Supplementary materials

Multiple Criteria Decision Making (MCDM) based Economic analysis of Solar PV System with respect to Performance investigation for Indian Market

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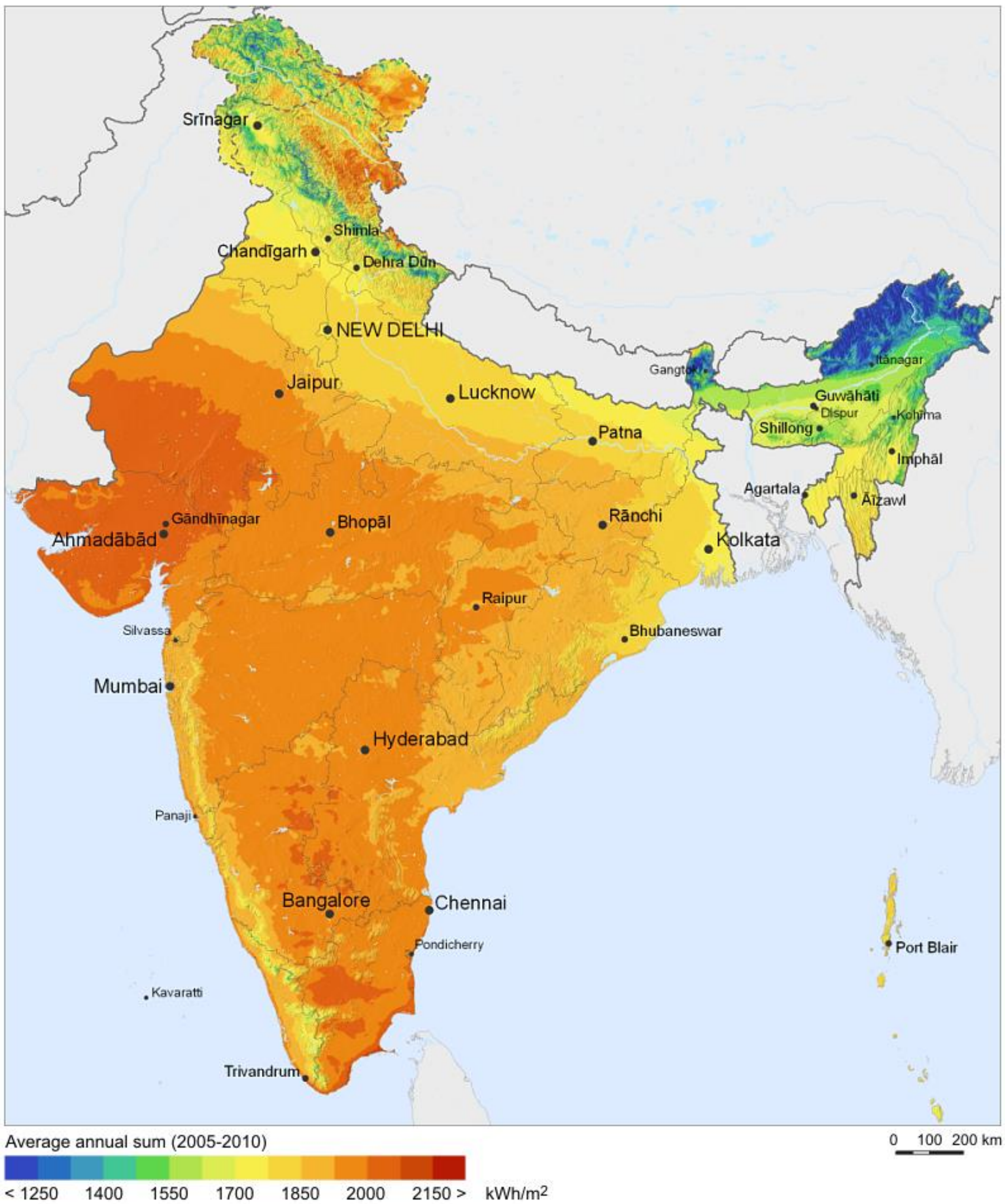

Figure S1. Illustration of Global Horizontal Solar Irradiance in India [42].

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Table S1. State wise installed solar power capacity and proposed capacity in 2022 [42].

S. No	State	Installed capacity MW as of 31 March 2016	Installed capacity MW as of 30 September 2016	Capacity Installed in 2016-17 till 31 December 2016 (MW)	Cumulative Capacity till 31 December 2016 (MW)	State Wise Target by 2022 (MW)	Yet to Achieve (MW)
1	Andaman & Nicobar	5.1	5.1	0.3	5.4	27	21.6
2	Andhra Pradesh	572.97	947.05	406.68	979.65	9834	8854.35
3	Arunachal Pradesh	0.27	0.27	0	0.27	39	38.73
4	Assam	0	0	11.18	11.18	663	651.82
5	Bihar	5.1	90.1	90.81	95.91	2493	2397.09
6	Chandigarh	6.81	6.81	9.4	16.2	153	136.8
7	Chhattisgarh	93.58	128.46	41.61	135.19	1783	1647.81
8	D.and N.Haveli	0	0	0.6	0.6	449	448.4
9	Daman & Diu	4	4	0	4	199	195
10	Delhi	14.28	23.87	24.5	38.78	2762	2723.22
11	Goa	0	0	0.05	0.05	358	357.95
12	Gujarat	1119.17	1136.32	39.32	1158.5	8020	6861.5
13	Haryana	15.39	15.39	37.88	53.27	4142	4088.73
14	Himachal Pradesh	0.2	0.2	0.13	0.33	776	775.67
15	Jammu and Kashmir	1	1	0	1	1155	1154
16	Jharkhand	16.19	16.19	1.33	17.51	1995	1977.49
17	Karnataka	145.46	289.13	182.06	327.53	5697	5369.47
18	Kerala	13.05	13.05	2.81	15.86	1870	1854.14
19	Lakshadweep	0.75	0.75	0	0.75	4	3.25
20	Madhya Pradesh	776.37	810.37	63.98	840.35	5675	4834.65
21	Maharashtra	385.76	385.76	44.7	430.46	11926	11495.54
22	Manipur	0	0	0.01	0.01	105	104.99
23	Meghalaya	0	0	0.01	0.01	161	160.99
24	Mizoram	0.1	0.1	0	0.1	72	71.9
25	Nagaland	0	0	0.5	0.5	61	60.5
26	Odisha	66.92	66.92	10.72	77.64	2377	2299.36
27	Puducherry	0.03	0.03	0	0.03	246	245.97
28	Punjab	405.06	571.2	140.37	545.43	4772	4226.57
29	Rajasthan	1269.93	1294.6	47.71	1317.64	5762	4444.36
30	Sikkim	0	0	0.01	0.01	36	35.99
31	Tamil Nadu	1061.82	1555.41	529.15	1590.97	8884	7293.03
32	Telangana	527.84	961.79	445.57	973.41		-973.41
33	Tripura	5	5	0.02	5.02	105	99.98
34	Uttar Pradesh	143.5	143.5	95.76	239.26	10697	10457.74
35	Uttarakhand	41.15	41.15	3.95	45.1	900	854.9
36	West Bengal	7.77	11.77	15.3	23.07	5336	5312.93
37	Others	58.31	100.92	3.39	61.7	0	
Total Capacity (MW)		**6762.88**	**8626.21**	**2249.81**	**9012.69**	**99534**	**90583.01**

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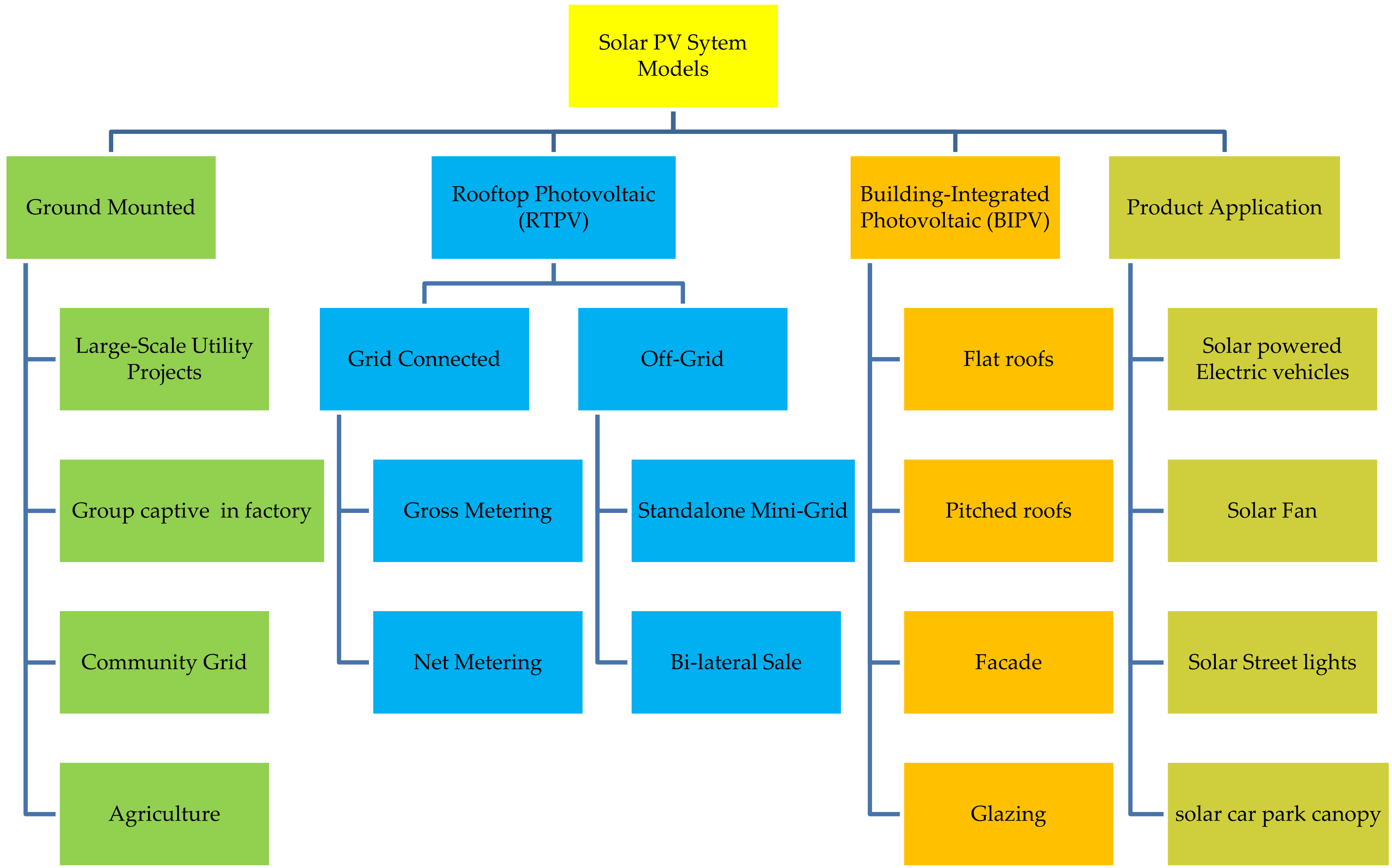

Figure S2. Classification of various Solar (PV) system models.

