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RESEARCH ARTICLE

GRADING OF SOLAR PHOTOVOLTAIC ELECTRICITY GENERATING SYSTEMS IN INDIAN CONTEXT

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ABSTRACT

The work presented seeks to assess the sustainability of different solar photovoltaic electricity generating systems based upon energy, environment and economics. The sustainability indicators evaluated for energy, environment and economics are electrical output, life cycle greenhouse gas (GHG) emissions and Life cycle cost of electricity generated per kWh. The selected solar photovoltaic based electricity generation technologies for sustainability evaluation are amorphous, mono crystalline and polycrystalline. For solar photovoltaic systems most of the emissions are the result of electricity use during manufacturing. In these cases, an average grid mix for the region of manufacture is typically used to calculate energy use and emissions. Based upon these three indicators, a figure of merit (FM) has been proposed. Further, based upon this figure of merit sustainability of solar photo voltaic based electricity generation technologies has been estimated.

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INTRODUCTION

Sustainable development is the development which meets the needs (energy, food etc.) of the present without compromising the ability of future generations to meet their own needs. Sustainable energy systems can be defined as those systems that can provide energy services to the present generation while ensuring that similar levels of energy services can be provided for future generations. The present fossil based electricity generation systems are not sustainable source of electricity generation (Ministry of New Renewable Energy, 2009). Due to limited fossil fuel resources, these systems will not be able to deliver electricity (at affordable rates) in future.

It is clear that present fossil fuel-driven energy systems are unsustainable in nature due to the finite fossil fuel reserves and the environmental impacts associated with these systems. It is therefore important to find a sustainable solution in the energy (electricity) sector and at the same time meet the increasing demand generated by the growing economy (Varun and Singal, 2007).

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Renewable energy sources like solar, biomass, small hydro etc. can contribute to build up a more sustainable energy system (Muneer *et al*., 2005).

Sustainability Indicators For Solar Photovoltaic Technologies

Sustainability evaluation for three different solar photovoltaic electricity generation systems based upon three different indicators has been carried out. These three indicators are electrical output, life cycle greenhouse gas (GHG) emissions and Life cycle cost of electricity generated per kWh. The SPV systems have a better results for GHG emissions has been studied by Sherwani and Usmani (Sherwani *et al*., 2010). The above said indicators are explained below.

Electrical output

Electrical output from the plant is calculated for all five different locations, ϕ=28º (New Delhi), 18 º(Mumbai), 12 º(Banglore), 34º(Ladhak)and 26 º(Jodhpur), four different Tilt angles β=15º, 25 º, 35 º and 45 º and for three different cells amorphous, mono crystalline and polycrystalline. Three different values of Hg i.e 4, 5 and 6kwh/m^2/day are considered. The efficiency of amorphous, mono crystalline and polycrystalline is taken as 0.07, 0.107, 0.137 respectively, with temperature correction factor (TCF) as 0.7 and inverter efficiency to be 0.9.

Green House Gas Emissions

Total life cycle GHG emissions (g-CO_{2eq}) have been generally estimated according to the full operational life cycle of each system from the commissioning of the plant to full operation of the system (cradle to grave) (Sherwani and Usmani, 2011). These emissions are found to vary widely within each technology. For the estimation of GHG emissions for the present study, life time of the projects is considered to be 30 years. Estimation of GHG emissions is given as:

$$GHG\ emissions = \frac{Total\ CO_2\ emissions\ throughout\ its\ life\ cycle\ (g - CO_{2eq})}{Annual\ power\ generation\ (kWh_e\ /\ year) \times lifetime\ (year)}$$

Life Cycle Cost of Electricity Generation

An average cost of production of electricity over the full life cycle of each generation technology accounts for construction, installation, operation, maintenance, decommissioning, and recycling / disposal. Wide-ranging values for the cost are seen for all the systems (Varun, Prakash *et al.*, 2009). PV system has the widest range of cost for electricity generation due to various type of solar cells, and location specific variations, i.e. solar radiation intensity and electricity cost to manufacture cells.

