Technology Fact Sheet for Adaptation

II. Solar power (Rooftop PV) [i]

Introduction

Solar power is generated by collecting sunlight and converting it into electricity. Solar photovoltaic (SPV) refers to the technology of using solar cells to convert solar radiation directly into electricity. A solar cell works based on the photovoltaic effect.

Technology characteristics[1]

The photovoltaic effect

The photovoltaic effect can be briefly summarized as sunlight striking a semiconductor and causing electrons to be excited due to energy in the sunlight (photons). The excited electrons become free of their atomic structure and, in moving away, they leave behind 'holes' of relative positive charge that can also migrate throughout the material. By placing two different semiconductors together in thin layers (or wafers) the free electrons and 'holes' can be separated at their interface/junction, creating a difference in charge, or voltage, across two materials. Sometimes, the term "p-n junction" is used which refers to the two different types of semiconductor used. A single such arrangement, or cell, creates only a modest voltage and current, but when arranged into larger arrays the cells can produce useful amounts of electricity which is known as solar PV electricity.

On the basis of their manufacturing process, solar cells consist basically of three main components - the semiconductor, which absorbs light and converts it into electron-hole pairs, the semiconductor junction, which separates the electrons and holes, and the electrical contacts on the front and back of the cell that allow the current to flow to the external circuit. R&D and practical experience with photovoltaic have led to the development of three generations of solar cells.

Crystalline silicon based solar cells

The first generation is represented by crystalline silicon based solar cells, which may be monocrystalline or multicrystalline depending on the manufacturing technique. It is the most mature technology and represents a market share of 80 to 90 percent (IEA, 2009; IPCC, 2010). Maximum recorded efficiencies (the percentage of the incoming energy that is converted to electricity) of roughly 20 and 25 percent have been achieved for multicrystalline and monocrystalline cells respectively, representing an approximate doubling of efficiency since 1990 (IPCC, 2010). These improvements in efficiency have been mirrored by improvements in manufacturing techniques including thinner cells (lower material costs), larger wafers, increased automation and other factors that likewise contribute to the significant cost reductions seen in the past decades (these are discussed further in the finance section below).

Thin film solar cells

Second generation technologies, so called thin film solar cells are based on alternative materials such as cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), amorphous silicon and micromorphous silicon set as thin films. The layer that absorbs the sunlight is only a few micrometers thick and can be deposited onto relatively large smooth surfaces such as glass, metal or plastic. This PV type has the advantage of lower labour and energy intensity compared to crystalline silicon PV but a reduced efficiency in terms of electricity generation (10 to 16% depending on the film type, IPCC, 2010). The majority of the remaining share of the PV market is taken by thin film technologies.

[1] http://climatetechwiki.org/technology/pv, last accessed on 15 June 2012

Third generation PV

Third generation technologies were originally developed for use in space and have multiple junctions typically using more exotic semiconductors such as gallium and indium compounds. These types of cells have already crossed the maximum theoretical efficiency of single junction solar cells, and many laboratories have reported lab scale solar cells reaching efficiencies in the excess of 40%. Third generation cells are typically considered in combination with solar concentrator systems as described below and are currently being commercialized in this context. The use of concentrators allows much smaller cells to be used which in turn reduces the cost associated with these more exotic materials.

Concentrated solar PV

Solar cells have been found to operate more efficiently under concentrated light which has led to the development of a range of approaches using mirrors or lenses to focus light on a specific point of the PV cell, called concentrator systems. Specially designed cells use heat sinks, or active cooling, to dissipate the large amount of heat that is generated. This type of concentrating configuration requires a sun tracking system using either single axis or double axis tracking to make sure that the mirrors/lenses are always pointing at the correct orientation.

Off-grid and grid connected PV

There is an obvious yet important qualification to the discussion above on efficiency, which is that solar panels are limited to only produce electricity in periods of sunlight, either direct light or diffuse sunlight on overcast days. During the night they will not produce power. This means that solar cells, if used for remote/off-grid generation purposes, need to be implemented in conjunction with some kind of storage system such as a battery or as a hybrid system with some other type of generator. Where solar cells are grid connected this is less of a problem. They can be used during the day to reduce the local demand from the grid (or even to export back to the grid) and then at night, or during periods of low incident light, the grid can supply the necessary power. The former kind of application, as a remote or off-grid generator, is most commonly observed in developing countries and isolated areas, while grid-connected solar PV is more common in industrialized countries which have a wider reaching grid.

Grid connected solar PV also can have differences in the approach used depending on the way in which customers purchase the electricity. If the solar array is distributed, for example over a larger number of residential houses, then the single installations are operated by the consumer directly. The advantage of this to the consumer is that the cost of electricity, that the consumer must compete with, is the distributed cost, i.e. the cost to purchase power at the location of demand which is normally significantly higher than the actual levelized production cost of electricity (that doesn't account for transmission/distribution charges/losses and profit margins along the value chain). Solar installations can also be large and centralized but this demands that the power is sold into the common grid at market prices and must compete directly with other technologies (bearing in mind any subsidies that might be applicable for solar generation).

Solar Home System (SHS)

"A SHS typically includes a photovoltaic (PV) module, a battery, a charge controller, wiring, fluorescent DC (direct current) lights, and outlets for other DC appliances. A standard small SHS can operate several lights, a black-and-white television, a radio or cassette player, and a small fan. A SHS can eliminate or reduce the need for candles, kerosene, liquid propane gas, and/or battery charging, and provide increased convenience and safety, improved indoor air quality, and a higher quality of light than kerosene lamps for reading. The size of the system (typically 10 to 100Wp) determines the number of 'light-hours' or 'TV-hours' available. It is estimated that there are more than 2 million such systems in use globally, the majority in Bangladesh, China, India, South Africa and Kenya[2] (REN21, 2010).

