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Multiple Criteria Decision Making (MCDM) Based Economic Analysis of Solar PV System with Respect to Performance Investigation for Indian Market

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Abstract: Energy market is subject to changing energy demands on a daily basis. The increasing demand for energy necessitates the use of renewable sources and promotes decentralized generation. Specifically, solar PV is preferred in the energy market to meet the increasing energy demand. New approaches are preferred in the economic analysis to simulate multiple actor interplays and intermittent behavior in order to predict the increasing complexity in solar PV. In the Indian society, there are various myths and perceptions regarding economics of electricity generated through solar PV system. Therefore, this paper will address the various Life Cycle Cost Analysis (LCCA) and economic analysis for all types of consumers in the Indian electricity market. A detailed economic and performance study is made by considering ten categories and seven sub categories of investment plan for 1 MW solar projects using Multi Criteria Decision Making (MCDM). Analytic Hierarchy Process (AHP) is applied to support the decision.

Keywords: solar PV system; levelized cost of energy (LCOE); internal rate of return (IRR); net present value (NPV); accelerated depreciation (AD); multiple criteria decision making (MCDM); analytic hierarchy process (AHP)

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1. Introduction

Energy economics is a broad area of science that covers energy supply and utilization. Many initiatives are in progress across the globe to harness solar energy, with cooperation from public, private and governments. India is targeting to generate 100 GW by 2022 exclusively through solar energy in the form of Utility-scale, Rooftop solar, Off-grid and Distributed Generation Micro-grid. However, the major obstacle in popularizing solar energy in India is the perception of high installation cost, among the public and private sectors. Hence, appropriate deterministic techniques are required to provide realistic cost.

Initiatives have been under taken by the Government of India since January 2008 to promote grid tied solar PV systems. Developers installed a maximum of 5 MW solar PV plants in India when Feed-In-Tariff (FiT) and Generation-Based Incentives (GBI) were introduced by the government in 2008. However, the above schemes failed to incorporate state utilities in the national project development leading to problems associated with land acquisition and power evacuation.

The historic fall in the cost of solar module since 2012 (i.e., 26% reduction of price in 2016) and the enhanced contractual structure for building solar PV systems have rekindled the interest in solar energy and led to the formation of a joint venture between Solar Energy Corporation of India Ltd. (SECI) and Madhya Pradesh Urja Vikas Nigam Ltd. (MPUVNL). The objective was to meet the energy requirement of India via large solar power projects. To everyone's surprise, the solar power tariff in India hit an all-time low of Indian rupee (INR) 2.97/kWh on 13 February 2017 compared to INR 18/kWh in 2008. Solar power tariff variations in India between 2008 and 2012 are depicted in Figure 1. Figure 1 indicates the FiT values at the time of commissioning the solar project [1–4].

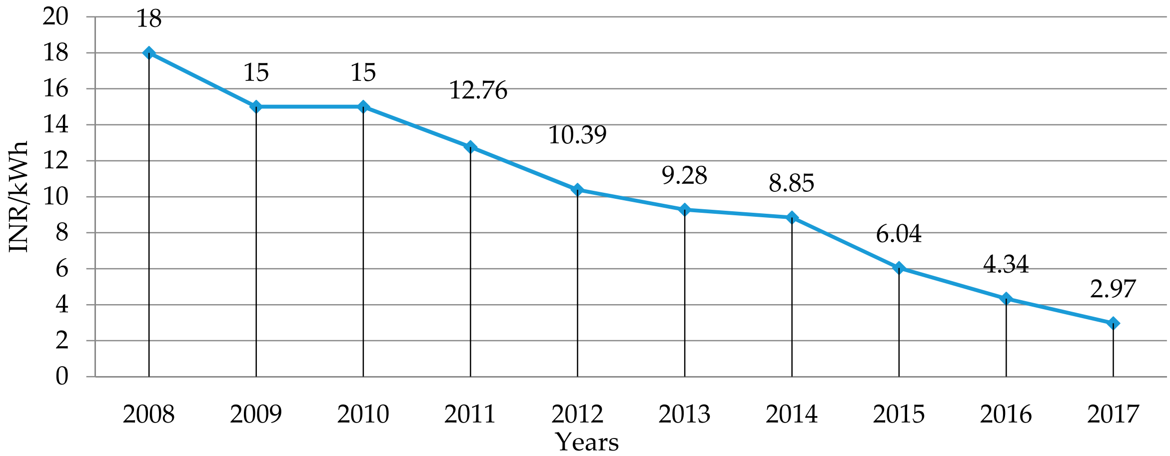

Figure 1. Solar Power tariff (INR/kWh) between 2008 and 2017 [1].

Figure 1 shows that the economics of solar PV energy market is highly dynamic. Presently, each State Electricity Regulatory Commissions (SERC) frames its own policy for solar power generation. This paper addresses the challenges towards the development of a unified national policy common to all the Indian states. Among the many factors, the Accelerated Depreciation (AD) is a key factor from the financial terms. After demonetization in 2016, Indian market showed positive signs in developing solar projects. Many players started investing in solar farms in order to utilize the AD benefits. Hence, this paper shall consider 10 different costing models for a 1 MW solar plant and evaluate the most suitable investment decision using MCDM technique (AHP) to enhance the growth of solar PV in India. Pertinent literature, stakeholders' process, policy significance are considered for best decision making.

In parallel, costing models for both grid-tied and off-grid solar PV system are analyzed and compared with grid parity using High Tension tariff and Low Tension tariff. This paper will also provide an overview of the Indian market and cost analyses of solar energy from 1 kW to 1 MW in the Supplementary Materials. Key insights into the solar energy sector and bottlenecks or obstacles preventing the growth of solar energy will be discussed.

2. Literature Review

Factors such as aggregated production, consumption, savings and investment are usually considered in many studies for economic analysis. About 18% of the global population does not have access to electricity due to the absence of sufficient infrastructure such as power grids to supply electricity [5]. Hence, many in rural areas live without electricity. This mandated the need for strategies that emphasize the growth of solar energy through National and State-level policies, targets and know-how to achieve those targets, ground-level operational issues, product development lifecycle, new financing models and optimized Operations and Maintenance (O&M) models for all solar PV projects. In India, capital cost for solar power plant is higher when compared to developed countries. Debt cost in India is 12–14%, whereas, for developed economics, it is in the range 3–7% [6]. Summary of closely related literature are presented in Table 1.

Table 1. Literature summary of closely related work.