The cost of electricity generation has been reported in Rs/kWh_e. Estimation of cost of electricity generation is shown by equation

$$Cost\ of\ electricity\ generation = \frac{Annualised\ \exp enses\ of\ the\ system\ (Rs\ /\ year)}{Annual\ electricity\ generation\ by\ the\ system\ (kWh_e\ /\ year)}$$

Figure of Merit

Figure of Merit (FM) is used to compare the different systems based upon their performance (Varun, Prakash, 2010), net energy requirement or gross carbon emission from the systems. A FM for solar photovoltaic electricity generating systems has been proposed on the basis of different sustainability indicators on a single platform by giving them equal weight age.

The sustainability indicators are we have considered are Electrical output, GHG emissions and cost per unit electricity generated. Each technology has been ranked from 1-10 according to the corresponding indicators. The minimum value of a particular indicator is assigned to be a relative rank 1 while for maximum value it is assigned to be 10; accordingly the distribution has been done from 1-10. If the value of Electrical output is higher, the relative rank value is assigned to be higher and if GHG emissions and cost of electricity generation is lower, then their respective relative rank value is assigned to be higher. This was achieved with the input from various experts through idea experiencing workshop.

The equation is used to estimate FM and is given below.

$$FM = \mathrm{Re}lativerank_{electricaloutput} \times \mathrm{Re}lativerank_{GHG\,emisions} \times \mathrm{Re}lativerank_{Cost}$$

For calculating FM all the data for different technologies i.e. amorphous, mono crystalline and polycrystalline has been taken into account. Relative rank for different indicators is assigned for five different locations, ϕ=28°, 18°, 12°, 34°and 26°, at four different tilt angles β=15°, 25 °, 35° and 45°. For electrical output global radiation Hg is taken as 4, 5, 6 kWh/m^2/day. The average electricity generation efficiency is taken as 0.40 and corresponding to the electrical output a relative rank is assigned. GHG emissions in kg-CO_2/kWh_e is calculated for emissions of energy mix per kWh taken to be 600. Relative rank for life cycle cost of standalone system is assigned for one autonomy day (AD), battery life (BL) of six years and interest rate to be 5%.

Based upon the proposed figure of merit, three solar photovoltaic electricity generation systems (amorphous, mono crystalline and polycrystalline) have been analyzed for five different locations and four different tilt angles. The criteria for assigning the relative rank are given in Table 1.

Comparison

Based on the above discussion, a figure of merit has been estimated for one city each from different climatic zones in Indian perspective (New Delhi, Mumbai, Banglore, Ladhak and Jodhpur) (Sukhatme *et al.*, 1996).

Table 1. Criteria for Assigning the Relative Rank

S. No	Range of electrical output kWh_e	Relative rank electrical output	Range of GHG emissions	Relative rank GHG emissions	Range of Cost	Relative rank cost
1.	>2,25000	10	0-25	10	0-5	10
2.	2,00000-2,25000	9	25-50	9	5-7.5	9
3.	1,75000-2,00000	8	50-75	8	7.5-10	8
4.	1,50000-1,75000	7	75-100	7	10-12.5	7
5.	1,25000-1,50000	6	100-125	6	12.5-15	6
6.	1,00000-1,25000	5	125-150	5	15-17.5	5
7.	75000-100000	4	150-175	4	17.5-20	4
8.	50,000-75,000	3	175-200	3	20-25	3
9.	25,000-50,000	2	200-250	2	25-30	2
10.	0-25,000	1	>250	1	>30	1

