Annotated bibliography and description of methodology for the factsheet

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-EGRS 352

Section A: Annotated Bibliography

1) Photovoltaic Glass: How does it work? (n.d.). Retrieved from http://www.solarenergyexperts.co.uk/buyersguides/photovoltaic-glass-how-does-it-work/

This is an UK based website for a company which provides regular advice to buyers and sellers of solar PV panels by keeping abreast of the latest developments and trends in the solar PV market. As a result of having to constantly communicate with the public they have a number of very helpful info-graphics and illustrations regarding the working of solar PV and one such figure was used in the factsheet. However, they lack the objectivity of research papers or journal articles.

2) Runyon, J. (2012, March 14). Solar Industry's Exponential Growth in 2011 Indicates Healthy US PV Market. *Renewable Energy World.com*. Retrieved from http://www.renewableenergyworld.com/rea/news/article/2012/03/solar-industrys-exponential-growth-in-2011-indicates-healthy-u-s-pv-market

This website was founded in 1998 by a group of renewable energy researchers. It claims to be the 'world's number 1 renewable energy website'. Although this claim can be disputed, there are very few other websites which presents such a comprehensive collection of data, opinion articles and news reports in one place. However, since it focuses so strongly on renewable energy (almost to the point of advocacy) there is a possibility that there exists an underlying bias to some of the information provided. Additionally, the article from which the figure was obtained was written in March 2012 and hence the age of the figure might comprise its accuracy.

3) Solar Market Insight Report 2013 Year In Review. *Solar Energy Industries Association.* (n.d.).Retrieved from http://www.seia.org/research-resources/solar-market-insight-report-2013-year-review

The Solar Energy Industries Association (SEIA) is a national non-profit trade association of the U.S. solar energy and was established in 1974. Every year it publishes an annual solar market insight report in which it reviews the performance of the solar market during the previous year. Being a non-profit association not linked to any particular solar energy company, the information it provides has a relatively high degree of objectivity. Additionally, the 40 years worth of experience that SEIA can boast of provides its data with a stamp of reliability and authority. According to the footnotes from numerous financial statements, a number of solar PV companies make important investing decisions based on the annual insight reports that SEIA produces.

4) National Renewable Energy Laboratory (n.d). Retrieved from http://www.nrel.gov/gis/solar.html

The National Renewable Energy Laboratory (NREL) is the U.S.'s primary lab for conducting research towards improving efficiencies of renewable energy sources and developing new techniques in renewable energy production. As it is funded by the U.S. Department of Energy it has access to relatively robust financing and the latest technologies allowing it to work on cutting edge projects and publish repeatable experiments and verifiable data. However, the NREL is a contractor-operated facility. Essentially, private entities can pay to use the facilities for their own research. Hence, NREL reports come along with a possible degree of bias due to the conflicts of interest.

5) Lacey, S. (2011, June 14). Solar is Ready Now: Ferocious Cost Reductions Make Solar PV Competitive. *The Solar Foundation.* Retrieved from http://thesolarfoundation.org/blog/solar-ready-now-%E2%80%98ferocious-cost-reductions%E2%80%99-make-solar-pv-competitive

The Solar Foundation (TSF) is an independent national non-profit organization which defines its mission as "increase understanding of solar energy through strategic research that educates the public and transforms markets". It has over 30 years of experience and often provides key reports on the basis of which the Department of Energy makes important recommendations. The relatively high degree of independence that this organization enjoys helps ensure that its data is objective and free from bias. However, the report from which the figures have been extracted for the factsheet was published in 2011 and hence the relative age of the report introduces a certain degree of inaccuracy in the forecasts and projections.

6) U.S. Department of Energy, Solar Energy Technologies Program. (2008, April 15). *Multiyear program plan 2008-2012.* Washington, DC: U.S. Government Printing Office. Retrieved from http://www1.eere.energy.gov/solar/pdfs/solar_program_mypp_2008-2012.pdf

The U.S. DOE is a Cabinet level department of the U.S. responsible for energy and safety policy especially regarding renewable energy. On the plus side, it has a vast amount of funding available to conduct research and develop the most efficient overall policies (a total budget of $27 billion which dwarfs the funding available to most independent organizations). However, on the negative side, it is firmly a government entity and hence is culpable to government influence and pressure.