Ref. No.	Authors	Year	Objective and Outcomes
[5]	Birol et al.	2015	By Year 2040, India is expected to add 600 million new electricity consumers as per the high priority policy. Majority of Indian population receive their power via power grids. Mini-grid and off-grid solutions supply approximately 50% of the electricity demand to the consumers, especially to those who reside at distant areas from existing transmission lines. By Year 2040, it is predicted that 340 GW of electricity will be generated from wind and solar projects due to the increased manufacturing and installation capabilities.
[6]	Anil et al.	2015	NITI Aayog (National Institute for Transforming India) discussed the hurdles in achieving 100 GW solar power and other renewable energy generation by 2022.
[7]	International Finance Corporation	2011	Provided guidance for developers in finance, design, construction and operation of utility scale solar PV plants.
[8]	Bhattacharyya et al.	2017	Discussed the impact of cross subsidy removal in electricity pricing in India. Removal of cross subsidy in India led to increased inflation, especially food inflation, that in turn resulted in decreased household income in rural areas.
[9]	Garg	2012	Proposed the "Energy Vision 2020". The electricity consumption per capita for India is just 566 kWh, which is lesser when compared with other countries. Eighty-four Million households in India do not have access to electricity. The electricity consumption of India is predicted to increase up to 2280 BkWh and 4500 BkWh by 2021–2022 and 2031–2032, respectively. In the past 25 years, the power capacity has increased by 5.87% yearly.
[10]	Ghosh et al.	2015	Evaluated the profitability of various existing Roof Top PV systems (RTPV) and different policy incentives in India. Indian cities with semi-urban spaces show good financial performance in both net metering as well as in Feed in Tariff (FiT) schemes.
[11]	Siali et al.	2016	A new optimization method was proposed to minimize the investment cost of a distribution grid supplied by PV sources.
[12]	Zhang et al.	2016	Analyzed the techno-economic aspects for Building Added PV (BAPV) for Hybrid Energy Systems (HES) in commercial and residential buildings. Authors concluded that commercial buildings demand high power supply during daytime due to the similarities in the building load profiles and the solar radiation profile. This scenario has mandated the presence of batteries with large capacities and increased charge-discharge cycle.
[13]	Köberle et al.	2015	Presented future techno-economic potentials of the PV electricity generation from concentrated solar energy.
[14]	Sommerfeldt et al.	2015	Provided insights on a rare phenomenon of hourly pricing model in PV techno-economic analysis. Authors proposed a dynamic pricing method.
[15]	Salehin et al.	2016	Investigated the wind-diesel systems and solar PV-diesel systems and concluded that, solar PV-diesel system has shorter payback period when compared with wind-diesel energy system.
[16]	Janko et al.	2016	Created the residential energy market model by using HOMER Microgrid software. Due to increasing installations of solar PV systems, this study focused on evaluating the overall effect of electric rate structures and the environmental policies.
[17]	Valentin et al.	2015	Discussed the factors such as declining subsidies, reduction in Feed-in-Tariff and timing difference between demand and the supply from solar power which decides the cost-efficacy of roof top solar systems. Concluded that Li-ion batteries are increasingly preferred for residential energy storage.
[18]	Adaramola, M.S	2015	Calculated the annual and monthly cost of energy production by the solar system. The Internal Rate of Return on investment of this installation was found to be approximately 7.5%.
[19]	Orioli et al.	2014	Analyzed the economic parameters that are involved in finding the effectiveness of grid-connected PV systems installed in multi-story buildings.

Table 1. *Cont.*

Ref. No.	Authors	Year	Objective and Outcomes
[20]	Zubi et al.	2016	Considered four different scenarios for different years such as 2020, 2030 and 2040. Authors proposed an evolutionary techno-economic assessment and presented an overview about the future developments in off-grid PV systems.
[21]	Kumar	2015	Investigated the Solar PV energy production and economic assessment for Indian scenario.
[22]	Soni et al.	2014	Domestic survey was conducted on techno-economic parameters of solar technologies with global attributes. The researchers concluded that various parameters, site location and direct investment cost are the most preferred technical and economical parameters.
[23]	Sukh et al.	2016	Various business and financial models which are currently used worldwide were presented. The study also suggested, how these models can be implemented in Indian context, thus paving way for the growth of this sector.
[24]	International Solar Alliance	2016	Information on existing innovative financing structures that can be implemented in streamlining the finance solar energy operations, renewable energy, in general at both national and international level investments were discussed.
[25]	Shrimali et al.	2013	Conducted financial modeling of renewable energy projects in India and identified that high cost of debt is the most imperative problem.
[26]	Aanesen et al.,	2012	Study covers strategies and resource productivity with specialization in renewable product development and its cost details.
[27]	Calise et al.	2015	Presented the simulation model and parametric analysis of a solar geothermal hybrid cogeneration.
[28]	Ferroni et al.	2016	Presented on Energy Return on Energy Invested (ERoEI).
[29]	Massimo et al.	2014	Presented the use of Geographic Information System (GIS) techniques for the exploitation of solar energy potential estimation.
[30]	Carbajales-Dale et al.	2015	Analyzed the Energy Return On Investment (EROI). The method serves as a useful metric for assessing long-term viability of energy-dependent systems from bands of hunter-gatherers, to modern society and, finally to the specific case of a solar electricity generating project.
[31–34]		2016	Benchmarked the Capital Cost Norm prescribed by Judgment against petition for Indian Solar PV power projects.
[35]			Tabulated the electricity tariff in India for year 2017. Each State Electricity Regulatory Commission (SERC) fixes electricity unit cost under various slabs.
[36,37]	Darling et al.	2011	Various methods and equations are presented related to Levelized Cost of Electricity (LCOE), Net Present Value (NPV), Internal Rate of Return (IRR) and Profitability.
[38]	Liou et al.	2012	Elucidated an economic model using MCDM methods.
[39]	Chioua	2005	A hierarchy is structured to set up a sustainable implementation. In this work, an Analytic Hierarchy Process (AHP) composed method is used to build the evaluation framework to study the criteria in order to achieve the sustainable development in the industry.
[40]	Khasreen et al.	2009	Life Cycle Assessment (LCA) of renewable energy is addressed.
[41]	Mälkki et al.	2017	

3. Present Scenario of Solar Energy in India

Indian states are widely exposed to natural sunshine, especially Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, Telangana and Rajasthan, during almost the entire year. Precisely, Indian regions harvest 5–6.5 kWh/m^2/day as energy yield which leads to the Capacity Factor (CF) of 17–23%. For various parts of India, the GHI (Global Horizontal Irradiance) resource map published by National Renewable Energy Laboratory (NREL) and Ministry of New and Renewable Energy (MNRE) [42] is used. In Supplementary Materials Figure S1, solar irradiance in India is demonstrated. The total installed solar power capacity in India as of 31 December 2016 is 9012.69 MW [42]. Similarly, in the same section of Table S1, the installed capacity in each state, state-wise target and difference to be achieved by 2022 are detailed.

