Technology Fact Sheet

Solar PV[i]

Solar photovoltaic, or simply photovoltaic (SPV or PV), refers to the technology of using solar cells to convert solar radiation directly into electricity. A solar cell works based on the photovoltaic effect. R&D and practical experience with photovoltaics have led to the development of three generations of solar cells: Crystalline silicon based solar cells, thin film solar cells and third generation PV. Solar PV is very likely to play a significant role in climate change mitigation in the future. However, today, inspite of significane decreases in the cost for solar PV systems, the majority of PV deployment is still driven by substantial subsidy schemes.

As a tropical country, Indonesian potential of solar energy is large enough. Based on the solar radiation data collected from 18 locations in Indonesia, the solar radiation in Indonesia can be classified respectively as follows: for the Western Region of Indonesia (KBI) the solar radiation is about 4.5 kWh/m^2/hari with monthly variation of about 10% and in Eastern Region of Indonesia (KTI) is about 5.1 kWh/m^2/hari with a monthly variation of about 9%. Thus, the average wind potensial in Indonesia is about 4.8 kWh/m^2/hari with a monthly variation of about 9%.

1) Introduction

A) The photovoltaic effect

The photovoltaic effect can be briefly summarised 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 photovoltaics have led to the development of three generations of solar cells.

B) 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).

C) 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 labor 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. Selection of type of solar cells that will be developed in Indonesia has not been decided because the study is still ongoing and results will be known by the end of 2011. But the trend of industrial development of crystalline silicon solar cell is due to raw material for making solar cell is very abundant.

D) 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 commercialised 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.

E) 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. Until recently, the use of concentrated solar PV does not exist in Indonesia.

F) 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 industrialised 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 levelised 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 centralised 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).

Utilization of off-grid PV in Indonesia has been going in recent years combined (hybrid) with diesel, for example PLTHybrid Nurambela 6 units of 100 kw (25 kva, 8 kWp PV) in Southeast Sulawesi, 5 units in the province of South Sulawesi, 25 kVA 8 kWp PV in Gorontalo province, and the baron 24 kwpPV 35 kw wind and 25 kVA diesel NTB. Development of off-grid PV in Indonesia have the potential is quite promising, especially on remote islands in eastern Indonesia region. Today, PT PLN (Persero) has a program in 1000 the island, which is developing the use of off-grid PV on a desert island, and for the year 2011 has been budgeted for 100 melistriki remote island. This program can be a hybrid with a diesel and off-grid PV.

G) Solar Home System (SHS)

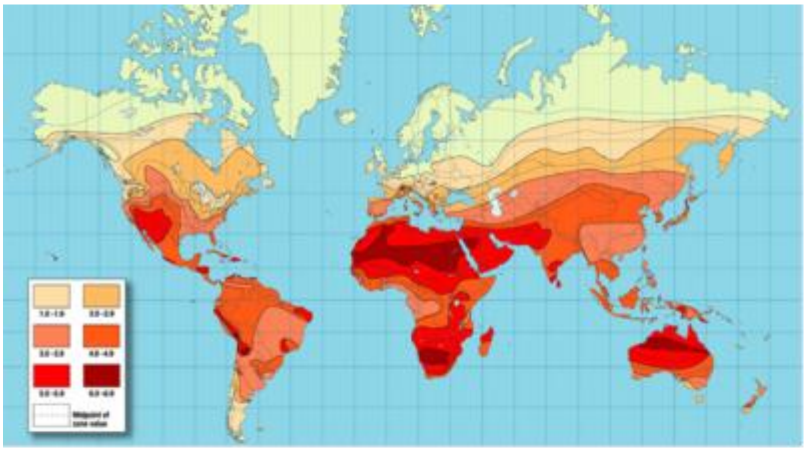
"A SHS typically includes a photovoltaic (PV) module, a battery, a charge controller, wiring, fluorescent DC (direct current) lights, and outlets for other DC appliances. A standard small SHS can operate several lights, a black-and-white television, a radio or cassette player, and a small fan. A SHS 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. In general, the utilization of solar PV in Indonesia in the form of SHS and is largely a grant from the government. The total installed capacity of SHS in Indonesia until the year 2009 reached 12.1 MWp.

2) Feasibility of technology and operational necessities

A) Resource and Location

As presented in Figure 1, locations closer to the tropics tend to have higher solar irradiation and hence a higher potential for solar PV electricity generation. There is a marked difference in resource levels geographically with northern Africa, for example, being exposed to more than twice the level of solar energy as northern Europe; implying that for the same size panel the electrical output could be doubled in the former location. Having said that, Germany has the largest installed capacity in the world due to domestic incentives there, illustrating that other factors related to cost greatly influence the current global distribution of solar PV installations. This is discussed further in the sections below on policy, markets and costs.

Figure 1 Worldwide average solar irradiation (kWh/m2 per day)



Typically satellite data is used to determine the average yearly radiation level at a site for a number of reasons i) local ground based measurements are expensive and equipment must be cleaned to prevent soiling ii) satellites can provide up to 20 years of data for an average which is important given the large annual variation in solar irradiation levels iii) the accuracy of satellite data is found to be good in correlation with ground based measurements (Pitz-Paal et al., 2007).