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Table S2. Classification of various Solar PV system models and its suitability

Ground Mounted Solar PV system	Utility Scale, Community Grid, Mini Grid, Agriculture pumps, Group Captive, etc.
Rooftop Solar PV systems	Residential, Commercial, Industrial, Factory, Apartments, Institution, Hospitals, Toll Plaza, etc.
Off Grid Solar PV systems	Unavailable power region, Severe power failure region, Street Lights, Rural Hunt, etc.
Building-Integrated Solar PV system	Malls, Apartments, Hi-Tech Buildings, etc.
Product Application	Electrical appliances, Battery charging of electric vehicles, solar car park canopy, etc.

1. Special Purpose Vehicle (SPV)

SPV is a fundamental unit of individual legal entity that consists of a small portion of equity holders and debt holders. The purpose of SPV is to execute projects. The SPV is normally applied by companies to separate the firm from financial risks. The debt raised for the project company will be non-recourse or limited recourse debt, i.e. if the project goes awful, then the money owing owners cannot allege from the parent company. This would function in parallel like commercial organisations, while utilizing a range of promotional methods of Ministry of New and Renewable Energy (MNRE) and State Governments for the purpose. SPV is incorporated to lift funds from different set of investors, with the objective to invest in large scale grid connected power generation projects as well as to set up off-grid solar projects using sophisticated equipment and market-based business solutions for promoting access to energy deficient population.

The solar PV projects are always ring-fenced in SPVs of project-specific self-financing companies who possess tight project governance as shown in the figure S3. Vendors, financiers, EPC contractors and even the governments are minority equity shareholders who may round off the SPV's equity part. The objective is to minimize the agency conflicts and tough bargaining (for example, refusing to offtake, or supply critical inputs) in the context of highly specific assets and strong dependencies. In a group captive scheme, one develops a solar power plant from which the electrical energy is consumed by many commercial users. In this scheme, the equity percentage would be 26% for the developer who is entitled to consume at least 51% of the power generated. In the year 1995, the term 'captive power scheme' was introduced in electric rule. The key contract in a Solar Power SPV is a formal structure of contract that has all the parties interacting with the SPV. PPA (Power Purchase Agreement) remains the first along with the off-taker (either a utility or a corporate entity via an open access agreement). This could include evacuation arrangements (For example, transmission interconnection); and the Central Electricity Regulatory Commission (CERC) or State Electricity Regulation Commission (SERC) may require operational schedules and forecasts by individual farm operator. There could be "take-or-pay" clauses that ensure that the project gets paid for production up to some levels.

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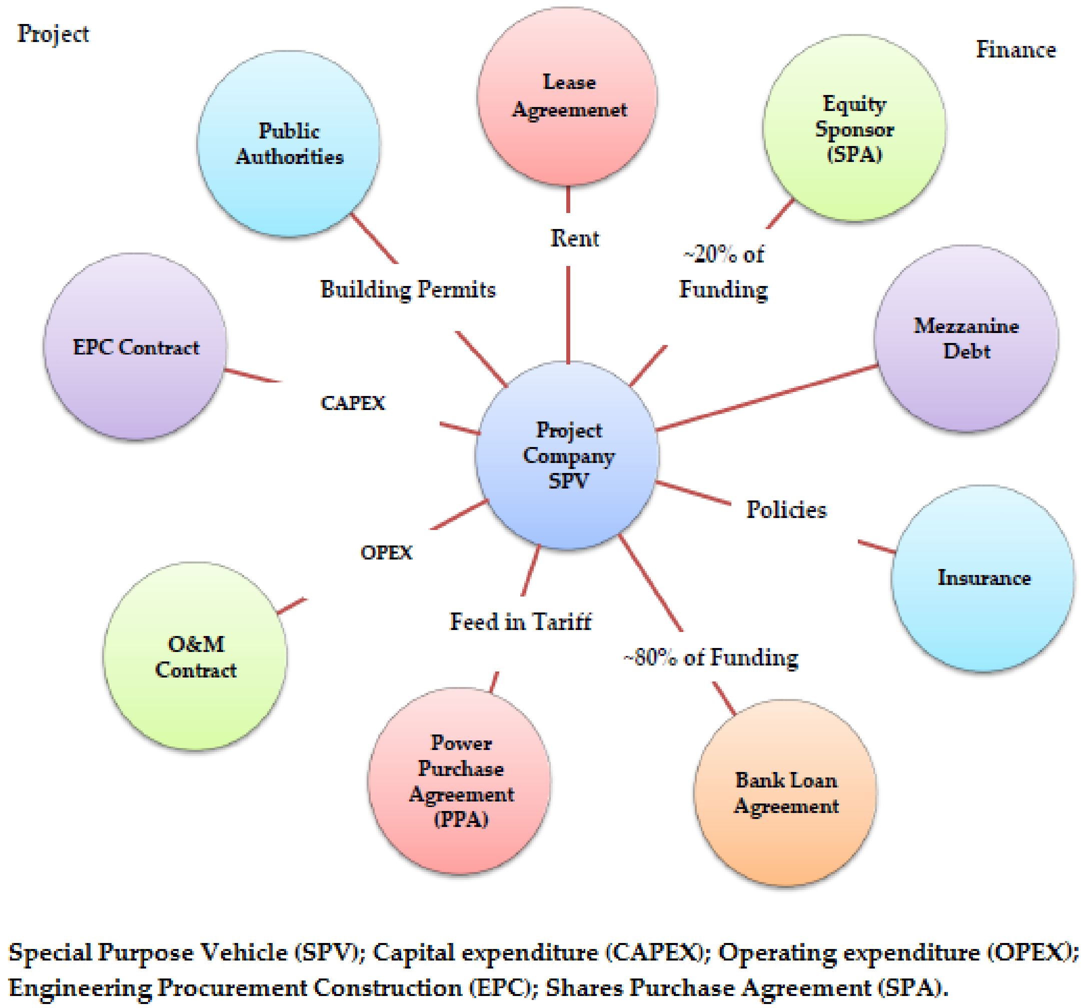

Figure S3. Special Purpose Vehicle (SPV)

2. Cost and performance study of Solar PV system

The cost for installing a solar PV system (inclusive of its components, exclusive of the land or area acquired for installing the facility) in western countries has dipped to INR (102.89-240.08) per W_P. The installed costs are marginally low in developing economies like India and in terms of utility-scale installation it is on higher ends due to distributed or retail installations. Interestingly, Germany, Australia and other such high labor cost economies had installed solar PV systems at the cost of INR 137.20 INR/W_P i.e., INR 548799.60 for per 4kW_P system to be installed. As per the CERC survey (2016), the installation costs in India seems to be the lowest i.e., INR 52.14-54.88 /W_P at utility scale. The solar module costs, at utility scale, observed to be 50-65% of the total costs in India, while it was only 25-30% in the US (CERC Survey, 2016). If a unit of energy is being generated at a retail location, it has the potential to equalize the same unit of energy which needs to be generated at a distant place and to be transported to the point-of-use. To be simple, a utility-scale solar plant need to generate the solar energy in wholesale level and wholesale price whereas for a home-scale solar plant, the price and the level need to be only a 'retail' in

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spite of using the same solar panel at both places. So, if a manufacturer is able to ensure the installed cost of retail solar PV is affordable as aligned with the installed cost of utility scale, there are opportunities for more value addition in the solar energy markets with the entry of new players.

In India, the EPC costs is (INR 42.65367 to INR 53.4769)/W_P utility scale or large commercial, which is the lowest across the globe. The presence of excellent, low cost labor is one of the prime advantages. Further many attributes such as technological advancements, favorable incentives by the government for green electricity, drop in PV module prices and so on positively impact the EPC costs. Solar PV technology remains the most incredible technology due to a number of factors and one of which is, it can be set up at any range from as low as 100-200 W_P solar PV plant for home or businesses and off-grid locations applications. The utility scale i.e., MW_P and GW_P has a major role and the intermediate scale has equal role based on the viability, requirement and feasibility.

If the annual operating expenses are 2% of Capital Expenditure (CAPEX), the Operating Expenses (OPEX) value would be INR 960/kW_P/year (wholesale) and INR 1500/kWp/year (retail) on the basis of an assumption that INR 75,000 average CAPEX for businesses). When subtracting this from the annual revenue yield, we can obtain EBITDA (Earnings Before Interest, Tax, Depreciation, Amortization) of INR 8165/kW_P/year (wholesale) and INR 11275 / kW_P/year (retail or rooftop). When EBITDA is divided by CAPEX in order to get annual earnings yield, we get (8165/48000=) 17% wholesale and (11275 / 70000) =16% (for a 50 kW_P scale system) and or (11275 / 100,000) = 11.275% (for a 1-5 kWp system). The earnings yield on invested capital (before depreciation or subsidies and financing) therefore rises from 11% small-scale retail to 16% medium scale rooftop to 17% utility scale.

If a residential investor deposits the capital amount in banks, the investor would receive 7.0-8.5% as interest for 5 years in almost all Indian banks. If the entire solar PV system is funded by the individual with 100% equity financing and on account of high productions above than PPA numbers and if PPA counterparty (i.e. the DISCOM) pays on time with good maintenance, the investor can expect a return of 11-17%. The system performance steadily decreases by 0.5% per year over 20-25 years. In case, if an IRR is computed, then it would be 10-16% over a period of 25-30 years (i.e. project-IRR or equity-IRR). This IRR is a function of number of years i.e., if it is few years, then low IRR will be there. Some of these numbers change if we assume an aggressive escalator for OPEX and higher module degradation parameters etc.

This can infer that the economics are just about breakeven (3% spread for retail and 1% spread for large-scale) when 10-16% IRR with 7-8.5% opportunity cost (i.e. Fixed Deposit- FD) rate for retail households) and 15% equity cost of capital for large-scale systems are compared. The small-scale solar projects show less returns and IRR though the EBITDA and revenue yield is higher because the system cost is double the time of utility scale and 33-50% of the medium-scale rooftop sector. But, since their opportunity costs (eg: FD rates) are lesser, it is still a modest deal (positive economic value).