Table 2. Estimated values of figure of merit

S.No.	Location	Tilt	Radiation	Cell	Elec. Output	Rel. Rank	Emission	GHG (Spav)	Rel. Rank	A.D	B.L	I.R (%)	Cost (Spav)	Rel. Rank	FOM
1	28	15	4	A	57979	3	600	0.1134	6	1	6	5	12.05	7	126
2	28	25	4	A	59686	3	600	0.1102	6	1	6	5	11.7	7	126
3	28	35	4	A	59990	3	600	0.1096	6	1	6	5	11.65	7	126
4	28	45	4	A	58882	3	600	0.1117	6	1	6	5	11.86	7	126
5	28	15	5	A	72955	3	600	0.0901	7	1	6	5	9.57	8	168
6	28	25	5	A	75337	4	600	0.0873	7	1	6	5	9.27	8	224
7	28	35	5	A	75876	4	600	0.0866	7	1	6	5	9.2	8	224
8	28	45	5	A	74617	3	600	0.0881	7	1	6	5	9.36	8	168
9	28	15	6	A	87932	4	600	0.0748	8	1	6	5	7.94	8	256
10	28	25	6	A	90988	4	600	0.0722	8	1	6	5	7.68	8	256
11	28	35	6	A	91802	4	600	0.0716	8	1	6	5	7.61	8	256
12	28	45	6	A	90351	4	600	0.0728	8	1	6	5	7.73	8	256
13	28	15	4	M	88625	4	600	0.1259	5	1	6	5	12.96	6	120
14	28	25	4	M	91235	4	600	0.1223	6	1	6	5	12.59	6	144
15	28	35	4	M	91700	4	600	0.1216	6	1	6	5	12.52	6	144
16	28	45	4	M	90006	4	600	0.1239	6	1	6	5	12.76	6	144
17	28	15	5	M	111518	5	600	0.1	7	1	6	5	10.3	7	245
18	28	25	5	M	115158	5	600	0.0969	7	1	6	5	9.97	8	280
19	28	35	5	M	116013	5	600	0.0961	7	1	6	5	9.9	8	280
20	28	45	5	M	114057	5	600	0.0978	7	1	6	5	10.07	7	245
21	28	15	6	M	134410	6	600	0.083	7	1	6	5	8.54	8	336
22	28	25	6	M	139082	6	600	0.0802	7	1	6	5	8.26	8	336
23	28	35	6	M	140327	6	600	0.0795	7	1	6	5	8.18	8	336
24	28	45	6	M	138109	6	600	0.0808	7	1	6	5	8.31	8	336
25	28	15	4	P	113473	5	600	0.1005	6	1	6	5	11.94	7	210
26	28	25	4	P	116815	5	600	0.0976	7	1	6	5	11.59	7	245
27	28	35	4	P	117410	5	600	0.0971	7	1	6	5	11.54	7	245
28	28	45	4	P	115242	5	600	0.0989	7	1	6	5	11.75	7	245
29	28	15	5	P	142785	6	600	0.0798	7	1	6	5	9.48	8	336
30	28	25	5	P	147446	6	600	0.0773	7	1	6	5	9.18	8	336
31	28	35	5	P	148541	6	600	0.0767	7	1	6	5	9.12	8	336
32	28	45	5	P	146036	6	600	0.0781	7	1	6	5	9.27	8	336
33	28	15	6	P	172096	7	600	0.0662	8	1	6	5	7.87	8	448
34	28	25	6	P	178077	7	600	0.064	8	1	6	5	7.6	8	448
35	28	35	6	P	179671	8	600	0.0634	8	1	6	5	7.54	8	512
36	28	45	6	P	176831	8	600	0.0645	8	1	6	5	7.66	8	512