4. Solar Photovoltaic (PV) System

The components in a solar PV system includes solar PV module, inverter system, structures and Balance of System (BOS) which can be either grid-tie or off-grid with battery storage. Solar PV modules are typically guaranteed for 25 years and last more than the guaranteed period producing 80% of its original rated capacity. The inverter system is typically warranted for 10–25 years. From the past learning curve, it is understood that due to Balance of System (BOS) and reduced installation costs, the Solar PV module costs dropped in recent times [31–34]. This has led to the entry of new business models and types of solar PV modules. Here, the capital cost per Watt-peak (e.g., INR/W_p) is used to measure the capacity installed, while it is applied either based on components (e.g., module cost and inverter cost) or based on the entire installed system itself. Classification of various Solar PV system models and its suitability is presented in Table S2 and Figure S2 (Supplementary Materials).

5. Solar PV System Cost

Solar PV plants can be broadly classified into utility scale (>50 MW_p), medium scale (50 kW_p–1 MW_p) and small scale rooftop system (1–50 kW_p). The installation of a small scale rooftop system costs around INR 65,000–100,000 kW_p for grid tied system and INR 85,000–125,000 kW_p for off grid. For medium scale, the cost lies between INR 55,000–65,000 kW_p. For larger farms and utility scale (MW_p) projects, the market cost varies from INR 39,000 kW_p to INR 55,000 kW_p. The cost for installing a solar PV system (inclusive of its components and acquired land area) in India lies between INR 42.65367 W_p and INR 120.89 W_p. A number of suggestions and objections were received from various stakeholders with regards to benchmarking the capital cost for solar PV plant. Central Electricity Regulatory Commission (CERC) benchmarked the capital cost and the detailed breakdown [31–34] of preliminary and pre-operative expenses combined with overall capital cost for Financial Years (FY) 2012–2017 [33] as listed in Table 2. For financial year 2016–2017, the EPC costs of INR 53.4769 W_p for utility scale or large commercial in percentage is envisaged [31] and displayed in Figure 2.

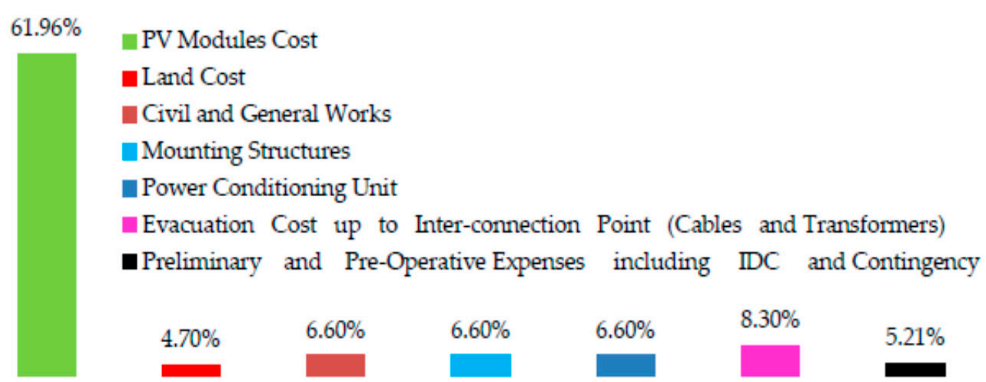

Figure 2. EPC costs per MW in percentage for utility scale and large scale [31–34].

Table 2. Central Electricity Regulatory Commission (CERC) benchmark capital cost and detailed breakup [31–34].

			FY 2016–2017			FY 2015–2016		FY 2014–2015		FY 2013–2014		FY 2012–2013	
S. No.	**Particulars**	**Change in Cost over Past 5 Years**	**Cost in INR Lakhs/MW**	**% of Total Cost**	**Change from Previous Year**	**Cost in INR Lakhs/MW**	**% of Total Cost**	**Cost in INR Lakhs/MW**	**% of Total Cost**	**Cost in INR Lakhs/MW**	**% of Total Cost**	**Cost in INR Lakhs/MW**	**% of Total Cost**
1	PV Modules Cost	−4.68%	328.39	61.96%	7.10%	332.35	54.53%	365.8	54.53%	335.71	42.12%	344.5	42.75%
2	Land Cost	48.81%	25	4.70%	0.59%	25	4.13%	25	3.73%	16.8	2.11%	16.8	2.08%
3	Civil and General Works	−62.96%	35	6.60%	−1.65%	50	8.25%	60	8.94%	94.5	11.86%	94.5	11.73%
4	Mounting Structures	−66.67%	35	6.60%	−1.65%	50	8.25%	50	7.45%	105	13.17%	105	13.03%
5	Power Conditioning Unit	−41.67%	35	6.60%	−0.82%	45	7.43%	50	7.45%	60	7.53%	60	7.45%
6	Evacuation Cost up to Inter-connection Point (Cables and Transformers)	−58.10%	44	8.30%	−0.78%	55	9.08%	60	8.94%	105	13.17%	105	13.03%
7	Preliminary and Pre-Operative Expenses including IDC and Contingency	−65.46%	27.63	5.21%	−2.79%	48.5	8.01%	60	8.94%	80	10.04%	80	9.93%
	Total Capital Cost	−34.22%	530.02			605.85		670.8		797.01		805.8	

In Figure 2, the cost is considered for grid connected PV system. 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. An actual costing and payback period are deliberated in Supplementary Materials.

6. Electricity Tariff in India

In electrical power systems, there are three elements: generation, transmission and distribution. India has its own Public Sector Undertaking (PSUs) and private-owned power generating stations. The transmission system is taken care by the central government authority, Power Grid Corporation of India Limited (PGCIL). Being a country with 29 states and seven union territories, India is segmented into Northern, Southern, Eastern, Western and Northeastern regions. Every state has its own State Load Dispatch Centre (SLDC). The distribution of the generated power is carried out by distribution companies (DISCOMS) and State Electricity Board (SEBs). Power System Operation Corporation Limited (POSOCO) and National Load Dispatch Centre (NLDC) websites provide daily information pertaining to power generation and demand for the entire country [42,43].

State Electricity Regulatory Commission (SERC) fixes the electricity unit cost under various slabs. Bijli Bachao (www.bijlibachao.com) explored and tabulated electricity tariff in India for the Year 2017 [35]. From this study, it is observed that Sikkim has the minimal unit cost of INR 1.1 kWh whereas Mumbai-BEST has the maximum unit cost of INR 13.85 kWh. The updated tariff slabs and rates for Low Tension (LT) domestic customers under various categories across India are detailed in this report. The entitled list does not cover commercial, industrial, and institutional and rest of the High Tension (HT) connections [35]. The HT connection varies based on prevailing demands and penalties such as power factor and harmonics. Hence, the consumption cost of HT connection varies between INR 7.5 kWh and INR 16.85 kWh across the country. Based on the observation, it becomes imperative to install the solar power plant at premises having demand more than 400 kWh (units) per month. However, all-state average unit cost beyond 400 kWh (units) for LT connection is INR 7.26 kWh.

