 50 meters.)
- 20 A.D. Chinese document use of burning mirrors to light torches for religious purposes.
- 1st to 4th Century A.D. The famous Roman bathhouses in the first to fourth centuries A.D. had large south facing windows to let in the sun's warmth.
- 6th Century A.D. Sunrooms on houses and public buildings were so common that the Justinian Code initiated "sun rights" to ensure individual access to the sun.
- 1200s A.D. Ancestors of Pueblo people called Anasazi in North America live in south-facing cliff dwellings that capture the winter sun.
- This timeline lists the milestones in the historical development of solar technology from 1767 to 1891.
- 1767, Swiss scientist Horace de Saussure was credited with building the world's first solar collector, later used by Sir John Herschel to cook food during his South Africa expedition in the 1830s.
- 1816, On September 27, 1816, Robert Stirling applied for a patent for his economizer at the Chancery in Edinburgh, Scotland. By trade, Robert Stirling was actually a minister in the Church of Scotland and he continued to give services until he was eighty-six years old! But, in his spare time, he built heat engines in his home workshop. Lord Kelvin used one of the working models during some of his university classes. This engine was later used in the dish/Sterling system, a solar thermal electric technology that concentrates the sun's thermal energy in order to produce power.
- 1839, French scientist Edmond Becquerel discovers the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution electricity-generation increased when exposed to light.
- 1860s, French mathematician August Mouchet proposed an idea for solar-powered steam engines. In the following two decades, he and his assistant, Abel Pifre, constructed the first solar powered engines and used them for a variety of applications. These engines became the predecessors of modern parabolic dish collectors.
- 1873, Willoughby Smith discovered the photoconductivity of selenium.
- 1876, 1876 William Grylls Adams and Richard Evans Day discover that selenium produces electricity when exposed to light. Although selenium solar cells failed to

convert enough sunlight to power electrical equipment, they proved that a solid material could change light into electricity without heat or moving parts.

- 1880, Samuel P. Langley, invents the bolometer, which is used to measure light from the faintest
- stars and the sun's heat rays. It consists of a fine wire connected to an electric circuit. When radiation falls on the wire, it becomes very slightly warmer. This increases the electrical resistance of the wire.
- 1883, Charles Fritts, an American inventor, described the first solar cells made from selenium wafers.
- 1887, Heinrich Hertz discovered that ultraviolet light altered the lowest voltage capable of causing a spark to jump between two metal electrodes.
- 1891, Baltimore inventor Clarence Kemp patented the first commercial solar water heater.
- This timeline lists the milestones in the historical development of solar technology in the 1900s.
- 1904, Wilhelm Hallwachs discovered that a combination of copper and cuprous oxide is photosensitive.