37	18	15	4	A	55388	3	600	0.1153	6	1	6	5	11.53	7	126
38	18	25	4	A	55452	3	600	0.1152	6	1	6	5	11.52	7	126
39	18	35	4	A	54244	3	600	0.1178	6	1	6	5	11.77	7	126
40	18	45	4	A	51805	3	600	0.1233	6	1	6	5	12.33	7	126
41	18	15	5	A	69501	3	600	0.0919	7	1	6	5	9.19	8	168
42	18	25	5	A	69692	3	600	0.0917	7	1	6	5	9.16	8	168
43	18	35	5	A	68235	3	600	0.0936	7	1	6	5	9.36	8	168
44	18	45	5	A	65180	3	600	0.098	7	1	6	5	9.8	8	168
45	18	15	6	A	83614	4	600	0.0764	7	1	6	5	7.64	8	224
46	18	25	6	A	83931	4	600	0.0761	7	1	6	5	7.61	8	224
47	18	35	6	A	82225	4	600	0.0777	7	1	6	5	7.77	8	224
48	18	45	6	A	78555	4	600	0.0813	7	1	6	5	8.13	8	224
49	18	15	4	M	84665	4	600	0.1249	6	1	6	5	12.4	7	168
50	18	25	4	M	84763	4	600	0.1248	6	1	6	5	12.38	7	168
51	18	35	4	M	82916	4	600	0.1275	5	1	6	5	12.66	6	120
52	18	45	4	M	79187	4	600	0.1335	5	1	6	5	13.26	6	120
53	18	15	5	M	104613	5	600	0.1011	6	1	6	5	10.03	7	210
54	18	25	5	M	104228	5	600	0.1014	6	1	6	5	10.07	7	210
55	18	35	5	M	101676	5	600	0.104	6	1	6	5	10.32	7	210
56	18	45	5	M	97040	4	600	0.109	6	1	6	5	10.82	7	168
57	18	15	6	M	127811	6	600	0.0827	7	1	6	5	8.21	8	336
58	18	25	6	M	128295	6	600	0.0824	7	1	6	5	8.18	8	336
59	18	35	6	M	125687	6	600	0.0841	7	1	6	5	8.35	8	336
60	18	45	6	M	120077	5	600	0.0881	7	1	6	5	8.74	8	280
61	18	15	4	P	108403	5	600	0.0996	7	1	6	5	11.42	7	245
62	18	25	4	P	108528	5	600	0.0995	7	1	6	5	11.41	7	245
63	18	35	4	P	106164	5	600	0.1017	6	1	6	5	11.66	7	210
64	18	45	4	P	101390	5	600	0.1065	6	1	6	5	12.21	7	210
65	18	15	5	P	133943	6	600	0.0806	7	1	6	5	9.24	8	336
66	18	25	5	P	133451	6	600	0.0809	7	1	6	5	9.28	8	336
67	18	35	5	P	130183	6	600	0.083	7	1	6	5	9.51	8	336
68	18	45	5	P	124248	5	600	0.0869	7	1	6	5	9.97	8	280
69	18	15	6	P	163646	7	600	0.066	8	1	6	5	7.56	8	448
70	18	25	6	P	164266	7	600	0.0657	8	1	6	5	7.54	8	448
71	18	35	6	P	160927	7	600	0.0671	8	1	6	5	7.69	8	448
72	18	45	6	P	153744	7	600	0.0702	8	1	6	5	8.05	8	448
73	12	15	4	A	54043	3	600	0.1171	6	1	6	5	11.46	7	126
74	12	25	4	A	53257	3	600	0.1188	6	1	6	5	11.63	7	126
75	12	35	4	A	51269	3	600	0.1234	6	1	6	5	12.08	7	126