7. Economic Analysis of Solar Tariffs in India

The electricity tariff system considers various factors before deciding the unit price of energy produced by grid-connected PV system and off grid battery storage system. Such factors are listed below.

(1). Site weather condition (e.g., daily solar insolation and sunshine hours, ambient temperature, and snow/frost duration)
(2). System components (e.g., PV module, inverter cost, cables and other electrical components cost)
(3). Site economic parameters (e.g., inflation in price of installation, and operation and maintenance costs)
(4). Site electricity price; (local state tariff, type of connections (HT/LT), group captive tariff and Wheeling and Banking charges)
(5). Government policy issues (includes tax exception and deduction, investment incentives and supports) and economic life of the system [18];
(6). Architectonic aspects
    i. Identifying the building roof surfaces such as flat and slanted
    ii. Estimating the number of floors for every building
    iii. Classification of roof shapes [19]
(7). Energy aspects
    i. Estimation of electricity produced from each floor by the PV systems
    ii. Estimation of electricity consumed by each house
    iii. Estimation of energy cover factor [19].

8. Pay Back Analysis of Solar PV System

The average yield of a well-maintained system (dust-free, no-shadow, etc.) is about 4.5–5 kWh/day/kW_p (17–20.8% capacity factor). This yield is due to the abundance of solar irradiance distributed across India. Researchers are now currently aiming to achieve 6–8 kWh/day/kW_p or more with the development of photonic harvesting technology. This yield may reduce to 0.5 to 1 kWh/day/kW_p due to various factors such as dirty panel, shadowing obstructions during the day, power cuts and curtailments. For a well-maintained system having average system life expectancy of 25 years or more, the energy can be monetized at INR 4.5–5.5 kWh wholesale via Power Purchase Agreements with National Thermal Power Corporation (NTPC) or state DISCOMs. If the same is multiplied with energy yield per year (assume 1825 kWh/year kW_p) with PPA rate assuming an average of INR 5 kWh wholesale and INR 7 kWh retail, an annual revenue of INR 9125 kW_p/year (wholesale) and INR 12,775 kW_p/year (retail) can be achieved. It is to be noted that the Capital expenditure (CAPEX) numbers cited above range from INR 48,000 kW_p (wholesale, MW_p scale) to INR 70,000 kW_p (50 kW_p scale) and INR 1 lakh/kW_p (1–5 kW_p scale rooftop). If the annual operating expenses are 2% of CAPEX, the operating expenditure (OPEX) value would be INR 960 kW_p. The solar energy economics model considering the above from the Indian perspective for various capacities of standard solar PV system can be realized from this paper.

The pay back analysis is carried out by utilizing subsequent benefit analysis and assumed period for capacities of 1 MW for central inverter and string inverter presented in Figure 3. 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. This is inclusive of the land cost being cheaper, but exclusive of network transmission costs and evacuation costs. India has the least installation cost of solar PV worldwide, which is refined in terms of scale, better supply chains and local manufacturing.

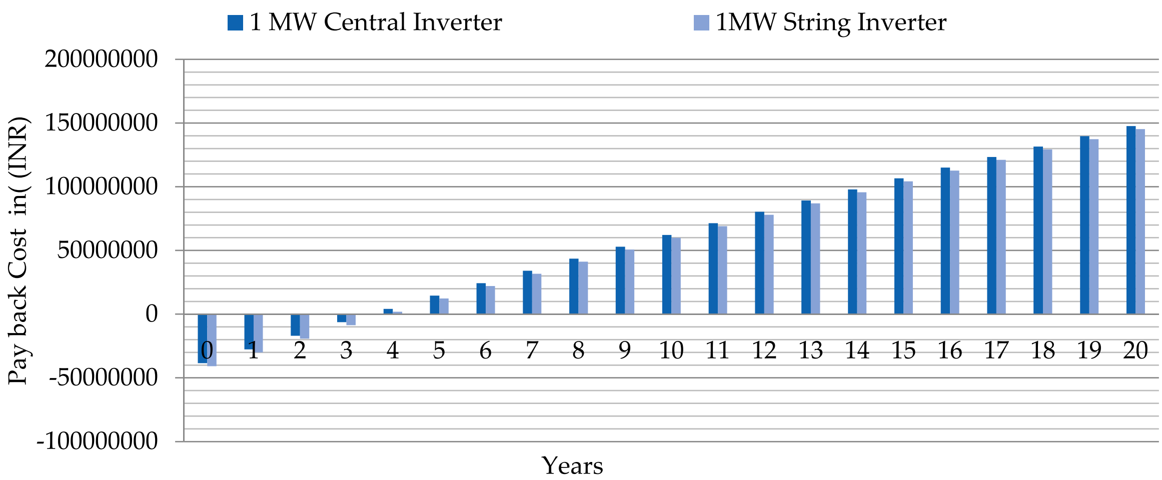

Figure 3. Comparison between Central Inverter and String Inverter for 1 MW.

Comparative study of Central and String Inverters, both in Industrial and Commercial application has been depicted in Figure 4.

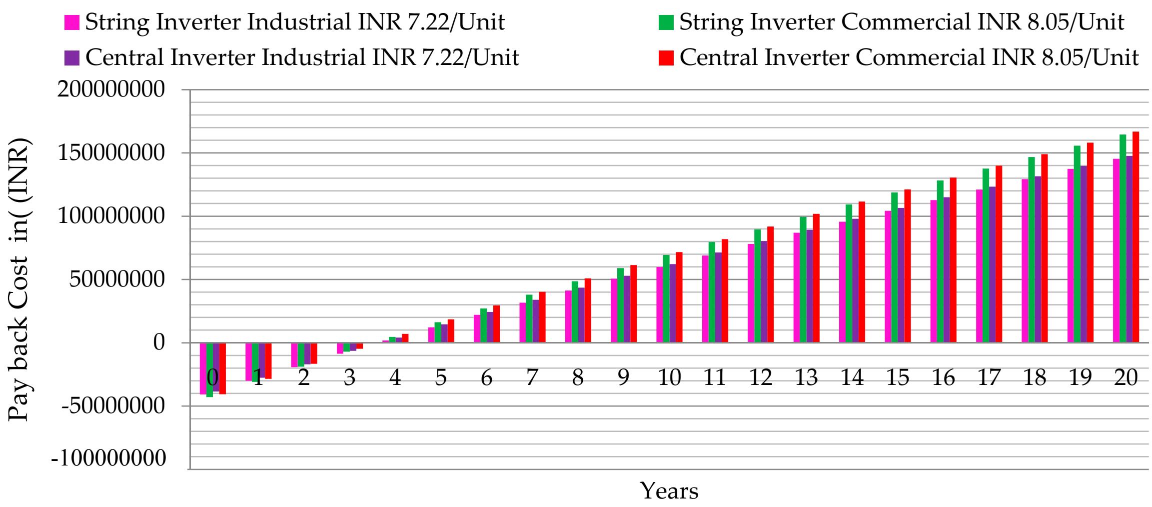

Figure 4. Comparison of payback Cost for 1 MW solar power plant utilizing Central and String Inverter in Industrial and Commercial applications.