Based on these estimates of resource and the associated time-series/seasonal-variation it is possible to estimate the power that would be generated throughout a typical year. This allows the economics of a project to be determined and also allows other aspects of the system (for example battery size if it is an off-grid application) to be calculated.

B) Technical Requirements

The technical requirements for the installation of solar PV vary greatly depending on the size of the system and kind of technology used. Small off-grid systems in remote/rural areas using first generation technology, such as solar home systems (see Box 1), can be bought in what is effectively a 'kit' form and installed with relatively little local expertise. Maintenance is minimal and mainly requires the cleaning of the solar panel to ensure efficiencies are maintained. Alternately the installation of grid scale concentrating solar power with third generation technology is a highly specialised field, requiring detailed calculations for the plant layout, expected yield and economics of the project. The equipment, with the required tracking mechanisms, requires maintenance and upkeep, and the power output must be forecast for export.

C) Legal/Regulatory

The legal and regulatory requirements for solar PV are relatively few compared to some other renewable technologies. They have a low local environmental impact and are not very visible (for small applications they are often mounted on the roofs of buildings) typically making public/permitting acceptance high. Grid connected systems require an appropriate licence or permit to export to the grid along with the necessary metering equipment, connected by a professional, to ensure that the level of export to the grid is measured for any subsequent compensation. Larger installations obviously require the appropriate planning permissions that would accompany any moderate to large infrastructure project.

Currently, the main policy instruments that have an impact on solar PV are incentives that subsidise its use and offset its currently uncompetitive cost; a handful of countries with strongly supportive policies account for 80% of global installed PV capacity (IEA, 2010). For the condition of Indonesia, incentive to the use of PV have not been there and selling price of PV grid-connected with a maximum of 1.506 USD / kWh. The selling price for PV off-grid in accordance with economic price (about 40 cents USD / kWh).

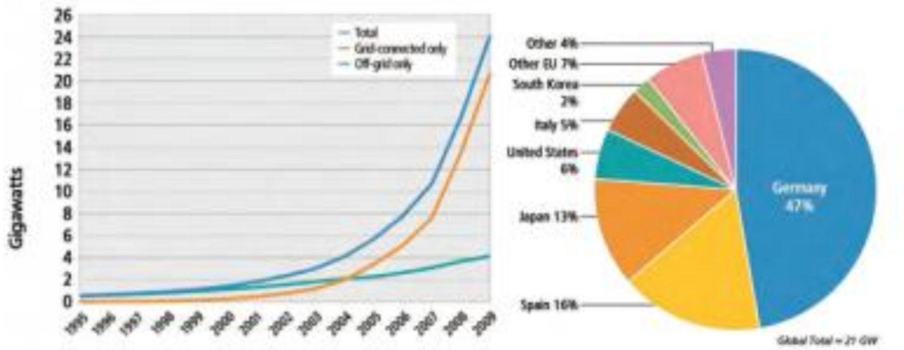
3) Status of the technology and its future market potential

While crystalline silicon based and thin film solar systems are in the early phases of rapid market deployment, third generation and concentrated solar PV are in the R&D and demonstration phase.

In the last two decades the global solar PV market has experienced rapid expansion, with an average annual growth rate of 40% (IEA, 2010) and 60% between 2004 and 2009 (REN21, 2010). A record 7GW of new grid-connected capacity was added in 2009, bringing total grid-connected capacity to 21GW with off-grid PV accounting for an additional 3 to 4 GW (Figure 2). It can be observed that the majority of installations are in countries that have only moderate solar resource levels however their strong policy regimes and support mechanisms have allowed their domestic markets to flourish.

The largest solar PV producers, those that had an output of more than 500MW in 2009, were First Solar (USA), Q-cells (Germany), Sharp (Japan), JA Solar Holdings, Suntech and Yingli (all China). However, the market is relatively diversified with significant number of global manufacturers vying for market share and the top ten manufacturers occupying only 45 percent of production of solar cells (Hirshman, 2010).

Figure 2 Solar PV: Existing world capacity 1995 to 2009 (left) and top six countries by cumulative capacity 2009



(Source: REN21, 2010)

The IEA (2010) forecasts an average annual market growth rate of 17% in the next decade, leading to a global cumulative installed PV power capacity of 200 GW by 2020 and 3000GW by 2040 (with repowering of older systems). This would represent roughly 11 percent of global energy demand should this scenario play out. In terms of technology, the market share of thin films is expected to grow to 35% by 2013, due to constraints in the availability of high grade silicon.

Photovoltaics Development Goals in Indonesia are:

- The more the role of photovoltaic solar energy utilization in providing energy in rural areas, so that in 2020 their installed capacity to 25 MW.
- The more the role of solar energy utilization in urban areas.
- The lowest price of solar photovoltaic energy, in order to reach the commercial stage.
- Implementation SESF production equipment and support equipment in the country that have a high quality and highly competitive.