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76	12	45	4	A	48150	2	600	0.1314	5	1	6	5	12.86	6	60
77	12	15	5	A	67707	3	600	0.0934	7	1	6	5	9.14	8	168
78	12	25	5	A	66764	3	600	0.0948	7	1	6	5	9.27	8	168
79	12	35	5	A	64269	3	600	0.0984	7	1	6	5	9.63	8	168
80	12	45	5	A	60307	3	600	0.1049	6	1	6	5	10.27	7	126
81	12	15	6	A	81372	4	600	0.0777	7	1	6	5	7.61	8	224
82	12	25	6	A	80272	4	600	0.0788	7	1	6	5	7.71	8	224
83	12	35	6	A	77268	4	600	0.0819	7	1	6	5	8.01	8	224
84	12	45	6	A	72464	3	600	0.0873	7	1	6	5	8.54	8	168
85	12	15	4	M	82608	4	600	0.1257	5	1	6	5	12.32	7	140
86	12	25	4	M	81407	4	600	0.1276	5	1	6	5	12.5	7	140
87	12	35	4	M	78369	4	600	0.1325	5	1	6	5	12.99	6	120
88	12	45	4	M	73602	3	600	0.1411	5	1	6	5	13.83	6	90
89	12	15	5	M	103496	5	600	0.1003	6	1	6	5	9.83	8	240
90	12	25	5	M	102054	5	600	0.1018	6	1	6	5	9.97	8	240
91	12	35	5	M	98239	4	600	0.1057	6	1	6	5	10.36	7	168
92	12	45	5	M	92184	4	600	0.1127	6	1	6	5	11.04	7	168
93	12	15	6	M	124383	5	600	0.0835	7	1	6	5	8.18	8	280
94	12	25	6	M	122702	5	600	0.0846	7	1	6	5	8.29	8	280
95	12	35	6	M	118109	5	600	0.0879	7	1	6	5	8.62	8	280
96	12	45	6	M	110767	5	600	0.0938	7	1	6	5	9.19	8	280
97	12	15	4	P	105770	5	600	0.1003	6	1	6	5	11.35	7	210
98	12	25	4	P	104231	5	600	0.1017	6	1	6	5	11.52	7	210
99	12	35	4	P	100342	5	600	0.1057	6	1	6	5	11.96	7	210
100	12	45	4	P	94238	4	600	0.1125	6	1	6	5	12.74	6	144
101	12	15	5	P	132513	6	600	.08	7	1	6	5	9.06	8	336
102	12	25	5	P	130668	6	600	0.0812	7	1	6	5	9.19	8	336
103	12	35	5	P	125783	6	600	0.0843	7	1	6	5	9.54	8	336
104	12	45	5	P	118031	5	600	0.0898	7	1	6	5	10.17	7	245
105	12	15	6	P	159257	7	600	0.0666	8	1	6	5	7.54	8	448
106	12	25	6	P	157104	7	600	0.0675	8	1	6	5	7.64	8	448
107	12	35	6	P	151224	7	600	0.0701	8	1	6	5	7.94	8	448
108	12	45	6	P	141824	6	600	0.0748	8	1	6	5	8.46	8	384
109	34	15	4	A	58767	3	600	0.1131	6	1	6	5	12.26	7	126
110	34	25	4	A	60976	3	600	0.109	6	1	6	5	11.82	7	126
111	34	35	4	A	61742	3	600	0.1076	6	1	6	5	11.67	7	126
112	34	45	4	A	61043	3	600	0.1088	6	1	6	5	11.81	7	126
113	34	15	5	A	74006	3	600	0.0898	7	1	6	5	9.74	8	168
114	34	25	5	A	77056	4	600	0.0862	7	1	6	5	9.35	8	224
115	34	35	5	A	78233	4	600	0.0849	7	1	6	5	9.21	8	224
116	34	45	5	A	77498	4	600	0.0857	7	1	6	5	9.3	8	224
117	34	15	6	A	89246	4	600	0.0744	8	1	6	5	8.07	8	256
118	34	25	6	A	93137	4	600	0.0713	8	1	6	5	7.74	8	256
119	34	35	6	A	94723	4	600	0.0701	8	1	6	5	7.61	8	256
120	34	45	6	A	93953	4	600	0.0707	8	1	6	5	7.67	8	256
121	34	15	4	M	89830	4	600	0.1266	5	1	6	5	13.19	6	120
122	34	25	4	M	93206	4	600	0.122	6	1	6	5	12.71	6	144
123	34	35	4	M	94378	4	600	0.1205	6	1	6	5	12.55	6	144
124	34	45	4	M	93309	4	600	0.1218	6	1	6	5	12.7	6	144
125	34	15	5	M	113124	5	600	0.1005	6	1	6	5	10.47	7	210
126	34	25	5	M	117786	5	600	0.0965	7	1	6	5	10.06	7	245
127	34	35	5	M	119584	5	600	0.0951	7	1	6	5	9.91	8	280
128	34	45	5	M	118462	5	600	0.096	7	1	6	5	10	8	280
129	34	15	6	M	136419	6	600	0.0833	7	1	6	5	8.68	8	336
130	34	25	6	M	142367	6	600	0.0798	7	1	6	5	8.32	8	336
131	34	35	6	M	144791	6	600	0.0785	7	1	6	5	8.18	8	336
132	34	45	6	M	143614	6	600	0.0791	7	1	6	5	8.25	8	336
133	34	15	4	P	115016	5	600	0.1011	6	1	6	5	12.15	7	210
134	34	25	4	P	119339	5	600	0.0974	7	1	6	5	11.71	7	245
135	34	35	4	P	120839	5	600	0.0962	7	1	6	5	11.56	7	245
136	34	45	4	P	119471	5	600	0.0973	7	1	6	5	11.7	7	245
137	34	15	5	P	144841	6	600	0.0802	7	1	6	5	9.65	8	336
138	34	25	5	P	150811	7	600	0.0771	7	1	6	5	9.27	8	392
139	34	35	5	P	153113	7	600	0.0759	7	1	6	5	9.13	8	392
140	34	45	5	P	151675	7	600	0.0766	7	1	6	5	9.21	8	392
141	34	15	6	P	174667	7	600	0.0665	8	1	6	5	8	8	448
142	34	25	6	P	182283	8	600	0.0638	8	1	6	5	7.66	8	512
143	34	35	6	P	185386	8	600	0.0627	8	1	6	5	7.54	8	512
144	34	45	6	P	183880	8	600	0.0632	8	1	6	5	7.6	8	512
145	26	15	4	A	57412	3	600	0.1516	4	1	6	5	11.85	7	84
146	26	25	4	A	58758	3	600	0.1481	5	1	6	5	11.58	7	105
147	26	35	4	A	58730	3	600	0.1482	5	1	6	5	11.59	7	105
148	26	45	4	A	57329	3	600	0.1518	4	1	6	5	11.87	7	84
149	26	15	5	A	72199	3	600	0.1206	6	1	6	5	9.42	8	144
150	26	25	5	A	74100	3	600	0.1175	6	1	6	5	9.18	8	144