Similarly, payback analyses carried out for solar PV systems ranging from 1 kW to 100 kW are detailed in Supplementary Materials.

9. Cost Consideration for MW Solar PV Power Plant

The project cost takes into consideration CERC benchmark of capital cost, preliminary and pre-operative expenses [31]. The standard cost used to analyze the solar PV power development with assumption is finally concluded through various results in different perspectives. For example, a benefit in terms of Accelerated Depreciation (AD) is calculated with and without being factored.

9.1. Term (or PPA Life)

As per the contract stated by NTPC, the term or PPA life is 25 years. If the short term PPA or short term loan for 10 or 15 years is considered, it becomes crucial to reduce the number and hence the residual value has to be estimated (earning upon renewal after 10 to 15 years). If the assumption is considered and put in the spreadsheet for a tenure of 10, 20, 25, and 30 years, the values acquired are INR 5.16 kWh, INR 4.1 kWh, INR 3.94 kWh and 3.86 kWh, respectively. However, the cost is levelized and does not agree with the Power Purchase Agreements (PPA) prices. Considering 25 years of tenure, a pre-tax margin of 17.5 percent yields INR 0.69 kWh.

However, in the Indian context, there are complexities in obtaining finance for 25 years. However, this is common in corporate bond markets outside India and hence funds could be acquired and hedged partially. On the contrary, if financing performed for 10–15 years term is completed, refinancing could be facilitated for another similar period considering the cash flow, patterns of risks along with credit and operational risk.

Supplementary Section 1 broadly documents information regarding solar energy market involving various stakeholders such as investors, lenders, project developers, utility, Engineering Procurement Construction (EPC) contractors, service companies, management, and insurance companies together grouped under Special Purpose Vehicles (SPV).

Comprehensive breakup of capital cost, Weighted Average Cost of Capital (WACC), EBITDA (Earnings before Interest, Tax, Depreciation, and Amortization), Debt Source Considerations and Levelized Cost of Energy (LCOE), Net Present Value (NPV) and Internal Rate of Return (IRR) are extensively documented in Supplementary Materials.

9.2. Subsidy and Accelerated Depreciation (AD)

The Accelerated Depreciation is determined by the government policy and is predicted to reduce up to 40% by Year 2017. A 30% MNRE subsidy was proposed for residential sector but some states such as Karnataka did not levy tax on residential PPA inflows for 10 years. Further, there are reforms from UDAY that enforce Renewable Purchase Obligations (RPOs), and ensure counterparties such as NTPC or DISCOMs pay regularly and on time. This can significantly improve economics to about (note: IRR computed for $\geq$15 years) 14–15% project IRR for residential, 20–22% project IRR for medium-scale rooftop and large-scale utility plants. Both the above discussed IRR numbers provide positive economic returns when opportunity costs (about 7–8.5% in residential Fixed Deposits; and 15% cost of equity for commercial and utility scale) are considered.

10. Grid Parity

Grid Parity is a simplification process that compares the Levelized Cost of Energy with the marginal cost of electricity offset obtained from the grid. To calculate the payback period, financial analysis is performed utilizing NPV, IRR and other metrics. This analysis compares the cost and revenue of the system and provides information regarding how quickly one can recover the costs (payback period), or the IRR or net value (discounted revenue minus discounted costs, for NPV). Though India has better solar resources compared to other countries, the retail prices are still low. Based on reference [35] and graphical comparisons (Figures S9 and S10) detailed in the Supplementary Materials, India (at their base rates) lies far away in grid parity due to low retail price and capital cost. Therefore, in order to push the market ahead, either the solar cost has to drop (well below for residential INR 62.40 W_p installed) or else the policy of subsidy support should be achieved. According to the recent market updates, INR/W_p installed cost point has reached utility scale (INR 39–54.76 W_p as of 2017). Solar PV is now beginning to compete with some customers without subsidies due to grid parity with their consumptions exceeding 1000 units (kWh)/month. In India, commercial or utility scale MW photovoltaic projects have already reached grid parity.

11. Levelized Cost of Energy, Net Present Value and Internal Rate of Return (IRR)

The conventional energy is significantly costlier than the solar energy, thereby leading to occurrence of wide-scale grid parity. In such a scenario, the regulators and policy makers need to provide reliable information to the investors in order to have insight about the expected ROI (Returns on Investment) and economics of energy production. For this, there is a need to compare and contrast different means of energy production which is done using Levelized Cost of Energy (LCOE) [36]. LCOE is a measure of marginal electricity cost for a particular period of time and a platform to perform comparative analysis of electricity generation cost among various sources [23,24]. Such a measure is easily understood by PV system energy consumers compared to conventional system energy consumers receiving electricity bill in cost per kWh format. The Supplementary Materials details the mathematical model of LCOE equations.

Internal Rate of Return (IRR) is the rate of return used in the capital budgeting, in order to measure and compare an investment's profitability. The IRR of an investment is the "Annualized Effective Compounded Return Rate" or else "Rate of Return" which makes the Net Present Value (NPV) equal to zero [37]. The mathematical equations and its clarification are detailed in the Supplementary Materials.

12. Impact of Demonetization

The solar industry has a positive impact due to demonetization of INR 500 and INR 1000 currency. As the solar project is considered as a tax-saving tool, after demonetization, solar projects have faced uplifted development, especially in Roof Top and self-consumption (Captive user(s) and Open Access) models creating a hope to achieve the 100 GW solar target.

Table 3 lists various categories of investment along with its project cost and metrics.

Table 3. Various categories of investment with project cost (INR) in Lakhs and its metrics.