Grid parity is normally used to compare the solar energy into electricity with grid power produced by non-renewable sources. To decide whether Solar PV energy is at grid parity or not is more complex than it is to be done for other sources. PV can scale successfully to systems as small as single panel or as numerous as millions of panel quantity interconnections. In case of small systems, they can be installed at the customer's location. In this case in India, the LCOE cannot conclude and compete against the retail/domestic price of grid power. In fact from the study [S1], residential grid-connected PV systems, based on the evidences suggest that the tariff rates of many states when compared for solar energy, it has

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already reached grid parity, but for those whose consumption is up to 200 units (kWh)/month have not yet reached the grid parity.

Battery storage for off grid system is mandatory for the frequent power cut regions and un-electrified areas. Cost of storage system varies depending upon the system size and configuration. In figure S4, Grid tied and Off Grid PV system cost is compared for different power scale (1 kW, 2 kW, 3 kW, 5 kW and 10 kW) considering available configuration in the market.

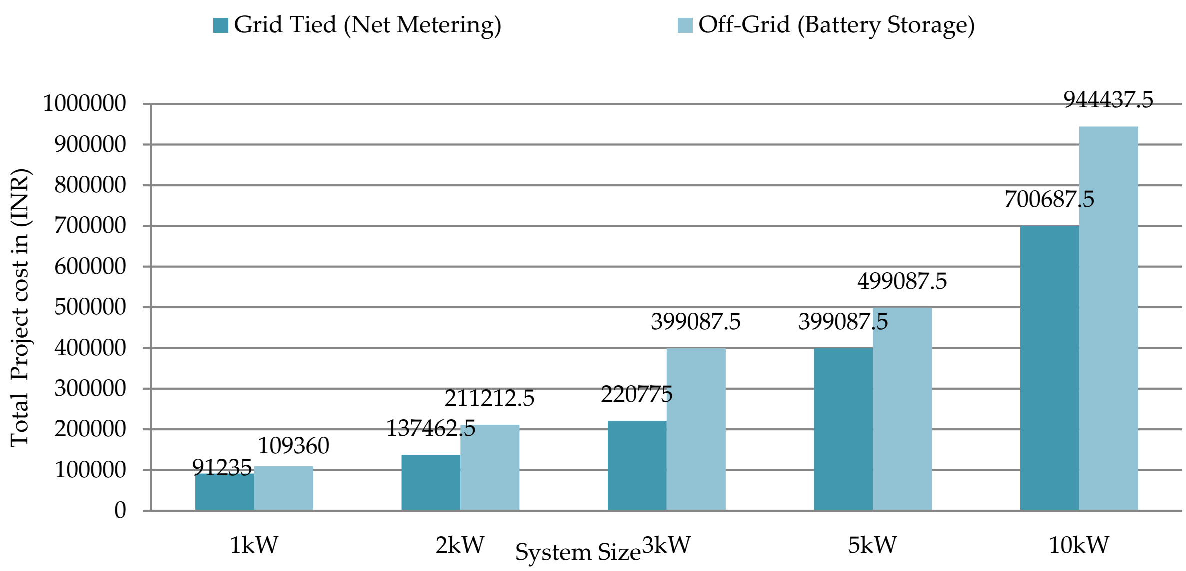

Figure S4. Cost comparison between and grid tied and off grid system

Performance analysis of Solar PV systems covers the impact of several factors such as ambient temperature, module temperature, wind speed, irradiance, dust, partial shadow, module (Poly crystalline, Mono crystalline c-Si, poly-Si, Thin film, CdTe, CIS) efficiency, power conditioning unit (Grid Tied & Off Grid) efficiency, inverter (Central, String, & Micro inverter) efficiency and energy losses, system configuration, system size, installed types (Ground Mounted, Rooftop, Building-Integrated), with or without tracking system and wiring pattern on plant performance. K. Padmavathi et.al (2013) investigated the efficiency of solar PV panel, inverter and overall system efficiency of grid tied solar PV system in India [S2]. The results showed the actual performance and efficiency of the solar system.

In figure S5, solar energy generated (kWh/MW) per month from both Crystalline and Thin Film technologies is presented for the year 2015 using data collected from the Ministry of New and Renewable Energy (MNRE). The monthly Capacity Utilisation Factor (CUF) (%) for each technology is represented in figure S6. The average energy generation for both technologies is nearly the same. Figure S7 compares the month wise energy yield of a 1 kW Grid Tied and Off Grid system. Figure S8 discusses the units (kWh)/day generated by 1 kW, 2 kW, 3 kW, 5 kW and 10 kW Grid Tied and Off Grid systems.

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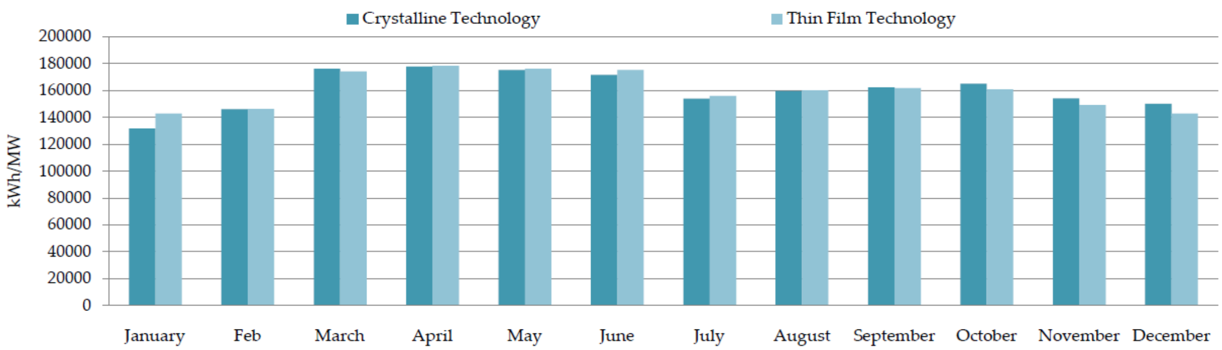

Figure S5. Electrical energy generated (kWh/MW) using solar PV for both Crystalline and Thin Film technologies [S3].

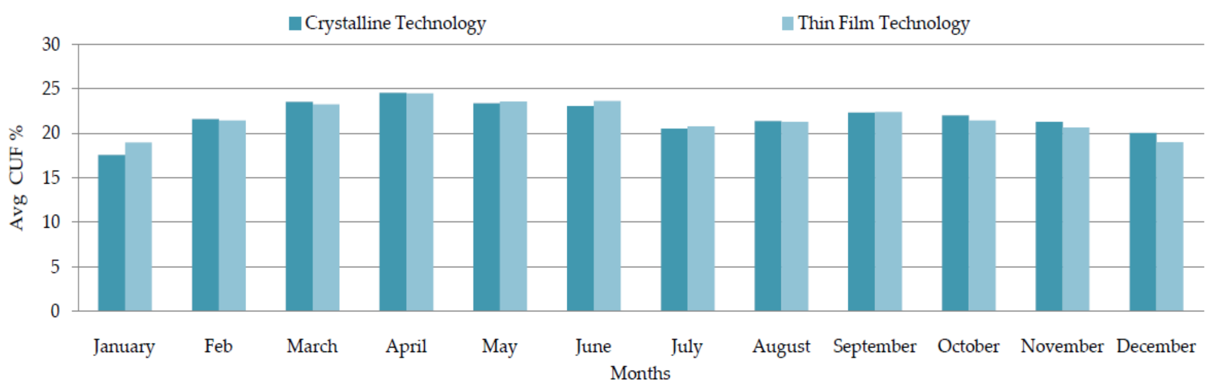

Figure S6. CUF in (%) for each technology [68].

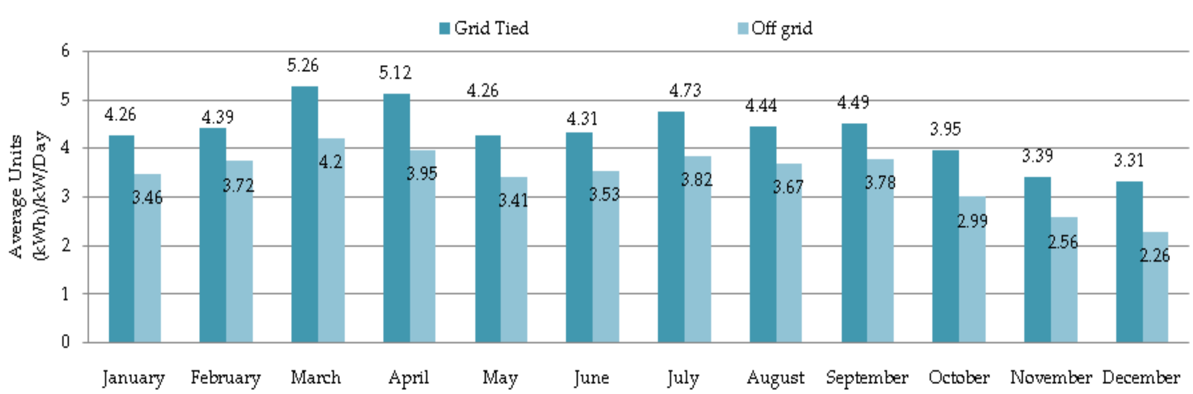

Figure S7. Comparison of Energy yield from 1 kW Grid Tied and Off Grid system.

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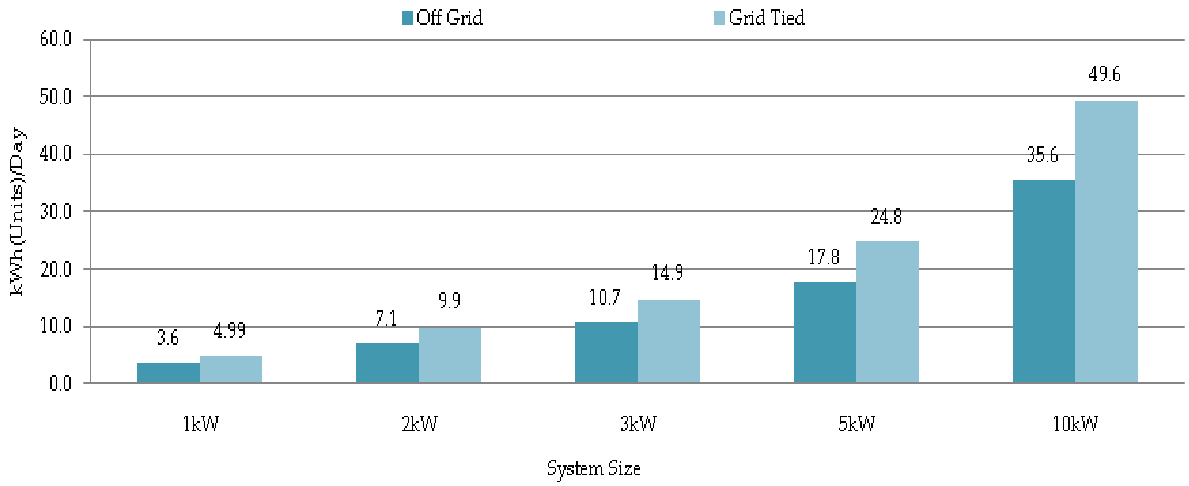

Figure S8. Comparison of Energy yield from Grid Tied and Off Grid system of various system sizes.