Continue……….

151	26	35	5	A	74216	3	600	0.1173	6	1	6	5	9.17	8	144
152	26	45	5	A	72546	3	600	0.12	6	1	6	5	9.38	8	144
153	26	15	6	A	86987	4	600	0.1001	6	1	6	5	7.82	8	192
154	26	25	6	A	89442	4	600	0.0973	7	1	6	5	7.61	8	224
155	26	35	6	A	89702	4	600	0.097	7	1	6	5	7.58	8	224
156	26	45	6	A	87762	4	600	0.0992	7	1	6	5	7.75	8	224
157	26	15	4	M	87758	4	600	0.1253	5	1	6	5	12.79	6	120
158	26	25	4	M	89817	4	600	0.1225	6	1	6	5	12.49	7	168
158	26	35	4	M	89774	4	600	0.1225	6	1	6	5	12.5	6	144
160	26	45	4	M	87632	4	600	0.1255	5	1	6	5	12.8	6	120
161	26	15	5	M	110362	5	600	0.0997	7	1	6	5	10.17	7	245
162	26	25	5	M	113267	5	600	0.0971	7	1	6	5	9.91	8	280
163	26	35	5	M	113445	5	600	0.097	7	1	6	5	9.89	8	280
164	26	45	5	M	110892	5	600	0.0992	7	1	6	5	10.12	7	245
165	26	15	6	M	132965	6	600	0.0827	7	1	6	5	8.44	8	336
166	26	25	6	M	136718	6	600	0.0804	7	1	6	5	8.21	8	336
167	26	35	6	M	137117	6	600	0.0802	7	1	6	5	8.18	8	336
168	26	45	6	M	134151	6	600	0.082	7	1	6	5	8.36	8	336
169	26	15	4	P	112363	5	600	0.1	7	1	6	5	11.78	7	245
170	26	25	4	P	114999	5	600	0.0978	7	1	6	5	11.51	7	245
171	26	35	4	P	114944	5	600	0.0978	7	1	6	5	11.51	7	245
172	26	45	4	P	112202	5	600	0.1002	6	1	6	5	11.8	7	210
173	26	15	5	P	131304	6	600	0.0795	7	1	6	5	9.37	8	336
174	26	25	5	P	145025	6	600	0.0775	7	1	6	5	9.12	8	336
175	26	35	5	P	145253	6	600	0.0774	7	1	6	5	9.11	8	336
176	26	45	5	P	141983	6	600	0.0792	7	1	6	5	9.32	8	336
177	26	15	6	P	170246	6	600	0.066	8	1	6	5	7.77	8	384
178	26	25	6	P	175051	7	600	0.0642	8	1	6	5	7.56	8	448
179	26	35	6	P	175561	7	600	0.064	8	1	6	5	7.54	8	448
180	26	45	6	P	171764	7	600	0.0654	8	1	6	5	7.7	8	448