[2] REN21, 2010, Renewables 2010, Global Status Report, Paris

Country specific applicability and potential

With rising energy demand in Bhutan, and with threats to hydro power generation from climate change risks, SPV could prove to be a sustainable source of power generation. Bhutan has good solar energy potential. The solar energy assessment was done by the U.S. National Renewable Energy Laboratory (NREL) under the financing from the U.S. Agency for International Development's (USAID) as part of the South Asia Regional Initiative for Energy (SARI/E) programme. The solar energy resources quantified at various places and solar resource map developed for the region under Solar and Wind Energy Resource Assessment (SWERA) project of UNEP have shown a resource potential of 4.5-5 kWh/m^2 in various locations[3].

Status of technology in country

The solar contribution to Bhutan's energy mix is negligible in comparison to hydroelectricity. However, SPVs have been provided to rural households as off-grid electrification where grid extension is found unviable due to the terrain and associated costs. The target during the 10th FYP was to electrify 3,582 households using SPV systems including site survey and rehabilitation of 1000 existing systems[4].

Also, there are no solar manufacturers in Bhutan. The Department of Renewable Energy (DRE) has few solar technicians and there are also solar technicians trained in different organizations and communities. The DRE also has experience in procuring SPV products from the few suppliers available in Bhutan.

Benefits to economic, social and environmental development

Economic Benefits

- Though initial investment is high, all the electricity produced is free and is profitable in the long run. Incentives and rebates offered by governments and utilities can compensate for the high prices. Further, with advancements in the technology, cost of solar panels are decreasing while efficiency is increasing

Social Benefits

- Solar energy can help provide a source of energy to far-flung and isolated communities dwelling in areas, social establishments like monasteries and schools where grid extension is made impossible due to costs, the topography and climatic conditions.
- There can be many jobs created in the solar sector, such as meet the demand for trainers and technicians.

Environmental Benefits[5]

Solar PV systems, once manufactured, are closed systems; during operation and electricity production they require no inputs such as fuels, nor generate any outputs such as solids, liquids, or gases (apart from electricity). They are silent and vibration free and can broadly be considered, particularly when installed on brownfield sites, as environmentally benign during operation. The main environmental impacts of solar cells are related to their production and decommissioning. In regards to pollutants released during manufacturing, IPCC (2010) summarizes literature that indicates that solar PV has a very low lifecycle cost of pollution per kilowatt-hour (compared to other technologies). Furthermore they predict that upwards of 80% of the bulk material in solar panels will be recyclable; recycling of solar panels is already economically viable. However, certain steps in the production chain of solar PV systems involve the use of toxic materials, e.g. the production of poly-silicon, and therefore require diligence in following environmental and safety guidelines. Careful decommissioning and recycling of PV system is especially important for cadmium telluride based thin-film solar cells as non-encapsulated Cadmium telluride is toxic if ingested or if its dust is inhaled, or in general the material is handled improperly. In terms of land use, the area required by PV is less than that of traditional fossil fuel cycles and does not involve any disturbance of the ground, fuel transport, or water contamination (IPCC, 2010).

[3] DOE 2011: National Road Map for Energy Security, Bhutan Climate Summit 2011, Department of Energy 2011
[4] Royal Government of Bhutan, 2009, Gross National Happiness Commission, Tenth Five Year Plan 2008-2013
[5] http://climatetechwiki.org/technology/pv, accessed on 15 June 2012.

Climate change adaptation benefits

Solar power presents a great avenue to bolster the adaptive capacities of Bhutan whose primary source of energy is large hydro. Large hydro is extremely vulnerable to the risks of climate change such as the reduction in the average flow of snow fed rivers, combined with an increase in peak flows and sediment yield. Generation of electricity from solar power would diversify the nation's energy sources, thereby reducing the dependence of communities on grid supply of electricity and on hydro power.

Bhutan energy requirements are met primarily from large hydro power projects. Impacts of climate change in terms of temporal and spatial variation in flow of water (having glaciers as source of origin) is most likely to affect electricity productivity/exports in Bhutan due to disruption of average flows for optimum hydropower generation from large hydro power projects.

Thus, hydropower generation is vulnerable to impacts of climate change. This also leads to vulnerability of the entire energy sector which is primarily dependent on water resources originating from glaciers. To address this vulnerability, diversification of energy sources is an important strategy. If certain areas' demand for electricity can be met through SPV, it will reduce the reliance on large hydro power.

Financial Requirements and Costs[6]

There has been a large decrease in the cost of solar PV systems in recent decades; the average global PV module price dropped from about 22 USD/W in 1980 to less than 4 USD/W in 2009, while for larger grid connected applications prices have dropped to roughly 2 USD/W in 2009 (IPCC, 2010).

Using a slightly different approach (based on a study of solar PV module and consumer electricity prices, i.e. a grid-parity study) Breyer et al. (2009) estimated that the "cost of PV electricity generation in regions of high solar irradiance will decrease from 17 to 7 €ct/kWh in the EU and from 20 to 8 $ct/kWh in the US in the years 2012 to 2020, respectively".

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[i] **This fact sheet has been extracted from TNA Report – Technology Needs Assessment and Technology Action Plans for Climate Change Adaptation – Bhutan. You can access the complete report from the TNA project website http://tech-action.org/**

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[6] http://climatetechwiki.org/technology/pv, accessed on 15 June 2012