II. A PHOTOVOLTAIC POWER GENERATION

A photovoltaic power generation system consists of multiple components like cells, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output. These systems are rated in peak kilowatts (kWp) which is an amount of electrical power that a system is expected to deliver when the sun is directly overhead on a clear day. A grid connected system is connected to a large independent grid which in most cases is the public electricity grid and feeds power into the grid. They vary in size from a few kWp for residential purpose to solar power stations up to tens of GWp. This is a form of decentralized electricity generation. Poponi assessed the prospects for diffusion of photovoltaic (PV) technology for electricity generation in grid-connected systems by the methodology of experience curves that is used to predict the different levels of cumulative world PV shipments required to reach the calculated break-even prices of PV systems, assuming different trends in the relationship between price and the increase in cumulative shipments. Rehman et al. utilized monthly average daily global solar radiation and sunshine duration data to study the distribution of radiation and sunshine duration over Saudi Arabia and also analyzed the renewable energy production and economical evaluation of a 5 MW installed capacity photovoltaic based grid connected power plant for electricity generation [7]. Al-Hasan et al. discussed optimization of the electrical load pattern in Kuwait using grid connected PV systems as the electric load demand can be satisfied from both the photovoltaic array and the utility grid and found during the performance evaluation that the peak load matches the maximum incident solar radiation in Kuwait, which would emphasize the role of using the PV station to minimize the electrical load demand and a significant reduction in peak load can be achieved with grid connected PV systems [8]. Ito et al. studied a 100 MW very large-scale photovoltaic power generation (VLS-PV) system which is to be installed in the Gobi desert and evaluated its potential from economic and environmental viewpoints deduced from energy payback time (EPT), life-cycle CO2 emission rate and generation cost of the system [9]. Zhou et al. performed the economic analysis of power generation from floating solar chimney power plant (FSCPP) by analyzing cash flows during the whole service period of a 100 MW plant [10]. Muneer et al. explored the long term prospects of large scale PV generation in arid/semi-arid locations, around the globe and its transmission using hydrogen as the energy vector [11]. Cunow et al. described the megawatt plant at the new Munich Trade Fair Centre that represents a significant advance in large PV plant technology, both in terms of system technology and the components employed, operational control and costs [12]. Bhuiyan et al. studied the economics of stand-alone photovoltaic power system to test its feasibility in remote and rural areas of Bangladesh and compared renewable generators with nonrenewable generators by determining their life cycle cost using the method of net present value analysis and showed that life cycle cost of PV energy is lower than the cost of energy from diesel or petrol generators in Bangladesh and thus is economically feasible in remote and rural areas of Bangladesh [13]. Alazraki and Haselip assessed the impact of small-scale PV systems installed in homes, schools and public buildings over the last six years under the PERMER (Renewable Energy Project for the Rural Electricity Market) co-funded by a range of public and private sources and the structure of financial subsidies has enabled these remote rural communities to receive an electricity supply replacing traditional energy sources [15]. Kivaisi presented the installation and use of a 3 kWp photovoltaic (PV) plant at Umbuji village, in Zanzibar, Tanzania that was intended to provide power supply for a village school, health centre, school staff quarters, and mosques [16]. Bansal et al. developed an integration of solar photovoltaics of 25 kWp capacity in an existing building of the cafeteria on the campus of the Indian Institute of Technology, Delhi by creating a solar roof covering with the photovoltaic array inclined at an angle of 15◦ from the horizontal and faces due south [17]. Ubertini and Desideri studied a 15 kWp photovoltaic plant and solar air collectors coupled with a sun breaker structure that was installed on the roof of a scientific high school [18].

III. SOLAR CELLS

A solar cell, or photovoltaic cell (previously termed "solar battery"), is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomeno[19]n. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels. Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light.[20] They are used as a photodetector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity. The operation of a photovoltaic (PV) cell requires 3 basic attributes[21]:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.

- The separate extraction of those carriers to an external circuit.

A. List of Types of Solar Cells

- A solar cell (also called photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. The following are the different types of solar cells.
- Amorphous Silicon solar cell (a-Si)
- Bio hybrid solar cell
- Buried contact solar cell
- Cadmium telluride solar cell (Cd Te)
- Concentrated PV cell (CVP and HCVP)
- Copper indium gallium selenide solar cells (CI(G)S)
- Crystalline silicon solar cell (c-Si)
- Dye-sensitized solar cell (DSSC)
- Gallium arsenide germanium solar cell (GaAs)
- Hybrid solar cell
- Luminescent solar concentrator cell (LSC)
- Micromorph (tandem cell using a-Si/μc-Si)
- Mono crystalline solar cell (mono-Si)
- Multi junction solar cell (MJ)
- Nano crystal solar cell
- Organic solar cell (OPV)
- Perovskite solar cell
- Photo electrochemical cell (PEC)
- Plasmonic solar cell
- Plastic solar cell
- Polycrystalline solar cell (multi-Si)
- Polymer solar cell
- Quantum dot solar cell
- Solid-state solar cell
- Thin film solar cell (TFSC)
- Wafer solar cell, or wafer-based solar cell (synonym for crystalline silicon solar cell)

IV. SOLAR PANEL

Solar panel refers to a panel designed to absorb the sun's rays as a source of energy for generating electricity or heating. A photovoltaic (in short PV) module is a packaged, connected assembly of typically 6×10 solar cells. Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications[22]. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module.[32] There are a few commercially available solar panels available that exceed 22% efficiency and reportedly also exceeding 24%. A single solar module can produce only a limited amount of power; most installations contain multiple modules[23]. A photovoltaic system typically includes a panel or an array of solar modules, a solar inverter, and sometimes a battery or solar tracker and interconnection wiring[24]. The price of solar power has continued to fall so that in many countries it is cheaper than ordinary fossil fuel electricity from the grid (there is "grid parity")

A. Types of Solar Panels

1) Mono Crystalline Silicon (Single Silicon)

Right now, these are the most efficient types of solar panels[25]. In other words, when sunlight hits these panels, more of it turns into electricity than the other types below. As a result of their high silicon content, they're also more expensive, but you need fewer of them. That's why they're ideal for roofs. You can tell if you have a mono crystalline solar panel by its square is h cells.