Table 3. Range of figure of merit for a radiation level 4-6 kWh/m^2/day

S. No.	Location	Cell type	Figure of merit
1	Delhi (ϕ=28^0)	Amorphous	126-256
		Monocrystalline	120-336
		Polycrystalline	210-512
2	Mumbai (ϕ=18^0)	Amorphous	126-224
		Monocrystalline	120-336
		Polycrystalline	210-448
3	Bangalore (ϕ=12^0)	Amorphous	60-224
		Monocrystalline	90-280
		Polycrystalline	144-448
4	Ladhakh (ϕ=34^0)	Amorphous	126-256
		Monocrystalline	120-336
		Polycrystalline	210-512
5	Jodhpur (ϕ=26^0)	Amorphous	84-224
		Monocrystalline	120-336
		Polycrystalline	210-448

From the above estimation, the range of values for figure of merit for different location is summarised and illustrated in Table 3.

For Delhi (ϕ=28^0), Amorphous with radiation level in the range of 4-6 kWh/m^2/day the figure of merit varies from 126-256. For monocrystalline cell the figure of merit varies from 120-336 and for polycrystalline it very from 210-512.

For Mumbai (ϕ=18^0), Amorphous with radiation level in the range of 4-6 kWh/ m^2/day the figure of merit varies from 126-224. For monocrystalline cell the figure of merit varies from 120-336 and for polycrystalline it very from 210-448.

For Bangalore (ϕ=12^0), Amorphous with radiation level in the range of 4-6 kWh/m^2/day the figure of merit varies from 60-224. For monocrystalline cell the figure of merit varies from 90-280 and for polycrystalline it very from 144-448.

For Ladhakh (ϕ=34^0), Amorphous with radiation level in the range of 4-6 kWh/ m^2 / day the figure of merit varies from 126-256. For monocrystalline cell the figure of merit varies from 120-336 and for polycrystalline it very from 210-512.

For Jodhpur (ϕ=26^0), Amorphous with radiation level in the range of 4-6 kWh/ m^2 / day the figure of merit varies from 84-224. For monocrystalline cell the figure of merit varies from 120-336 and for polycrystalline it very from 210-448.

Table 3 shows the estimated values of FM. For every location a figure of merit is defined corresponding to four different tilt angles, three different radiations and all the three technologies namely amorphous , mono crystalline and poly crystalline are considered. GHG emissions. GHG emission is not the only environmental parameter to be considered; there could be many more parameters e.g. land use may also be included for more exhaustive evaluation of figure of merit. However, GHG emissions were chosen because of the very serious problem of global warming. With the invention of new technologies and mass production, the cost of generation and GHG emissions are likely to go down and electrical output is going up. We can therefore expect an improvement in the figure of merit in future.

Conclusion

A higher value of figure of merit represents a better solar photovoltaic electricity generation system, and vice versa. This FM for better solar photovoltaic electricity generation system can provide a more rational choice of electricity generation sources for energy planners, compared to the case where only one of the sustainability parameters is considered.

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