S. No.	Case	Different Consideration	Project Cost Investment (INR)	AD (INR)	NPV (INR)	LCOE (INR)	IRR %	PI
1	Case 1	Solar Panel costs expected to fall 5% from CERC Benchmark Cost with AD	50,351,900	17,114,609	66,025,510	2.65	25%	2.31
2	Case 2	Solar Panel costs expected to fall 5% from CERC Benchmark Cost without AD	50,351,900	0	50,466,773	2.65	18%	2.00
3	Case 3	Self Solar Project EPC Development Cost with AD	48,761,840	16,574,148	67,527,875	2.57	26%	2.38
4	Case 4	Self Solar Project EPC Development Cost without AD	48,761,840	0	52,460,467	2.57	19%	2.08
5	Case 5	Rooftop Solar Project Cost with AD	55,000,000	18,694,498	61,633,762	2.90	23%	2.12
6	Case 6	Rooftop Solar Project Cost without AD	55,000,000	0	44,638,763	2.90	16%	1.81
7	Case 7	Solar Parks Development Cost with AD (Lowest Price in India)	39,000,000	13,256,099	76,751,330	2.055	32%	2.97
8	Case 8	Solar Parks Development Cost without AD (Lowest Price in India)	39,000,000	0	64,700,330	2.055	24%	2.66
9	Case 9	CERC Benchmark with AD (2016–2017)	53,002,000	18,015,378	63,521,568	2.7928	24%	2.20
10	Case 10	CERC Benchmark Cost without AD (2016–2017)	53,002,000	0	47,143,951	2.7928	17%	1.89

AD: Accelerated Depreciation; NPV: Net Present Values; LCOE: Levelized Cost of Energy; IRR: Internal Rate of Return; Profitability Index (PI).

The benchmark capital cost norm for the FY 2016–2017 is INR 530.02 lakhs/MW. This shows that the capital cost differs in lakhs for various categories of investment (INR) as observed in Table 3. The break up details guideline put forth by CERC (Table 2) is considered for the analysis.

The Annual net cash flow, LCOE, IRR, NPV and Profitability Index (PI) for the solar PV projects are estimated using Equations (1)–(9) given in the Supplementary Materials. Figure 5 represents the annual net cash flow (in INR) of ten categories (Cases 1–10), for a span of 25 years.

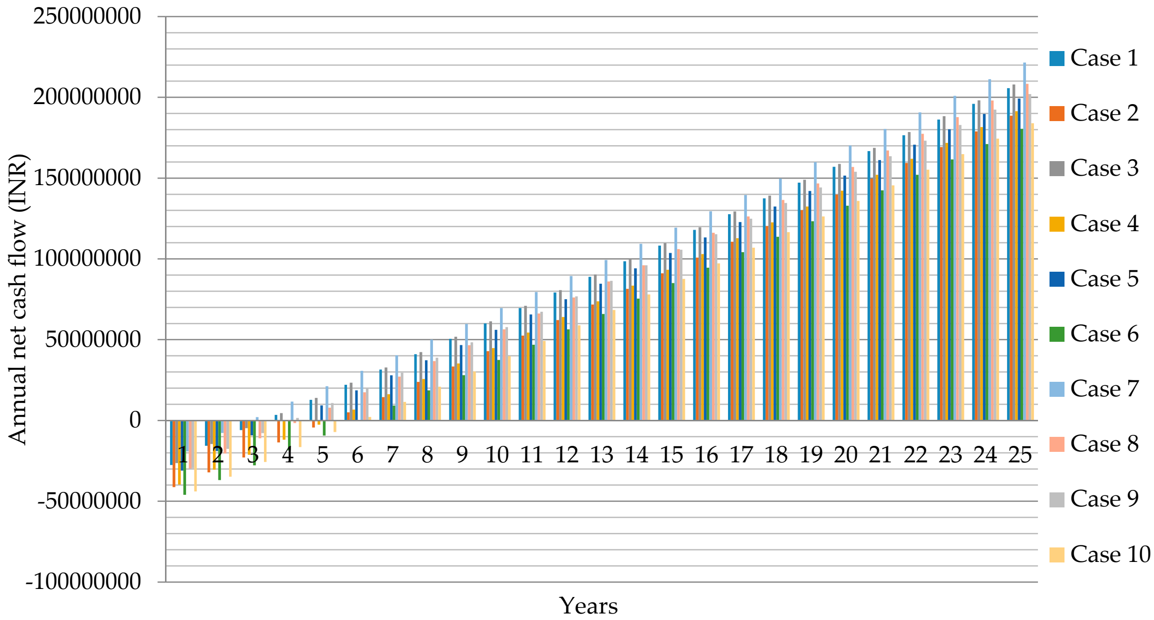

Figure 5. Annual net cash flow (INR) of ten categories (Cases 1–10).

The ten categories are further analyzed as presented in the Supplementary Materials. LCOE, IRR, NPV and Profitability Index (PI) are analyzed in Figures S13–S16 respectively.

12.1. High Costs of Equity and Debt

Consider a project with debt to equity ratio of 70:30, with debt interest of 12% and equity tax of 20%. This leads to Weighted Average Cost of Capital (WACC) of approximately 14.5%. For 10, 20, 25 and 30 years, the LCOE obtained are INR 5.53 kWh, INR 4.56 kWh, INR 4.43 kWh and INR 4.38 kWh respectively. The obtained LCOE is not competitive enough to win the bid.

If the interest rate or WACC is halved, i.e., 6%, the LCOE becomes INR 4.31 kWh, INR 3.03 kWh, INR 2.80 kWh and INR 2.65 kWh for 10, 20, 25 and 30 years, respectively. Generally, a span of 25 years is considered an appropriate term. Such compounding power results in a reduced rate. It is further interesting to note that the reduced trend for 10 years from INR 5.16 to INR 4.31 is not as great as that for 25 years where it drops from INR 3.94 to INR 2.80. If the value of WACC is assumed to be around 8%, which is similar to developed markets, the LCOE becomes INR 4.59 kWh, INR 3.37 kWh, INR 3.17 kWh and INR 3.05 kWh for 10, 20, 25 and 30 years, respectively.

12.2. Sensitivity to Capital Costs

If the CAPEX values are increased from INR 53.75 W_p to INR 68.45 W_p, the LCOE increases by 28–38% resulting in INR 6.45 kWh, INR 5.12 kWh, INR 4.93 kWh, and INR 4.83 kWh for 10, 20, 25, 30 years, respectively. Thus, there exist no uniform relationship between LCOE and CAPEX. The data obtained since 2010 shows that CAPEX value reduced progressively, resulting in increased access to capital with longer tenures and low interest rates. Altogether, these factors have an impact and multiplicative implication on the numbers of LCOE and reverse auction prices.

12.3. Sensitivity to PPA Term

With low PPA term of 10 years, the value of LCOE is found to be around INR 5.16 kWh without assumptions of residual value. Furthermore, it is interesting to note that there is a drop in the LCOE value to INR 4.1 kWh for 20 years and to INR 3.86 kWh for 30 years (implies a difference of 24 paise from 20 years to 30 years). Thus, for a term of 20–25 years, it is better to acquire a decent value of LCOE for the given capital cost.