Figure S9 and figure S10 exemplifies the comparison between Solar Tariff and CERC Tariff with respect to major power consumers for the next 25 years with both LT and HT connections respectively.

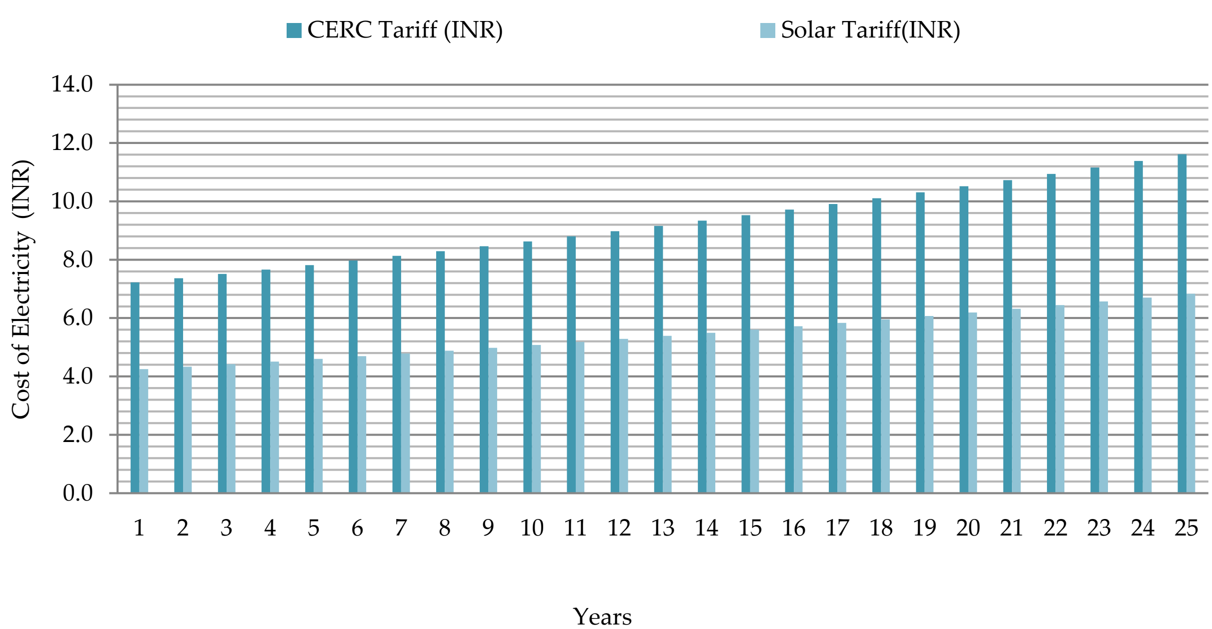

Figure S9. Comparison of Solar Tariff and CERC Tariff considering major power consumers in LT.

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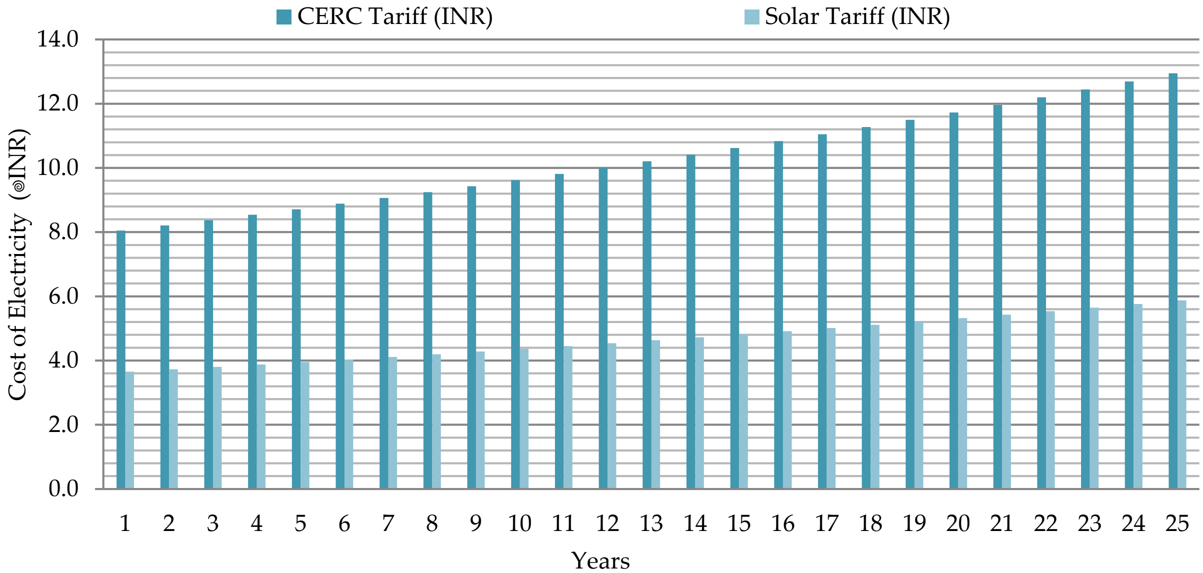

Figure S10. Comparison of Solar Tariff and CERC Tariff considering major power consumers in HT.

Figure S11 illustrates the Payback cost comparisons between Grid Tied and Off Grid Solar Power Plant for 1 kW, 3 kW, 5 kW and 10 kW.

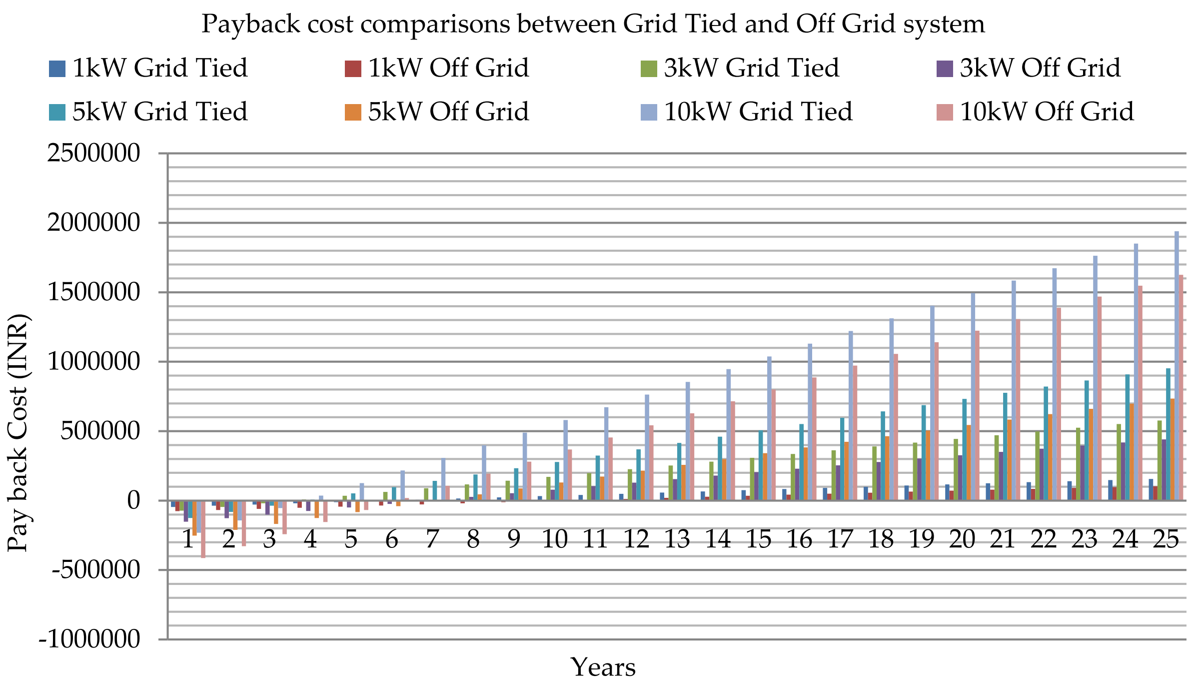

Figure S11. Payback cost comparisons between Grid Tied and Off Grid system.

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Figure S12 compares payback cost of central inverter and string inverter used in solar power plants for 10 kW, 50 kW and 100 kW. Central inverter configuration uses single inverter for the entire solar panel whereas the string inverter configuration has connections decentralized in each sequence of solar panel used in solar power plant.

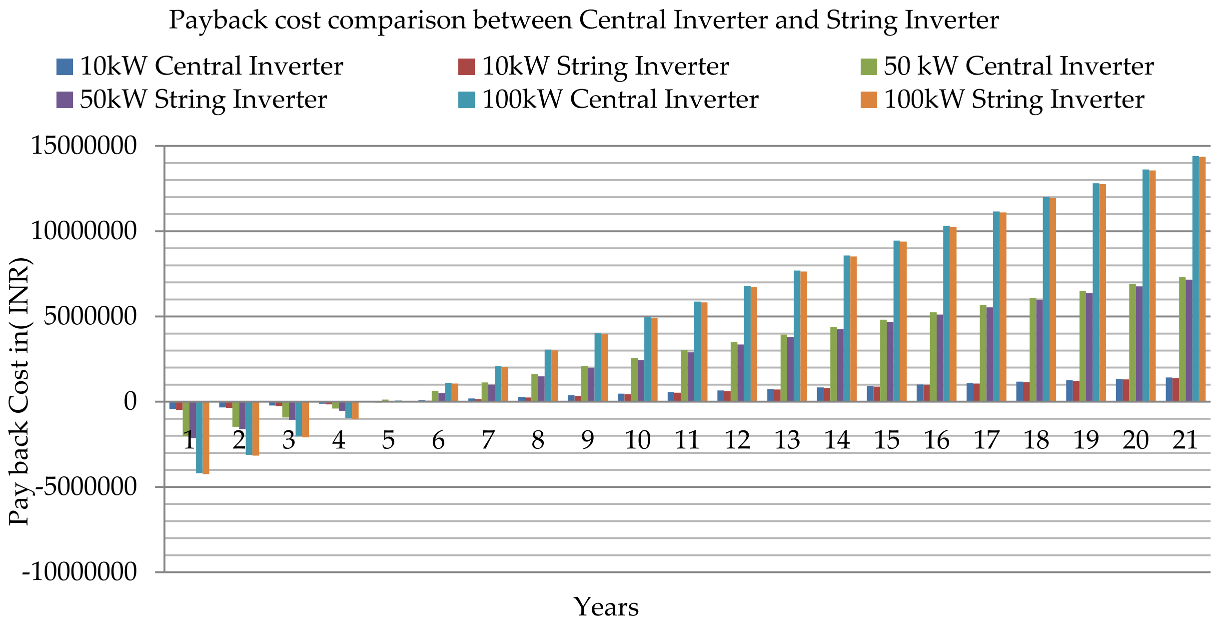

Figure S12. Payback cost comparison between Central Inverter and String Inverter (10 kW, 50 kW, 100 kW).

