Analysing the potential of Solar PV installation in India

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***Abstract*— A large scale adoption of solar energy is solution to curtailing the emissions produced with conventional power generation. This study analyses the annual energy output of 1 MW solar PV installation for several locations across India. NREL-SAM software output energy values and its comparative analysis with tilt angle 30 degrees is presented. Annual reduction of emission by comparing emission levels with coal based generation is analysed and a quantified solution to reduce emissions is presented.**

***Index Terms*—solar photovoltaics (PV), photoelectric effect, tilt angle, GHG emissions, carbon trading, SAM-System Advisor Model.**

I. INTRODUCTION

Use of solar energy in large scale is the need of the hour. A greater reliance on conventional energy resources not only increases the greenhouse emissions but also depletes the natural resources [1]. The carbon emissions due to coal based thermal power accounts to 0.94 kg/kWh [2]. The global temperature has risen by degree 0.99 C [3]. Thus, an effective use of renewable energy especially solar becomes ideal choice in solving this problem which in turn leads mitigation of climate change..

Mitigation of climate change due arising greenhouse gases is challenge both nationally and globally. Several initiatives includes: regulation of emissions by industries and use of renewable energy such as solar, wind and hydroelectricity. The installed capacity of solar PV is 9,235.24 MW as on Jan 2017 [4]. But there is huge untapped potential in various parts of India for commercial solar photovoltaics installation.

With rising need of renewable energy across the world a consistent improvement in solar technology is recorded. In past few years the efficiency of solar PV has improved. Hong Kong Polytechnic University records solar PV efficiency of 25.5% [5] and University of California Riverside records upto 30% [6]. Moreover, the subsidy provided by government also provides solution to finance problems.

Since, major proportion of solar PV installations happen in places with higher values of solar irradiance but, it is proven that even for places with low irradiance solar PV installation is viable. For instance, Germany being close to Northern hemisphere experiences way less solar radiation than India. But for Germany in 2016, total installed capacity is 40.85 GW [7]. Hence, in this study various parts of India are studied for their potential and annual energy outputs are obtained using NREL System Advisor Model.

Mitigation of greenhouse gas emissions is a global challenge and due to the ill effects of increased emissions several island regions have started feeling the effects. For instance, Maldives has experienced a rise in sea level of 0.07-0.15 cm/year [8]. UNDP has consistently introduced various programs to support sustainable development in both developed and developing nations [9]. Although, a proper monitoring system for progress in sustainable development has always been a point of discussion but with initiatives such as REDD+ [10] for forestation and carbon trading [11] between countries and industries has provided solution to depleting environment conducive to human health.

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II. THEORY

A. Solar Energy

The underlying principle of operation of solar photovoltaic panel is photoelectric effect. A ray of light when hits the surface of semiconductor then there is a generation of electron. The movement of electron in the external circuit results in current in the external circuit. A schematic diagram of this process in shown in Fig. 1 [13].

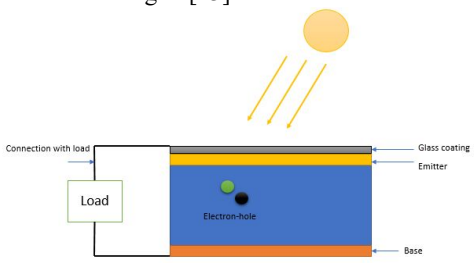

Fig. 1. A schematic diagram of solar cell

Moreover, a simplified circuit of a solar cell is shown in Fig. 2 [14].

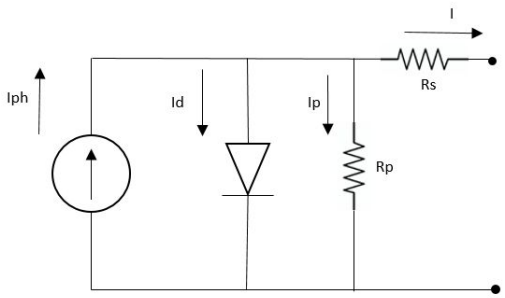

Fig. 2. Simplified circuit diagram of solar cell

The total current I, in the external circuit is given by (1) [14]:

$$I = I_{ph} - I_d - I_p \quad (1)$$

Where, I_{ph} is the light generated current, I_d is the diode current

and I_p is the current in the parallel resistance (R_p).

B. Energy Output

The annual energy output of the solar PV depends on numerous factors namely: solar irradiance, temperature and invertor losses in conversion from dc to ac power or losses in battery in case of storage. NREL's System Advisor Model is one of the open source software packages which provides most accurate results for solar PV installations [15]. Moreover, Matlab provides detailed electrical circuit modeling but, it imports data for PV modules from the NREL database [16]. So, SAM modelling is suitable and with its PVWatts method which provides modelling with least known parameters such as location, tilt, azimuth angle, cost of electricity and system losses due to shading, soiling etc. [16].

C. GHG Emission reduction

The emissions due to conventional power generation can be reduced with use of solar PV installations. The amount of emissions from conventional generation can be reduced by generating equivalent amount of power using solar energy. Thus, the solar PV installations can act as sink for carbon dioxide emissions by any conventional method of power generation.