13. Multiple Criteria Decision Making (MCDM)

During 1970s, Multiple Criteria Decision Making (MCDM) and Analytic Hierarchy Process (AHP) were developed to make mathematical based decisions taking in account optimum contribution from experience, intuition and heuristics. A research conducted by Saaty (2008) and Bhushan et al. (2004), with the help of AHP provided easy understanding of decision-making process [44,45]. This systematic approach prioritizes the economics-based justification for the time being spent in decision-making to achieve a better quality output in finding the solution to the problem [44]. The AHP flow chart in Figure 6 demonstrates the implementation of this approach to problem applications.

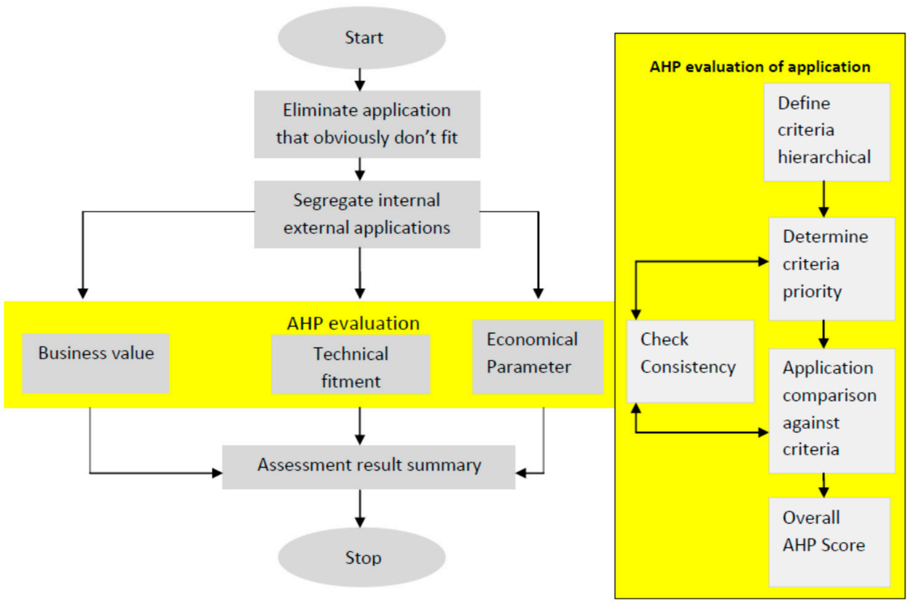

Figure 6. AHP method approach to support decision making process [44].

Figure 7 provides all-inclusive and coherent structures to understand the decision making process. These structures quantify the elements (various main categories and sub categories) by relating with other elements to achieve overall goals and evaluate alternate solutions. The ten main categories and seven sub categories are described in Tables 3 and 4, respectively. The following assumptions are considered for estimating the rank with beneficial and non-beneficial sub categories.

Table 4. Sub categories assumption (Beneficial and Non-Beneficial).

Case	Beneficial or Non-Beneficial
Case A	Considered all cases are Beneficial
Case B	Considered all cases are Non-Beneficial (Ignored Accelerated Depreciation consideration)
Case C	Considered Case 1 and Case 2 are Beneficial and all the remaining cases to be Non-Beneficial
Case D	Considered Case 3 and Case 4 are Beneficial and all the remaining cases to be Non-Beneficial
Case E	Considered Case 5 and Case 6 are Beneficial and all the remaining cases to be Non-Beneficial
Case F	Considered Case 7 and Case 8 are Beneficial and all the remaining cases to be Non-Beneficial
Case G	Considered Case 9 and Case 10 are Beneficial and all the remaining cases to be Non-Beneficial

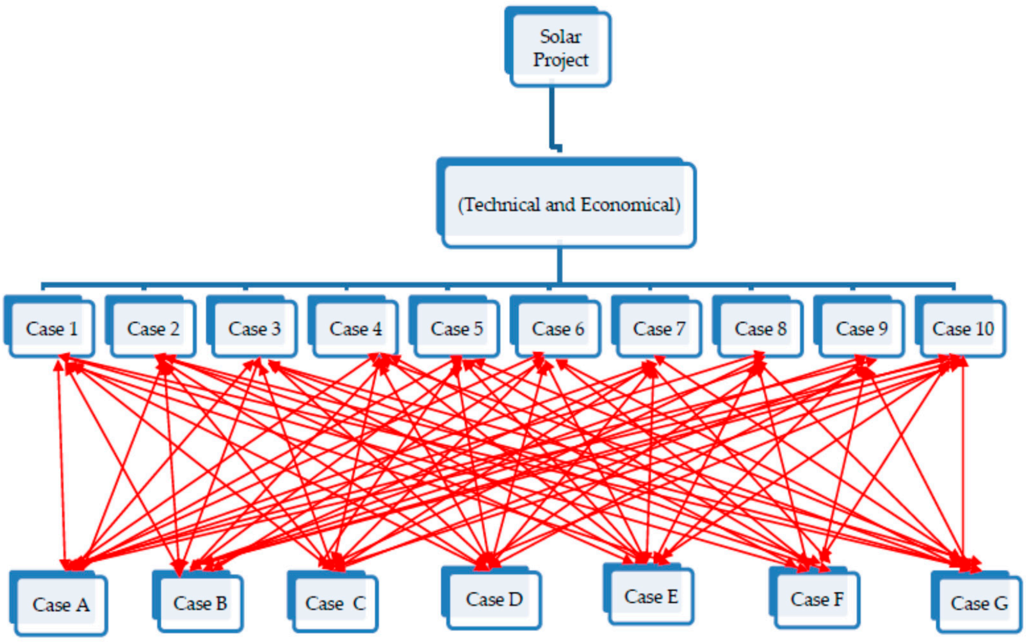

Figure 7. Classification of groups designed for a problem as per AHP method.

AHP deals with objective and subjective conclusions given by various individuals and group of constitute. This plays a vital role in decision making process and prioritizing the preference. In AHP, the decision problem is structured into a hierarchy of different sub-problems in order to perform techno-economical analysis. Using pair-wise comparison, the decision maker compares and contrasts each hierarchical element with the other, resulting in optimum outcome i.e., alternative cases with highest importance. The weights of an attribute with that of the other are scaled in 0–1 range.

The program is designed using MATLAB in order to satisfy the AHP needs. The instance when AHP relative weight is applied, the vector considered for pair-wise comparison matrix for the attributes such as normalized decision matrix and relative closeness of alternatives for ideal solution (both for Ideal mode weights and Relative mode weights) is tabulated in Table S3 for all the ten categories and seven sub-categories considered. Figures 8 and 9 represent graphical demonstrations of the data given in Table S3. Table 5 lists down the overall performance scores and rankings.