3. Levelised Cost Of Energy

The Levelised Cost of Electricity (LCOE), Net Present Value (NPV), Internal Rate of Return (IRR) and Profitability technique and equations are presented in literature [S4-S18].

In this regard, the LCOE approach is used to examine the economic performance of PV systems through the present research. The assessment of economic performance is conducted through following steps: i) Estimation of total energy produced by the PV system over the economic life; ii) Assessment of various investment costs including Operation and Maintenance costs of the installed system; and iii) Division of life-cycle cost by energy generated from the system. It is further claimed that if a PV system generates the same energy output every year during its lifetime, then the cost of investment could be annualized by the capital recovery factor as stated in the literature [18].

LCOE remains to be the fairest comparison among the energy supply technologies, in which the energy produced in a lifetime and the cost associated with a system for lifetime is accounted. The LCOE for utility-scale solar PV is being evaluated here where the current paper specifically list out the assumptions for such calculations. In the real world scenario, a number of input parameters with regards to cost and the energy production are certainly not revealed. When these parameters are analyzed repeatedly with statistical probability distributions, it is possible to develop the LCOE output distribution which captures the uncertainties that are associated with the inputs. From such LCOE distributions, it is

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possible to get greater insights on the projected costs for a solar energy project that can provide enriched information to the stakeholders [S4].

LCOE can otherwise be considered as the price at which the energy must be sold for the break even during the lifetime of the technology. A Net Present Value (NPV) is yielded in terms of INR/kWh. This is said to be the economic assessment of the lifetime energy cost and lifetime energy production equation. (1) which can be applied in any essential energy technology. When calculating the financial costs, the equations can consider the system costs and the other factors such as financing, insurance, maintenance, and different types of depreciation schedules [S4].

It can be represented [S4] as

$$\mathrm{LCOE} = \frac{\text{Lifecycle cost}}{\text{Lifetime energy production}} \tag{1}$$

$$\mathrm{LCOE} = \frac{\text{Project cost} + \sum_{n-1}^{N} \frac{\mathrm{AO}}{(1+\mathrm{DR})^{n}} - \frac{\mathrm{RV}}{(1+\mathrm{DR})^{n}}}{\sum_{n-1}^{N} \frac{\text{Iniitial kWh X}(1-\mathrm{SDR})^{n}}{(1+\mathrm{DR})^{n}}} \tag{2}$$

The equation components are AO (Annual Operations cost), DR (Discount Rate), RV (Residual Value), and SDR (System Degradation Rate), whereas the N denotes the number of system operation years. The economic LCOE is computed by the equation (2) which can be customized to accommodate financial considerations such as subsidies, taxes and many such complexities. When such complexities are added into the equation, then the equation will be as given in 3. In the equation, the PCI is the Project Cost minus any Investment tax credit or grant and DEP is the depreciation. The other components are INT (Interest paid), LP (Loan Payment) and TR (Tax Rate) [S4].

$$\mathrm{LCOE} = \frac{\mathrm{PCI} - \sum_{n=1}^{N} \frac{\mathrm{DEP}+\mathrm{INT}}{(1+\mathrm{DR})^{n}}\,\mathrm{TR} + \sum_{n=1}^{N} \frac{\mathrm{LP}}{(1+\mathrm{DR})^{n}} + \sum_{n=1}^{N} \frac{\mathrm{AO}}{(1+\mathrm{DR})^{n}}(1-\mathrm{TR}) - \frac{\mathrm{RV}}{(1+\mathrm{DR})^{n}}}{\sum_{n=1}^{N} \frac{\text{Iniitial kWh X}(1-\mathrm{SDR})^{n}}{(1+\mathrm{DR})^{n}}} \tag{3}$$

But it is important to recognize that every parameter is associated with a set of assumptions. In a number of cases, uncertainty prevails around the above mentioned assumptions in order to provide only a crude estimate. The uncertainty cannot be currently quantified essentially from all LCOE calculations.

Solar Advisor Model (SAM) is one of the performance-based financing models which can be applied from utility scale to residential projects [S4]. This software enables the users to assess the solar technologies for identified locations and enables users to question the relative influence of input parameters in terms of both financial aspects as well as energy production. This seems to be best tool in the industry available to the public to examine a solar project's financial feasibility. According to the literature [24], during SAM analysis, the utility-scale LCOE is estimated on the basis of required revenues over the project life which is otherwise called 'real' or nominal.

$$\text{Real LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+\mathrm{D}\,R_{nominal})^{n}}}{\sum_{n=1}^{N} \frac{Q_n}{(1+\mathrm{DR}_{real})^{n}}} \tag{4}$$

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where 'Q_n' is the electricity generated during the year 'n' and 'R_n' is the required revenue from selling electricity during the year 'n'. The other parameters DR_{real} denote the Real Discount Rate (No inflation) whereas the $DR_{nominal}$ denotes the nominal discount rate (with inflation). There are various factors such as price escalation rate, degradation rate, weather data etc., which are hidden within Q and R [S4].

$$\text{Nominal LCOE}=\frac{\sum_{n=1}^{N}\frac{R_n}{(1+DR_{nominal})^n}}{\sum_{n=1}^{N}\frac{Q_n}{(1+DR_{real})^n}} \tag{5}$$

There are number of decisions provided by the investors to technologists and regulators who rely only on the financial calculations when it comes to solar energy technologies. But there is a lack of established method to compare the costs between electricity-generating technologies and LCOE which is misused in almost all PV cases [S4].

When LCOE is calculated, a number of assumptions are made which must be appreciated by the one who use LCOE calculation or its results. In LCOE calculation, it is not advisable to have a single number as an input so that the single LCOE number result can be avoided. This carries with it an unfounded and potentially misleading sense of certainty [S4].

Rather than which the input parameter distributions on the basis of the best available data should be kept in place that results in a LCOE distribution which reflects cost uncertainty associated with a solar project in an accurate manner [S4]. The results will be based on distribution and so the current paper focused on assumptions on the basis of inflation, operating costs, (decoupled) sunlight variation and panel performance.

4. Internal Rate of Return

$$\text{NPV} = NET * \frac{1}{(1+\text{IRR})^{Year}} = 0 \tag{6}$$

All cash flows (both positive and negative) from a particular investment should be equal to zero [S5]. To be more specific, an investments' IRR is *"the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment"* [S5].

IRR is commonly used to assess the desirability of a project or an investment. When the project's IRR is high, then the project is desired to be undertaken. If all the projects are assumed with such up-front investment, the project with the highest IRR would be considered as the best one to be implemented first [S5]. Theoretically, an individual or a firm should undertake whatever may be the projects or investments available with IRRs when it exceeds the cost of capital. The investment is impacted either by the firm's funds availability or by the firm's capability to manage a number of projects [25]. Given a collection of pairs (time, cash flow) involved in a project, the Internal Rate of Return follows from the Net Present Value as a function of the rate of return. A rate of return for which this function is zero is an Internal Rate of Return [S5].

On the basis of pairs (Period, Cash flow) (n, C_n) where n denotes the positive integer whereas N denotes the total number of periods. The NPV and the IRR is given in the following equation [S5].

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$$NPV=\sum_{n=0}^{N}\frac{C_n}{(1+r)^n} \quad (7)$$

Usually the period is denoted as years, but it is easy to calculate when r is calculated using the period in which the majority of the problems are defined (e.g., using months if most of the cash flows occur at monthly intervals) and converted to annual periods from then [S5].

Any fixed time can be used in place of the present (e.g., the end of one interval of an annuity); the value obtained is zero if and only if the NPV is zero.

In case, the cash flows are random variables as in the case of a life annuity, the expected values are put into the above formula [S5].

It is not possible always to find the value analytically. In such case, either graphical methods or numerical methods must be used [S5].

If an investment may be given by the sequence of cash flows

Year (n)	**Cash flow (C_n)**
0	-53002000
1	9058972
2	9112578
3	9164697
4	9263950

Then the IRR 'r' is given by

$$NPV = -5300200 + \frac{9058972}{(1+r)^1} + \frac{9112578}{(1+r)^2} + \frac{9164697}{(1+r)^3} + \frac{9263950}{(1+r)^4} = 0$$

Numerical solution

Since the above is a manifestation of the general problem of finding the roots of the equation NPV (r), there are many numerical methods that can be used to estimate 'r'. For example, using the secant method [S5], r is given by

$$r_{n+1}=r_n- NPV_n\left(\frac{r_n-r_{n-1}}{NPV_n\ -NPV_{n-1}}\right) \quad (8)$$

$$r_{n+1} = r_n - NPV_n\left(\frac{r_n-r_{n-1}}{NPV_n\ -NPV_{n-1}}\right)\left(1-1.4\ \frac{NPV_{n-1}}{NPV_{n-1}\ -3NPV_n\ +2C_0}\right) \quad (9)$$

where 'r_n' is considered the n^{th} approximation of the IRR. This 'r' can be found to an arbitrary degree of accuracy.

The convergence behaviour of the sequence is governed by the following properties:

If the function NPV (i) has a single real root r, then the sequence will converge reproducibly towards r.

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If the function NPV (i) has real roots, r_1, r_2, r_3,…r_n then the sequence will converge to one of the roots and when the values of the initial pairs are changed, then it may change the root to which it converges [S5].

If function has no real roots, then the sequence will tend towards +∞.

Having $r_1 > r_0$ when $NPV_0 > 0$ or when $r_1 < r_0$ when $NPV_0 < 0$ may speed up convergence of r_n to r [S5].

Decision criterion

If the IRR is greater than the cost of capital, accept the project.

If the IRR is less than the cost of capital, reject the project.

Only negative cash flows — the NPV is negative for every rate of return.