Photovoltaic solar energy development strategies in Indonesia are:

- Encourage the use of PV in an integrated manner, ie for the purposes of illumination (consumptive) and SESF produktif.Mengembangan activities through two patterns, namely patterns of spread and centralized adapted to field conditions. The pattern of spread is applied when the location of houses spread a considerable distance, while the pattern is applied when the centralized location of houses centered.
- Develop the use of PV in rural and urban areas.
- Encourage the commercialization of PV by maximizing private sector involvement.
- Develop the domestic PV industry is export oriented.
- Encourage the creation of systems and efficient funding pattern involving the banking sector.

Photovoltaics Development Program in Indonesia are:

- Develop PV for rural electrification programs, particularly to meet the electricity needs in areas far from the reach of electricity.
- Increase the use of hybrid technology, particularly to meet the shortage of electricity supply from isolated diesel.
- Replace all or most of the electricity supply for customers Social Small and Small Households with SESF PLN.

The proposed patterns are:

- Fulfilling all electrical needs for customers S1 with 220 VA power limit;
- Meet all requirements for customers S2 with 450 VA power limit;
- Meet 50% of electricity needs to subscribers S2 with 900 VA power limit;
- Meeting the 50% requirement for R1 customers with 450 VA power limit.
- Encourage the use of PV in buildings, especially the Government House.
- Assess possibility of establishing a solar module factory to meet domestic and export possibilities.
- Encourage private sector participation in the utilization of photovoltaic solar energy.
- Carrying out cooperation with foreign countries to the construction of large-scale PV.

4) Contribution of the technology to protection of the environment

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) summarises 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).

5) Climate

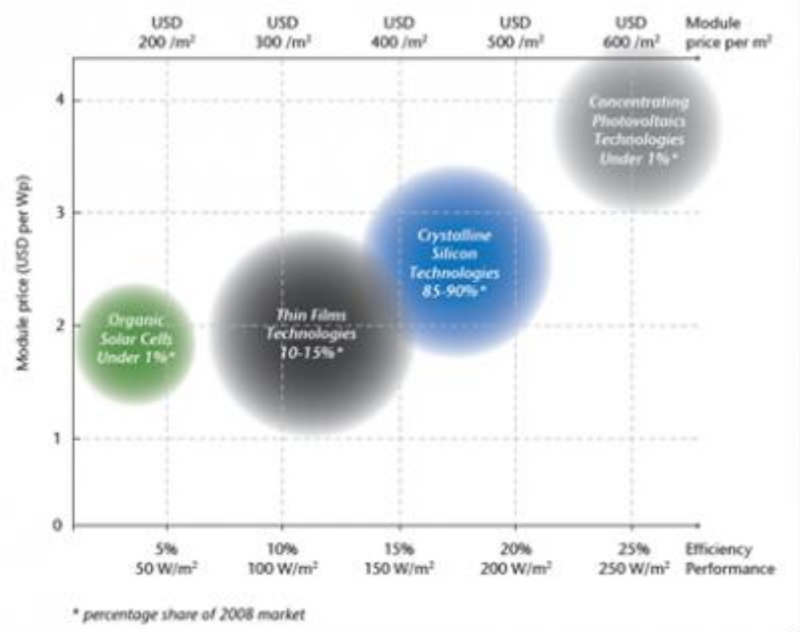
Solar PV is very likely to play a significant role in climate change mitigation in the future. As described above solar PV is a rapidly growing market and forecasted by the IEA (2010) it will contribute more than 10 percent of global electricity supply by 2050. It has energy payback periods ranging from 2 to 5 years for good to moderate locations and life cycle of GHG emissions vary from 30 to 70 gCO_2e/kWh (IPCC, 2010), depending on panel type, solar resource, manufacturing method and installation size. Comparing to emission factors for coal fired plants of more than 900 gCO_2e/kWh and for gas fired power stations of more than 400 gCO_2e/kWh (Sovacool, 2008) showing the large potential for solar PV to contribute to reductions in carbon emissions from the electricity sector.

6) Financial requirements and costs

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 the price of larger grid connected applications has dropped to roughly 2 USD/W in 2009 (IPCC, 2010). A review of the available literature on historical solar PV learning rates (the percentage reduction in price for every doubling of installed capacity) shows a range of estimates from 11 to 26 percent (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”.

Figure 3 Current performance and price of different PV module technologies in 2008



(Source: IEA, 2010)

It is important to note that these prices only apply to those wishing to install large, utility scale, solar parks in industrialised countries. The costs of Solar Home Systems in developing countries have been shown to be orders of magnitude higher per kilowatt-hour. Wamukonya (2007) presents costs of SHS systems ranging from 1.51 to 1.75 US$/kWh in African countries using favourable discount rates and PV lifetimes. She concludes that on a simple cost basis petrol/diesel generators may be preferable which suggests that a thorough study of the economics of any planned solar PV deployment is advisable before proceeding.

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[i] **This fact sheet has been extracted from TNA Report - Mitigation for Indonesia. You can access the complete report from the TNA project website http://tech-action.org/**