7) Green, D. (2012, December 19). Advantages and Disadvantages of Solar Photovoltaic. *Renewable Energy World.com*. Retrieved from http://www.renewableenergyworld.com/rea/blog/post/2012/12/advantages-and-disadvantages-of-solar-photovoltaic-quick-pros-and-cons-of-solar-pv

This citation has already been addressed (citation 2).

8) Shah, A., Torres, P., Tscharner, R. (1999, July 30). Photovoltaic Technology: The Case for Thin-Film Solar Cells. *Science*, 285 (5428), 692-698. Retrieved from http://www.sciencemag.org/content/285/5428/692.long

This is an online journal citation. *Science* is the academic journal of the American Association for the Advancement of Science and is widely considered to be one of the top scientific journals in the world. Hence the data published by this journal can be considered highly reliable as it undergoes multiple peer edits and reviews. However, this particular issue was published in 1999 and hence the content of the issue might have been compromised by the relatively high age of the article.

9) United States Environmental Protection Agency.. (n.d.). *Renewable Energy: Solar Energy*. Retrieved from http://www.epa.gov/region1/eco/energy/re_solar.html

The EPA is an U.S. federal government agency armed with the responsibility of safeguarding the environment by writing and enforcing regulations based on Congress laws. Due to the relatively high degree of funding and government financial and political support, the EPA has the latest tools and technology to conduct its research. However, there have been reports of political pressure and scientific integrity with the work conducted by the EPA. A survey conducted in 2008 found that more than half of the EPA scientists reported that they had experienced incidents of political interference in their work and hence their reports come with a degree of political bias.

10) National Renewable Energy Laboratory, U.S. Environmental Protection Agency. (2013, February). *Best Practices For Siting Solar Photovoltaics on Municipal Solid Waste Landfills.* Washington, DC: U.S. Government Printing Office. Retrieved from http://www.epa.gov/oswercpa/docs/best_practices_siting_solar_photovoltaic_final.pdf

Both the above sources have been already covered in previous citations (4,9)

11) Hall, M. (2014, March 5). US Posts Record Year For Solar in 2013. *Photovoltaics Magazine.* Retrieved from http://www.pv-magazine.com/news/details/beitrag/us-posts-record-year-for-solar-in-2013_100014415/#ixzz2xrmJhaPV

This source is an online, independent magazine which published news, stories and opinions on the latest developments on photovoltaic in the worldwide market. This endeavor was launched in 2008 and hence this source doesn't necessarily have the vast years of experience or expertise of other sources. However, on the plus side, this source provides very up to date information and news. Both the articles used for this factsheet are based on events which took place within the last year and hence are topical issues in the PV market.

12) Meza, E. (2014, April 9). Hanwha Q CELLSS Completes First US Solar Farm On A Superfund Site. *Photovoltaics Magazine.* Retrieved from http://www.pv-magazine.com/news/details/beitrag/hanwha-q-cells-completes-first-us-solar-farm-on-a-superfund-site_100014787/#axzz2z09fNwtz

This citation has already been addressed. (11)

13) Farell, J. (2011, November 7). Nuance on Krugman's "Solar is now cost-effective". *Institute for Local Self Reliance.* Retrieved from http://www.ilsr.org/nuance-krugmans-solar-now-cost-effective/

The Institute for Local Self-Reliance (ILSR) is a national research and policy organization which was founded in 1974. Its goal is to foster community-centered and at the same time environmentally sound economic growth especially in so called 'rural' areas'. The vast experience that ILSR possesses provides its data with a degree of verification and reliability. Additionally, the figure used from this website explains clearly each and every assumption that went into the modeling.

Section B: Detailed Methodology

With the increasing demand for energy and the increasing clamor for a higher proportion of renewable energy sources involved in the mix, energy generated from solar photovoltaic sources will play a key role in the future. This fact sheet focuses on the key statistics, trends and facts involved with solar energy production, consumption and costs.

A] Overall fact sheet methodology

It is important to note first and foremost that this fact sheet focuses on solar PV production, consumption and costs only within the United States. Significant advances in solar energy and technology have been made in Europe, specially Germany and Italy as well as in China over the last two to three years. However, a decision was taken to focus on only the United States because as of 2016, the U.S. has been projected to have almost 14% of the share of global PV installations. Hence it appears important to perform a U.S.-centric research and analysis of solar PV resources and capacity to understand the current capabilities and future potential for solar PV in the U.S.