(−1, 1, −1), rather small positive cash flow between two negative cash flows; the NPV is a quadratic function of 1/(1 + r), where r is the rate of return, or put differently, a quadratic function of the discount rate r/(1 + r); the highest NPV is −0.75, for r = 100% [S5].

Similarly, in the case of a series of exclusively positive cash flows followed by a series of exclusively negative ones the IRR is also unique. Finally, by Descartes' rule of signs, the number of Internal Rates of Return can never be more than the number of changes in sign of cash flow [S5].

Based on the above equation, it has to evaluate the performance of an actual PV system and investment LCOE, IRR, NPV, and Profitability Index were arrived for the considerations 10 cases (S13,S14,S15 and S16).

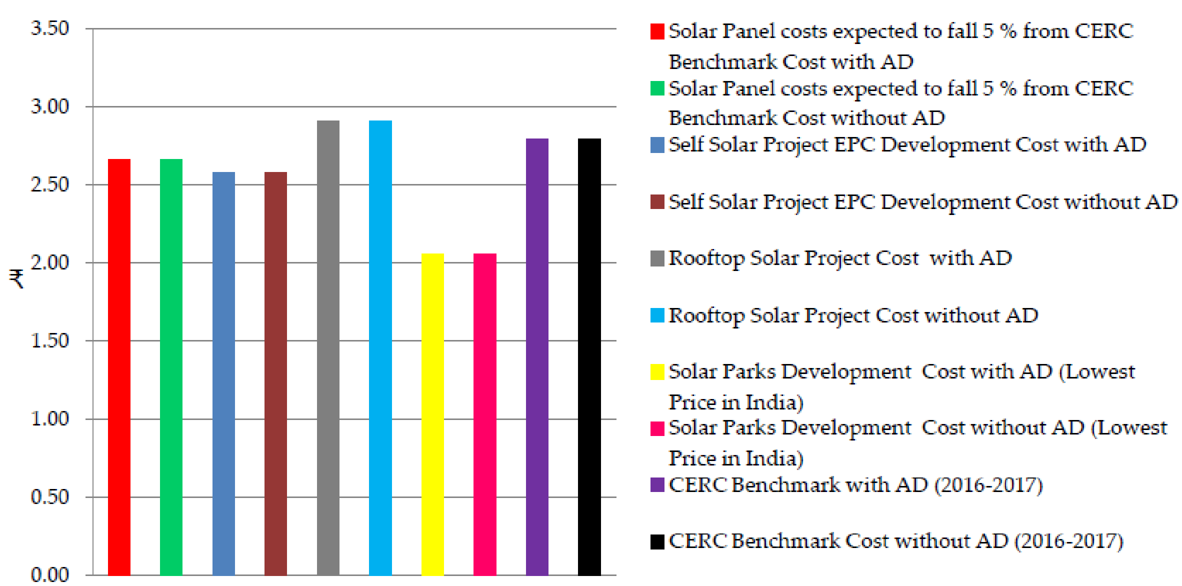

Figure S13. Levelised Cost of Energy (LCOE)

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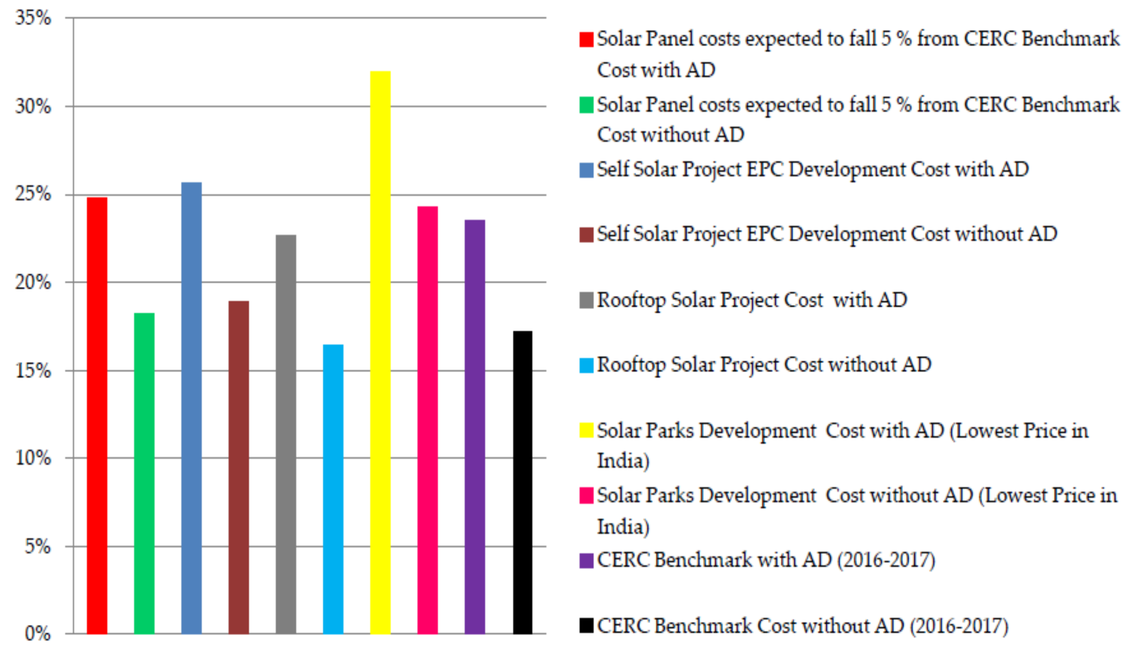

Figure S14. Internal Rate of Return (IRR)

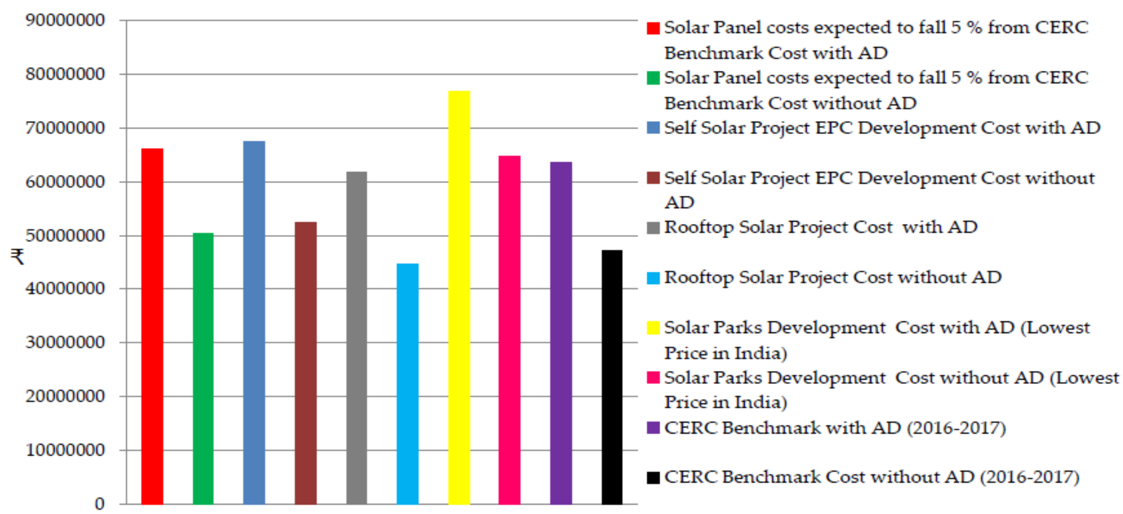

Figure S15. Net Present Values (NPV)

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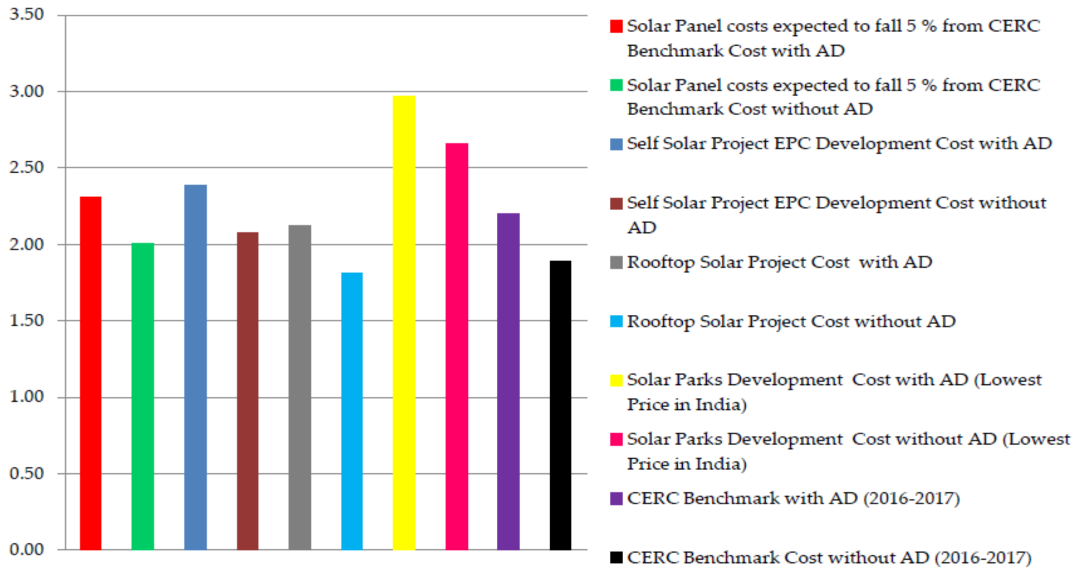

Figure S16. Profitability Index (PI)

5. Types of debt source and arrangement of Funds

To ensure the success of the project, the sponsors will have to provide strong incentives and the equity would be held by small set of parties (unlike a public company with large dispersed holdings). The vendors (for example, solar PV module manufacturers), who may provide equipment warranties, minimum performance guarantees, and insurers who insure the performance of the project are included by the minority equity vendors. The key parties and strong contractual arrangements to align incentives and minimize principal-agent conflicts are included by the sponsor equity as stated earlier.

Debt sources are primarily segmented into two types such as public or private in which the former consists of banks or generally organized as a club or syndicate of banks. Generally, banks hold a primary source of capital only from its Current Account, Savings Account (CASA) deposits and Fixed Deposits (which tend to be of shorter tenor 5 years). So, the banks always lend this amount for shorter periods especially in the case of construction etc., It also tend to lend with a floating interest rate in which the interest rates tend to be higher than bonds. Despite, bank syndicate loans come with following flexibilities. In case of longer term capital, the banks may raise capital from the public or institution sources via infrastructure bonds, green bonds, climate bonds, rupee-denominated masala bonds etc (for example, Yes Bank's INR. 1000 crore green infra bond) and add a spread and lend it to the projects. There are no easy exit options available for bank syndicate lenders or otherwise they do not have secondary market for these loans. Insurance companies such as Life Insurance Corporation of India (LIC) are other sources which provide long term private debt. Our sources are institutions (which may consists of dedicated power finance companies like PFC (Power Finance Corporation), REC (Rural Electrification Corporation), university endowments, infrastructure mutual funds, pension funds, High Net worth Individuals (HNIs), and Private equity. For instance, the UDAY bonds are being privately placed. Since insurance and other such agencies funding are on long-term basis which generate a lot of float, these institutions also can strike fixed interest rate deals for long term loans (for example, in the operating phase of a project).