2) Polycrystalline Silicon (Multi-Silicon)

"Poly" panels have lower silicon levels than "mono" panels. In general, that makes them less expensive to produce, but they're also slightly less efficient. The good news is that their overall construction design can often make up for the efficiency loss, so they're also good for roofs[26]. You can tell poly-silicon panels by their groovy mélange of silicon woven through thin rectangular conduit wires Thin film (amorphous silicon, cadmium telluride, copper indium gallium diselenide). Everyone talks about "thin film" because they're really inexpensive to make and they don't mind the heat, which is all cool. Except right now, they're very inefficient, which means you'll see them in big solar farm projects with a lot of land, but not on your roof.

B. Efficiencies

Depending on construction, photovoltaic modules can produce electricity from a range of frequencies of light, but usually cannot cover the entire solar range (specifically, ultraviolet, infrared and low or diffused light). Hence, much of the incident sunlight energy is wasted by solar modules, and they can give far higher efficiencies if illuminated with monochromatic light. This has been projected to be capable of raising efficiency by 50%. Scientists from Spectro lab, a subsidiary of Boeing, have reported development of multi junction solar cells with an efficiency of more than 40%, a new world record for solar photovoltaic cells.[27] The Spectro lab scientists also predict that concentrator solar cells could achieve efficiencies of more than 45% or even 50% in the future, with theoretical efficiencies being about 58% in cells with more than three junctions. The research also noted that the increase in current makes thinner film solar panels technically feasible without "compromising power conversion efficiencies, thus reducing material consumption".

- Efficiencies of solar panel can be calculated by MPP (Maximum power point) value of solar panels.
- Solar inverters convert the DC power to AC power by performing MPPT process: solar inverter samples the output Power (I-V curve) from the solar cell and applies the proper
- resistance (load) to solar cells to obtain maximum power.
- MPP (Maximum power point) of the solar panel consists of MPP voltage (V mpp) and MPP current (I mpp): it is a capacity of the solar panel and the higher value can make higher MPP.

C. Who Invented Solar Panel?

The solar cell technology is extremely old and work started on this way back in the 1800's. The French physicist Antoine – Cesar Becquerel is credited with the solar panel research, in 1839. While he was experimenting with a solid electrode that was dipped in the electrolyte solution he was able to see a photovoltaic effect.[28] He even saw a voltage develop when the sunlight fell on the electrode. The solar cell creation for the first time is credited to Charles Fritts, who used junctions that were created when the semiconductor was coated by a very thin layer of gold. The earliest solar cells and panels that were created were extremely inefficient and the energy conversation received from the sun stood under 1%. Russell Ohl was the first inventor, who created the silicon solar cell in 1941. in 1954, the three American researchers Gerald Pearson, Calvin Fuller and Daryl Chapin were able to create a solar panel that could the had the efficiency level of 6% with direct sunlight[29].

D. Advantages of Solar Panels

As solar energy becomes increasingly accepted as many people start to take note of the rapidly increasing global warming problems, it is important to weigh both the advantages and disadvantages of this renewable energy source[30]. The main aspect of solar energy that differentiates it from other sources of energy is that it is free. The only cost is usually linked to purchasing the solar panels that are then used to capture solar energy. Discussed below are several benefits and demerits of solar panels.

E. Applications

There are many practical applications for the use of solar panels or photovoltaics. It can first be used in agriculture as a power source for irrigation. In health care solar panels can be used to refrigerate medical supplies. It can also be used for infrastructure. PV modules are used in photovoltaic systems and include a large variety of electric devices:

- Photovoltaic power stations
- Rooftop solar PV systems
- Standalone PV systems
- Solar hybrid power systems
- Concentrated photovoltaics
- Solar planes
- Solar-pumped lasers
- Solar vehicles
- Solar panels on spacecrafts and space stations

V. CURRENT STATUS OF SOLAR ENERGY TECHNOLOGIES AND MARKETS

A. 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, 2017). 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, 2017; Chiras, 2016). 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) 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, 2014). 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 nonelectric 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 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).

VI. 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-39 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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