B] Individual section methodology

'How do solar cells produce electricity?' section:

It is important to start the factsheet with this discussion in order to provide readers who are unaware of the exact method of energy production in solar PV cells a brief summary and to provide other readers who are aware of this mechanism a helpful refresher. Solar PV cells have typical efficiencies ranging from about 7%-20% and hence an approximate average value of 14-15% is provided in this section. An average value provides readers with a single, direct number with which quick, rough comparisons can be made to the efficiencies of other traditional electric energy generation sources.

'Available resources and capacity' section:

In terms of resources, solar PV cells need two essential requirements: solar radiation and the land on which to build the solar panels. The solar resource is shown in the top-most graph in this section. It displays a map of the U.S. color coded based on the intensity of the incoming solar radiation which is measured in units of $\frac{kWh}{\frac{m^2}{day}}$. The kWh term provides a measure of energy and dividing it by the $\frac{m^2}{day}$ term provides a measure of area energy intensity per day.

Along with the solar resources available, it is important to consider the available land resources. To this effect, an original calculation was performed to determine how much land would be required if all of the current electricity generated in the U.S. was to obtained from solar PV panels with varying efficiency values. Solar panels of efficiencies 7%, 15% and 20% were chosen for this calculation. From the solar resource graph, an average value of 5 $\frac{kWh}{\frac{m^2}{day}}$ was selected and multiplied by 365 days to obtain a solar energy of 1825$\frac{kWh}{\frac{m^2}{year}}$. This value was then multiplied by the efficiency of the panel to obtain the total possible electrical energy that can be generated per square meter. To obtain the area of each panel, the equation 1 was used as shown below:

$$Area\ of\ each\ panel\ (in\ m^2) = \frac{Electrical\ energy_{total}}{Electrical\ energy_{per\ square\ meter}} \qquad (1)$$

In this calculation, $Electrical\ energy_{total}$ was considered to be the total electrical energy generated in the US in 2012, approximately 15.7 EJ annually. The objective behind this decision was to determine how much land would be required if solar PV produced the *entire* electricity demand of the U.S. After obtaining the area of the panels required, a factor of 2 was used to multiply this value in order to obtain a number for the total land area required. The graph shows that for the lowest efficiency under consideration (7%), the total land required to generate all of the U.S. electric energy demand is only 10% higher than the area of Maryland, the 9th smallest state in the U.S. This would suggest that there is an abundance of land resources available for generating electrical energy in the U.S. However, the fraction of available land actually free for construction of solar panel arrays is another issue altogether.

Having considered the resource availability, the focus of the factsheet turns towards installation trends and sector-wise consumption. It was deemed important to show the installation (in MW) trends for the residential, non-residential and utility sectors over the last 3 years because it clearly depicts the emergence of solar PV installations in the utility sector over this period of time. Total US PV installations for the utility sector increased by approximately 80% in 2013 compared to 2012. Large spikes in installations in the utility sector can especially be seen in quarter four of 2012 and 2013. However, how much of this increase in installations was due to the harsh winter (especially in 2013) rather than the perceived long-term benefits of solar PV are still up for debate. The severe winter of last year caused an unanticipated increase in the demand for natural gas which consequently led to a meteoric increase in its price. Hence it can be argued that the drastic increase in solar PV installations took place due to the increase in natural gas prices. However, on the flip side, one could argue that the total annual installations in the utility sector have increased on a year over year basis for the last 3 years as shown by the figure and this suggests a more permanent, long-term switch towards solar PV cells. In terms of the overall installation trends in the US, the figure on the bottom right of this segment shows that projected annual installations of PV systems in the US is forecasted to reach almost 8000 MW by 2016, a 166.7% increase compared to 2005. It was deemed important to place this figure right next to the sector-wise consumption because of three primary reasons. Firstly, it provides a macro-view contrast to the more micro-view that the former provides. It helps to connect the sector-wise story to the national wide installation increase which leads to a more coherent story. Secondly, the sector-wise consumption graph only shows data for the last 4 years. To obtain an idea about the trend of total solar PV installations in the US, more data points are required, which are supplied by this graph. Furthermore, the sector-wise graph does not address any future projections regarding PV installations which are addressed by the national installations figure. Finally, it depicts how the annual PV installations have increased every single year from 2005 onwards which clearly indicates the gradual but steady shift towards solar PV as a viable source of energy. For the above mentioned reasons, it was important to place these two graphs side by side.