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5.*1 Solar project fund from Public sector companies*

In public debts, the project companies directly sell the bonds by approaching the markets directly where investors are invited. This market has large potentials with longer tenor financing. A bond seems to be simple with liquidity (there is an active secondary market, also known as the bond market). One can own a debt mutual fund perhaps it is advisable to invest in a combination of government, private and project bonds. However, all public markets are subject to greater degree of disclosure or transparency and regulatory scrutiny. The bonds (i.e. issue) and issuer also need to be rated by rating companies like CARE, CRISIL etc., who are subsidiaries of global companies like Moody's, S&P global rating (Standard and Poors) etc. The rating key is provided to the general public and the investors with less knowledge. These ratings tend to change according to time by the evolution of project cash flows and risk to creditors. It can be an option for the developers who have strong track record of raising funds and execution. The figure S17 shows the cost analysis benefits like savings per year, profit per year and loan repayment per year when considering 13 % interest rate for 1 MW solar energy project in India.

Financing in such context increases the equity of leverage IRRs wherein it is assumed that the capital costs are low, leverage ratio is high (70 by 30 financing), and the loans are on long term basis (more than 15 years and a 10 per cent of post-tax rate). This makes solar PV based investments more attractive for Solar PV project developers (high IRR= high ROI).

Banks are powerful enough to sell a solar power plant like a home loan model and convert the same into money; however, there is a lack of visible secondary well-operating markets for the utilized solar PV systems or assets of the system (example: used inverters and PV modules). This further suggests the opportunities for innovation beyond monitoring certain aspects such as performance of the solar PVs, escrow accounts wherein with the emergence of secondary market for solar PV equipment, the flow of funds into solar loans will also increase.

If the loans for solar PV systems are classified under the housing loan category, then regulations and fund availability could be facilitated with low interest rates based on the powers under the Securitisation and Reconstruction of Financial Assets and Enforcement of Security Interest Act (SARFAESI), 2002. However, defaulted payments may lead to seizure of home in case of Housing Loans, whereas in the solar power plant concerns are questionable. Furthermore, the renewable energy sector is also prioritized as a sector of greater importance by the government of India wherein more than 40 per cent of a bank’s lending will be dedicated for the priority sector.

Supplementary materials

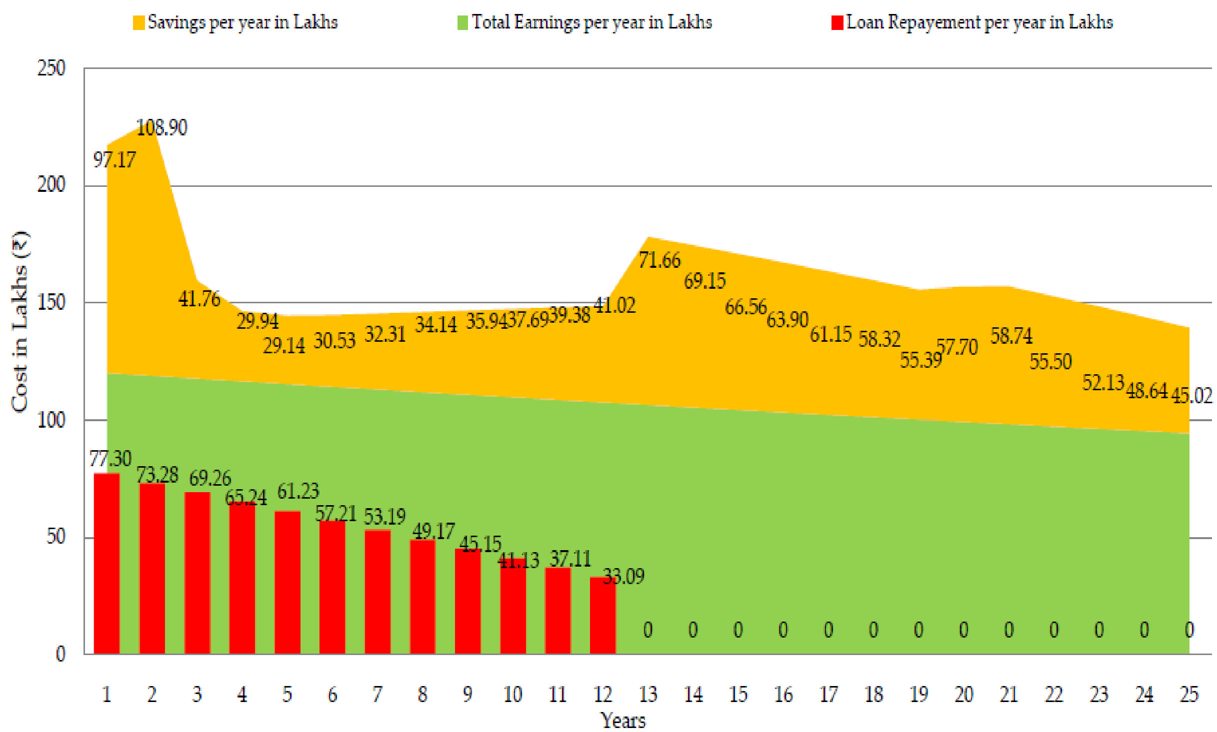

Figure S17. Cost benefits analysis of 1 MW solar energy project at interest 13% in India.

5.2 *Solar project dept from International capital markets*

5.2.1 *LIBOR Based Loan for Solar Power Project*

LIBOR (London Interbank Offered Rate), official to BBA Libor (for British Bankers' Association Libor (BBALIBOR), is the interest rate estimated and charged in an average by the leading London banks if they borrow from other banks. LIBOR and Euribor is the primary benchmark across the globe for short-term interest rates. On the basis of ten currencies and 15 borrowing periods (range from overnight to one year), LIBOR rates are calculated. Thomson Reuters publish this data on a daily basis as per 11.30 am London Time. Indian solar power projects that generate solar electricity rely on LIBOR-based loans. The LIBOR interest rates change according to the credit rating of the borrower and amount of the loan.

5.2.2 *External Commercial Borrowing (ECB) Debt Funding*

In External Commercial Borrowing (ECB) it is possible to set up solar power projects at low interest rates and long-term, debt funding or loans. In order to be funded by ECB with no collaterals of about 70% - 95% of the total cost, the solar power project developer should either be a public limited company or a private-limited company. It can also be tapped for rupee-denominated or foreign currency borrowings or External Commercial Borrowings (ECBs). An external borrowing of infrastructure space that is provided with fully hedged (else the currency risks can be significant during market panics) norms has been relaxed by the Reserve Bank of India (RBI) on long term basis (min 5 years). Masala bonds (i.e. rupee denominated, but issued in capital markets abroad) are a relatively new option. Dollar- or Pound- or Yen-

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denominated bonds (also known as Yankee, Bulldog or Samurai bonds) are other options to tap deeper capital markets; however it comes with associated swap contracts and currency risks since revenues are in India. Since hedging costs are high, there are some discussions going on about the government's Clean Environment Fund (funded by the formerly named Coal Cess) partnered with multi-lateral institutions to provide lower cost hedging solutions for renewable projects in India.

5.2.3 *Asian Infrastructure Investment Bank*

Thomson Reuters cited about Indian energy requirements and mentioned that 100 Billion USD is required for the Indian solar power projects to be successful in the next five to six years. Being a country that aims to enhance the solar power capacity to 100 GW which is approximately 16 times more than the present capacity of (9012.69 MW), India hopes to be funded by the newly founded one Asian Infrastructure Investment Bank. In order to increase the capacity to 100 GW by 2022, India is looking forward to be funded with 500 Million USD loan at lower interest rates of 2-2.5 per cent for its solar power projects in accordance to LIBOR for a term of 15 years. LIBOR is a floating benchmark based on the rate at which commercial banks lend each other. The Proposition of Goods and Services Tax (GST) on the delivered cost of solar energy (Solar PV grid [12% - 16%] and Solar off grid [16%-20%]) range of increase in Levelised tariff and cost of setting up followed by its operations. A domestic estimation by the finance ministry has shown that the mode would help banks lend below the base rate by avoiding hedging costs that add up to 6-8%. Lending below base rate is something that the Reserve Bank of India does not allow currently [49]. Hence, solar project can be executed with the minimal interest rate of 6% is shown in figure S18. The analysis of cost benefits like savings per year, profit per year and loan repayment per year when considering 6 % interest rate for 1 MW solar energy project in India are listed in the table. This suggests an innovation opportunity that if beyond monitoring, escrow accounts (where the EMI slice of the bank comes directly from the escrow account), if a secondary market emerges for solar PV equipment, it will increase the funds flow into solar loans. Attaching residential or home to the debt contract makes optimal sense when implemented as Solar Roof Top systems.

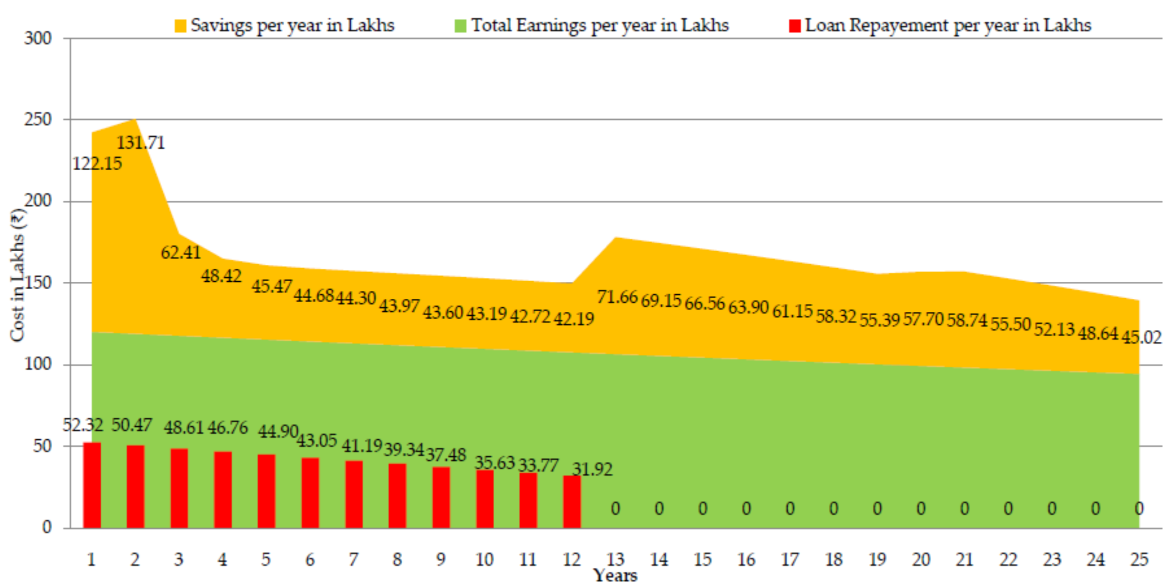

Figure S18. Cost benefits analysis of 1 MW solar energy project at interest 6% in India.