III. SAM Modeling

Using PVWatts method in NREL's System Advisor Model (SAM) the annual energy outputs for various parts of India are studied. The energy output of 1 MW commercial installation with tilt angle of 30 degrees is shown in Table 1, 2 and 3. Losses due to shading, soiling, mismatch, wiring and connections and inverter losses are assumed 14%. Although, for various locations the total losses might vary and results including these effects can also be accounted.

Table 1. Annual energy output for locations in Rajasthan

Month	Chittorgarh	Ajmer	Kota	Jaipur
Jan	152,139	145,444	143,971	140,943
Feb	149,327	147,276	145,670	138,578
Mar	170,220	168,199	164,442	162,555
Apr	162,069	159,680	155,982	155,189
May	156,411	161,362	151,868	151,604
Jun	127,751	132,181	130,086	132,391
Jul	110,329	117,207	116,700	122,085
Aug	111,236	121,808	114,774	117,964
Sep	144,774	143,425	140,908	144,477
Oct	170,235	168,087	167,974	164,009
Nov	151,834	142,810	142,647	141,576
Dec	142,544	139,140	131,174	130,608
Total	**1,748,869**	**1,746,619**	**1,706,196**	**1,701,979**

Table 2. Annual energy output for locations in Gujarat

Month	Gandhinagar	Ahmedabad	Rajkot	Porbandar
Jan	159,691	158,785	161,798	162,844
Feb	149,820	153,038	150,641	153,846
Mar	172,876	171,445	172,093	173,224
Apr	159,174	157,669	157,743	162,223
May	152,738	151,282	150,229	151,992
Jun	127,486	126,372	122,067	125,366
Jul	100,160	100,662	94,710	100,835
Aug	107,567	108,143	104,073	102,911
Sep	131,949	133,284	136,164	141,539
Oct	166,431	166,471	164,024	165,133
Nov	153,130	145,634	151,850	154,516
Dec	144,761	145,766	158,329	154,585
Total	**1,725,783**	**1,718,551**	**1,723,721**	**1,749,014**

Table 3. Annual energy output for locations in U.P.

Month	Kanpur	Lucknow	Allahabad	Varanasi
Jan	101,334	101,439	110,949	107,842
Feb	126,333	121,296	127,442	126,855
Mar	155,122	156,067	164,220	162,798
Apr	150,460	152,725	151,775	150,458
May	142,772	136,927	142,571	141,541
Jun	112,725	115,014	120,158	119,524
Jul	108,520	122,425	110,906	113,015
Aug	121,751	118,660	115,644	116,913
Sep	117,866	117,310	124,458	123,170
Oct	144,459	139,282	141,617	141,701
Nov	127,288	114,512	120,287	124,132
Dec	109,818	107,165	102,375	106,614
Total	**1,518,448**	**1,502,822**	**1,532,402**	**1,534,563**

IV. Results

As seen from the Tables 1, 2 and 3, for locations in Rajasthan and Gujarat, the average annual generation of electricity is 1.72 MWh whereas, for location in Uttar Pradesh (U.P.), 1.52 MWh is generated. Chittorgarh is one potential location for solar PV installation.

The emissions reduced with solar PV installations assuming an equivalent coal based generation is shown in Fig. 3. Coal based thermal power plant generates emissions equivalent to 0.94 kg/kWh [2]. Based on this emission level, the amount of emissions reduced with 1 MW solar PV installation were obtained.

Using the state tariff rates (Rajasthan- 5.71 ₹/kWh, 5.09 ₹/kWh, Uttar Pradesh 5.75 ₹/kWh [17]), the yearly savings in energy produced by solar PV installation is shown in Fig. 4.

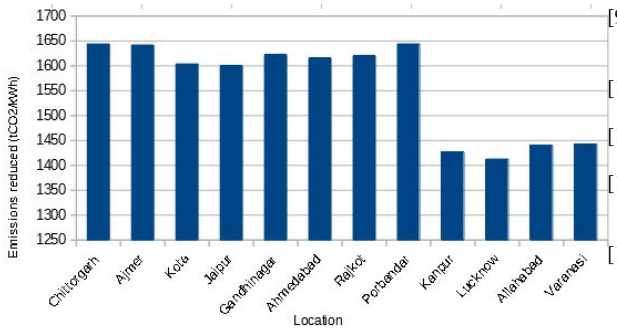

Fig. 3. Emissions reduction with 1 MW solar installation

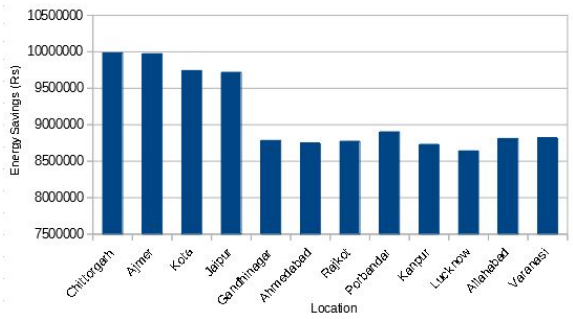

Fig. 4. Energy savings (₹) for 1MW solar installation

V. Conclusion

In order to solve the global issue of climate change due to increased emissions from conventional energy generation, solar PV installation is recommended. Identification of potential areas for solar PV installation is important. The study indicates feasibility of installation 1 MW solar PV for major locations in India. An average effective reduction in CO_2 emissions by 1,560 tCO_2/year is estimated with such installation.

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