'Costs associated with solar PV' section:

Having discussed the resources, capacity and sector-wise consumption trends of solar PV in the U.S., the logical next step is to consider the costs associated with this technology. When considering the cost of any new form of technology, four key issues need to be considered: What is the cost to install the new systems which will produce energy? How do these costs compare with other, more traditional forms of energy? How are the companies involved with this energy performing currently in the economy? Finally, what are the effects of tax incentives on the technology?

The energy cost vs. time period graph shown on the bottom left of this section graphically represents historical prices and projected performances of solar PV. This graph was obtained from the U.S. Department of Energy's "Multi Year Program Plan 2008-2012". The cost shown on the y-axis is a 'Levelized cost of energy' (LCOE) and it represents the price at which electricity from a specific source must be sold in order to recover the cost of producing it over the lifetime of the project. A decision was made to use this graph which shows levelized cost over other similar graphs which simply provide installation or operating costs because the LCOE is a more comprehensive economic evaluation of the cost of the entire system. It includes the various costs of the lifetime of the system starting from initial investment and cost of capital up to fuel costs and operating and maintenance costs. According to the figure, solar PV will obtain grid parity approximately around 2015-2016. Although this data was published in 2008 and hence does not reflect the effects of some of the more recent technological advances in solar PV on the cost of this technology, it was selected over other, more recent data sets for one primary reason. Most of the recent data and figures on solar PV costs reflect 'installation costs' as the dependent variable on the y-axis. Although the installation costs do comprise the most significant portion of total solar PV costs, the LCOE value provides a more comprehensive measure of the cost of setting up PV panels since it measures the cost over the entire lifetime of the system.

The graph on the top left highlights that by the time it takes to build a new American coal facility in the next 6 years, solar PV in the regions with the best insolation will be competitive with these plants. For the purposes of the calculation a 500 MW coal plant is assumed and the cost shown on the y-axis is the LCOE whose merits have been discussed above. This is a very important figure since it provides financing companies which are planning to invest in a diversified portfolio of energy stocks a new issue to think about. In terms of long-term investment, would they rather invest in the tried and tested coal or in solar PV which will be competitive with coal in 6 years time and, on the plus side emit negligible carbon dioxide or particulate matter? An additional graph highlighting the fact that solar PV already beats natural gas peak power plants today is shown below in figure 1. Peaking power plants are those that typically run only when there is high demand for electricity. The data is obtained from Lazzard, an international financial services firm that analyzes and tracks energy data, and the Department of Energy (DOE). For purposes of modeling, the 2011 gas price is assumed to be the midpoint of the LOCE range provided by Lazzard, while the 2016 gas price is calculated assuming a 1% annual escalation. The 2011 and 2016 solar PV prices have are obtained from DOE reports. This graph was *not included* in the actual factsheet because it deals with only peak natural gas power plants and not general natural gas plants. Hence it was deemed less important than the solar PV vs. coal plant which already gives the reader the impression that solar PV costs are approaching traditional sources.

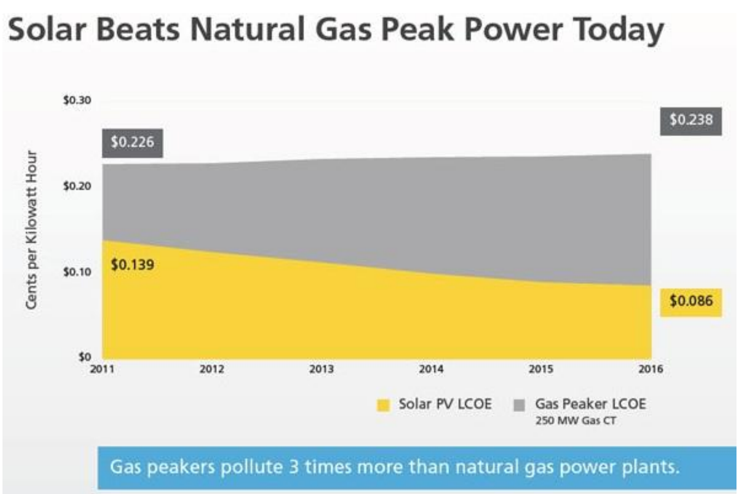

Fig 1: Solar PV is currently more cost effective than natural gas peak power.