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5.2.4 ***Leasing (or third-party ownership) for solar project***

There is one another model where the ability of the third party who can raise capital at lower costs, and claim tax shields (for example, depreciation benefits) can be used to create a form of "super-senior" debt (since leases are considered operational expenses on the income statement, even before any senior debt service). In some cases to transcend, a pure economic return for the development or welfare and for a clean technology deployment, multi-lateral agencies like Asian Development Bank (ADB), World Bank, International Finance Corporation (IFC), solar park investments by Japan International Cooperation Agency (JICA), KfW Development Bank, Asian Development Bank (ADB) and United States Agency for International Development (USAID) and bilateral Export-Import Bank of India (EXIM) banks may provide "ecosystem" stimulating finance .

6. Financial effectiveness and Economic growth

In Indian solar energy financing, the most important problem faced is the high cost of debt due to huge interest rates. This has significant impact on LCOE as well. In the current analysis, Indian solar projects cost add 24-32% high value due to the cost and terms of debt. But, currently, neither the availability of equity, nor the cost is a problem in front of us. This might get changed in the future when debts are least available. The financial market condition in India is the primary reason of high interest rates in solar energy. This is fueled by growth, high inflation and other risks in the country. So, it is better to examine the design and implementation of funding mechanisms for long-term investment and low-cost debt [25].

In India, for the past several years, the energy needs are increasing and has resulted in economic growth and modernization. There was a notable progression component for the Indian economy in the form of electrification even when quarter of its population had no access to electricity. As a result, India has one of the fastest-growing electricity sectors in the world. There was a constant increase of India's net electricity generation 6.6% per year from the period of 2005 to 2012. As per IEO 2016, India is the fastest growing economy in the world. For reference, the averaging is about 5.5% per year from 2012 to 2040. For a shorter term, there will be an increase in the investment and consumption which had supported the fusion of lower interest rates and moderate inflation.

For an essential Gross Domestic Product (GDP) growth rate, additional structural reforms such as reforming labor markets and bankruptcy terms, ending regulatory impediments to the consolidation of labor-intensive industries and liberalizing agricultural and trade practices need to be achieved on a long-term basis. According to IEO 2016, from the year 2012 to 2040, India's net electricity generation is predicted to increase from 1,052 billion kWh to 2,769 billion kWh in 2040 at the rate of 3.5%/year which tops the list of any other IEO 2016 region over the projection period [S17]. The preferable polices should bring cost effectiveness in terms of leveraging that government support. To bring down LCOE of the baseline coal power plant, all renewable power plants are to be commissioned by 2022, the cost effectiveness of different policies and the total cost in terms of NPV support is required where both the analysis are determined accordingly. This is about the Indian solar finance context which is compared with financial contexts of developed markets. The paper already covered the basic ideas in solar PV, CAPEX, OPEX, production yield, monetization, project equity IRR with and without debt, risk and reward characteristics that form the basis of finance, recourse and non-recourse financing ideas. The liability side of the balance sheet is structured into mezzanine debtors (subordinated), senior debtors, common equity and preferred equity. It is not like the liability side of a corporation's balance sheet, but

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the debt or equity ratio changes in accordance to the phase of the project. Mezzanine debt impacts their return on invested capital whereas the timing of cash flows is decided when the sponsor themselves capture the part of cash flow (senior to preferred equity). The mezzanine debt has some other special forms such as Viability Gap Funding (VGF) in which either the government agencies or the multi-lateral agencies might supply some debt or loan guarantees in order to take care of some losses so that the senior debtors are given some confidence as they have significantly contributed through high capital than others. This debt is also a higher-interest rated debt that reflects high amount of risk. Mezzanine debt is also at a higher interest rate reflective of higher risk. Debt source and funding arrangements are extensively documented in Appendix E in supplementary section.

The effect of sensitivity to the energy yield is considerable wherein with the increase of energy yield by 50 percent without the influence of CAPEX and then the percentage of LCOE drop will come to 33 percent. Furthermore, such methods to improve energy yield will further increase the costs incurred. However, if the net effect is way better than the yield of energy with very meager increase in costs, then LCOE will be reduced. On the whole, it is clear that the bids made by different vendors and developers of Solar PVs in India such as INR 4.34 and INR 4.63/ kWh (Unit) are made through the aforementioned assumptions. It is however significant to note that India is a pioneer in beating the costs of solar PV system installation with low CAPEX and OPEX values. Though the cost of capital and the rate of interest are to be considered, the term or tenure of the loans are somewhat sufficing the budget requirements of the consumers with decent nominal interest rates available in the market with nominal loans for decades. Through sensitivity analysis, it is deemed that the impact of interest rates is predominantly higher for the PPAs on long term basis (25-30 years) which is the direct effect of low cost compounding even for projects with long time. It is further evident that capital cost reduction has greater effects on the reduction of costs as such, an effect that linearly impact. Furthermore, the yield of energy has a reciprocal effect on LCOE.

Table S3. Realistic weights for the "Ideal Mode" and "Relative Mode"

	Realistic weights for the "Ideal Mode"							Realistic weights for the "Relative Mode"						
Years	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case A	Case B	Case C	Case D	Case E	Case F	Case G
Year 1	0.0176	0.0206	0.0198	0.0167	0.0273	0.0177	0.0187	0.1935	0.0539	0.057	0.0633	0.1351	0.0572	0.0966
Year 2	0.0125	0.0345	0.0324	0.0253	0.0387	0.0266	0.0274	0.137	0.0903	0.0876	0.073	0.1488	0.0793	0.1094
Year 3	0.008	0.0855	0.0799	0.0577	0.0867	0.0585	0.067	0.087	0.2292	0.2136	0.1344	0.2666	0.1751	0.2139
Year 4	0.0045	0.3516	0.3417	0.3187	0.1632	0.3217	0.2656	0.0489	0.584	0.5532	0.4705	0.4039	0.5279	0.4291
Year 5	0.0045	0.0957	0.0874	0.0502	0.0942	0.0887	0.0668	0.0505	0.2488	0.2192	0.124	0.2651	0.2404	0.1971
Year 6	0.0057	0.2931	0.2867	0.2748	0.1019	0.2901	0.2246	0.0647	0.4541	0.4321	0.4106	0.2719	0.4572	0.3093
Year 7	0.0103	0.0332	0.0309	0.0257	0.0346	0.0318	0.02	0.1152	0.0836	0.0791	0.0777	0.1198	0.0937	0.0793
Year 8	0.0149	0.0214	0.0203	0.0178	0.0254	0.021	0.0159	0.166	0.0544	0.0559	0.0671	0.1112	0.0702	0.0791
Year 9	0.0195	0.016	0.0156	0.0148	0.0222	0.0165	0.0145	0.2171	0.0409	0.0465	0.0679	0.1179	0.0621	0.0862
Year 10	0.0242	0.0128	0.0129	0.0135	0.021	0.014	0.0141	0.2683	0.0329	0.0419	0.0725	0.13	0.0592	0.0963
Year 11	0.0288	0.0107	0.0112	0.0129	0.0209	0.0125	0.0143	0.3198	0.0276	0.0397	0.0789	0.1448	0.0589	0.1079
Year 12	0.0335	0.0092	0.0101	0.0127	0.0213	0.0115	0.0149	0.3715	0.0237	0.0388	0.0862	0.1611	0.0599	0.1204
Year 13	0.0382	0.0081	0.0092	0.0128	0.022	0.0109	0.0156	0.4233	0.0208	0.0387	0.0942	0.1784	0.0619	0.1335
Year 14	0.0429	0.0072	0.0087	0.0131	0.023	0.0106	0.0164	0.4752	0.0186	0.0392	0.1026	0.1963	0.0645	0.147
Year 15	0.0476	0.0065	0.0082	0.0135	0.0242	0.0103	0.0174	0.5273	0.0168	0.04	0.1113	0.2147	0.0675	0.1608
Year 16	0.0524	0.0059	0.0079	0.014	0.0255	0.0102	0.0184	0.5795	0.0153	0.0412	0.1202	0.2335	0.0709	0.1749
Year 17	0.0571	0.0054	0.0077	0.0146	0.0269	0.0102	0.0195	0.6318	0.014	0.0425	0.1293	0.2525	0.0744	0.1891
Year 18	0.0618	0.005	0.0075	0.0152	0.0283	0.0103	0.0206	0.6842	0.013	0.0441	0.1385	0.2717	0.0782	0.2035
Year 19	0.0666	0.0047	0.0074	0.0158	0.0298	0.0104	0.0218	0.7366	0.012	0.0458	0.1478	0.291	0.0821	0.218
Year 20	0.0713	0.0044	0.0074	0.0165	0.0314	0.0105	0.023	0.7889	0.0112	0.0475	0.1572	0.3105	0.0862	0.2325
Year 21	0.0761	0.0041	0.0074	0.0172	0.033	0.0107	0.0242	0.8413	0.0106	0.0494	0.1667	0.33	0.0903	0.2471
Year 22	0.0808	0.0039	0.0074	0.0179	0.0346	0.0109	0.0254	0.8937	0.0099	0.0514	0.1762	0.3496	0.0945	0.2617
Year 23	0.0855	0.0036	0.0074	0.0187	0.0362	0.0112	0.0267	0.9459	0.0094	0.0534	0.1858	0.3692	0.0988	0.2763
Year 24	0.0903	0.0035	0.0074	0.0194	0.0379	0.0114	0.0279	0.998	0.0089	0.0554	0.1953	0.3888	0.1032	0.291
Year 25	0.095	0.0033	0.0075	0.0202	0.0395	0.0117	0.0292	1.05	0.0085	0.0575	0.2049	0.4083	0.1076	0.3056

Supplementary materials

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