The impact of tax incentives on solar PV have formed an integral portion of the PV debate and hence it was decided to include the figure (in the top right hand corner of this segment) which shows the effectiveness of tax credits on the affordability of solar PV compared to average grid power costs. The figure shows the number of Americans in the top 40 metropolitan areas who would find solar PV (at $3.50 per Watt in 2011) more affordable than grid electricity prices (average residential retail prices) over the next 10 years. The figure assumes that the price of solar PV declines by 7% every year and grid electricity prices increase by 3%. As seen in the graph, even without federal tax incentives or the preferred 'time of use' pricing (TOU), almost 50 million Americans are projected to favor solar by 2016. However, if the tax incentives and the TOU pricing were added to the model, the number of Americans who would find solar PV more affordable than their utility's electricity price go up to almost 150 million. However, the website likely underestimates over time since historically, the largest growth rate of population takes place in metropolitan areas which tend to have the highest electricity prices.

Finally, to analyze the stock prices of solar companies in the U.S., an original calculation was performed. 6 U.S. solar energy companies were selected: First Solar, Advanced Energy Industries, Inc., SunPower, SunEdison, TrinaSolar and SolarCity. The companies were selected such that there was a mix of solar companies which had been performing well in the stock market over the past 5 quarters (such as First Solar, etc) and those which were not performing as well (such as SunEdison). In this manner, a more meaningful industry trend could be obtained than if only the top few or bottom few companies were being analyzed. The stock prices of these companies dating back to April 2012 were obtained from Yahoo finance. Although stock prices from further before (2008 onwards) were available, a conscious decision was made to select only the prices from 2012 onwards in order to minimize the aftereffects of the 2007 recession on the trends. The prices were recorded on a per month basis all the way up to the most current stock price reported. Subsequently, an average stock price was determined for each time period. Finally, the average stock price was plotted as a function of time, showing an increasing overall industry trend which bodes well for the future of solar PV energy. Additionally, a profit-margin bar graph was constructed for the 4 of the 6 companies analyzed. Profit-margin of a company is defined as the ratio of the net profit to the net revenue of a company and represents the fraction of the company earnings that is actually being converted into profit. The income and revenue data was obtained from the 10-K financial report filings on the U.S. SEC website (data was not available for the other two companies). The resultant bar graph is shown below in figure 2. It was decided not to put this figure into the factsheet because it provides similar information to the stock price graph. As the profit-margin of the company increases, it is able to pay higher rates of dividend, thus attracting more stock buyers which drive up the stock price. Thus in order to avoid repetition of data, this bar graph was omitted from the actual factsheet.

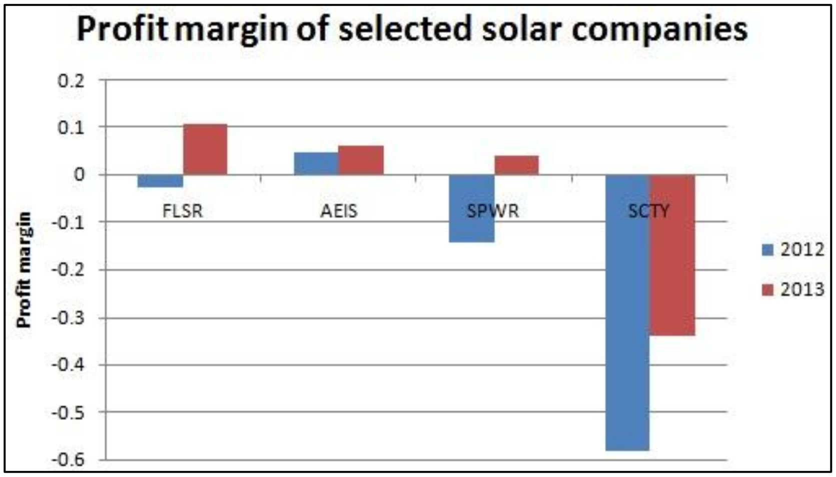

Fig 2: Profit margin for 2012 and 2013 for selected solar energy companies

'Advantages vs. Disadvantages' section:

Having discussed the capabilities and economic costs of solar PV it is important to summarize the advantages and disadvantages in a table format to allow readers to understand the benefits and costs of solar PV at a quick glance. Hence the advantages and disadvantages were prepared and presented in a tabular format.

'Key current developments' section:

Three key developments in solar PV have been listed in this section in bullet point form for ease of reading.