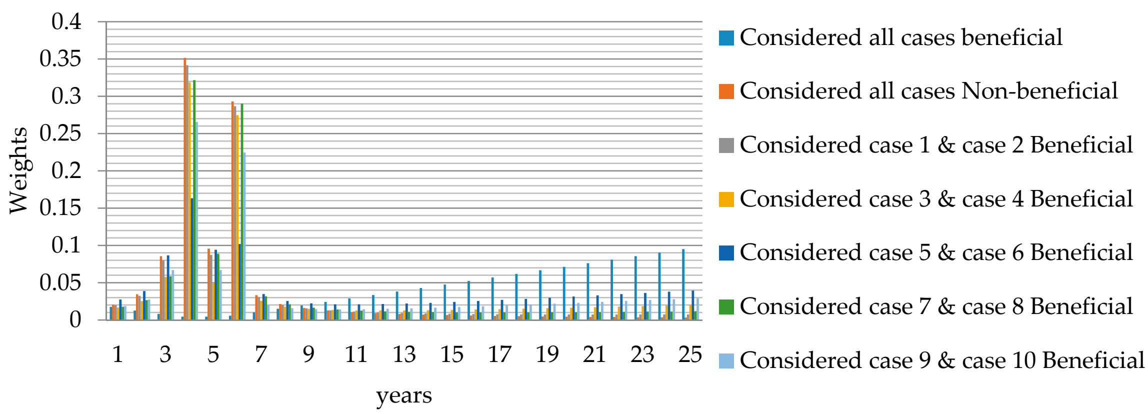

Figure 8. Weights chart for “Ideal Mode”.

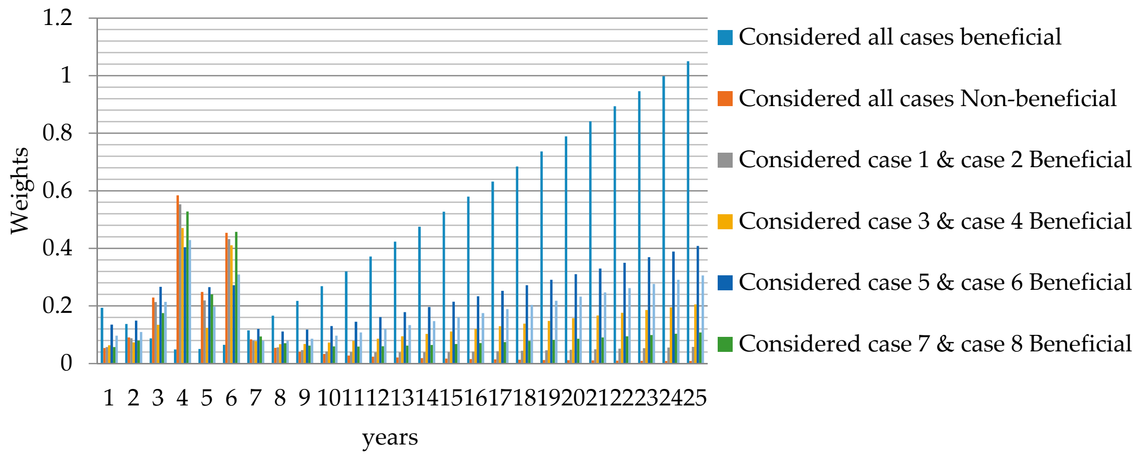

Figure 9. Weights chart for "Relative Mode".

Table 5. Various cases rank list exemplify for the decision making.

Years	Hierarchy Rank List for Different Cases with Respect to Years						
	Case A	Case B	Case C	Case D	Case E	Case F	Case G
1	25	4	4	4	4	4	4
2	24	6	6	6	6	6	6
3	23	5	5	3 [a]	5	5	3 [a]
4	22	3 [a]	3 [a]	5	3 [a]	3 [a]	5
5	21	2 [b]	2 [b]	7	25	7	25
6	20	7	7	2 [b]	2 [b]	2 [b]	24
7	19	8	8	25	24	8	2 [b]
8	18	1 [c]	1 [c]	24	23	1 [c]	23
9	17	9	9	23	7	9	22
10	16	10	10	22	22	10	21
11	15	11	11	8	21	11	20
12	14	12	12	21	20	25	19
13	13	13	13	1 [c]	19	12	18
14	12	14	14	20	18	24	7
15	11	15	15	19	1 [c]	23	17
16	10	16	16	18	17	13	1 [c]
17	9	17	17	9	16	22	16
18	1 [c]	18	18	17	8	21	15
19	8	19	25	16	15	14	14
20	2 [b]	20	24	15	14	20	8
21	7	21	19	10	9	19	13
22	3 [a]	22	23	14	13	15	12
23	6	23	20	11	12	18	9
24	5	24	22	13	10	16	11
25	4	25	21	12	11	17	10

Note: c, b, a indicate the upper standard for the first three rank list in different years.

From Figure 8 and Table S3, weights for "Ideal Mode "can be realized each year. Similarly, from Figure 9 and Table S3, weights for "Relative Mode" can be realized each year. From this interpretation, 4th and 6th year show high significance compared to all cases. The overall scores and rankings of various cases are tabulated in Table 5. Analysis carried out using MCDM-AHP method from Tables 4 and 5 inferred that, there are several stages in the Life Cycle Cost Analyses (LCCA) and various insights on investment planning and decision making. Table 5 rank list exemplifies the decision making support. From the result, highest rank during 8th year has been obtained by Case B, Case C and Case F. Except Case A, for the first and second year ranks obtained are 4th and 6th, respectively. These inferences will help provide support in decision making.

14. Opportunities and Challenges in Solar Energy Sectors

The opportunities for megawatt generation from utility-scale projects are abundant, whereas for generation of kilowatt and Wattage scale projects such as Rooftop projects are fewer. The opportunity grows with change in policies and replacement of inferior quality mechanisms. There is a need for complete refining and restructuring of the central government subsidy policies in order to achieve the objectives. The central government should streamline, standardize and collate all the state government policies. The lack of growth in the solar industry is due to involvement of various factors such as lower popularity for Roof Top systems, bank guarantee, financial mechanism, power evacuation, transmission line, and third party sales. Though experiences were gained during the period 2000–2016, there is no reflection of those experiences in implementation, due to which the gestation period and learning period has also increased. The gap between the reality and the projected expectation is too large. In terms of bank guarantee, despite the government priorities, banks still resist to offer loans on solar power projects. The governments also hesitate to intervene and solve such financial assistance issues. Though there are opportunities abundantly available, the search is conducted only at places where there is no opportunity. This bottleneck is creating immense effects on growth, affecting local manufacturing due to non-achievement of results that could have been easily achieved. In this perspective, all solar companies must convey uniform message to society regarding price, quality, specification etc.

15. Conclusions

This article offers new contributions and comparisons of the Indian electricity markets after investigating patterns of awareness, access, and public perceptions. The LCOE for large and utility scale projects is performed through a unique model built for solar infrastructure which focuses on optimization of its design. For every project, the optimum solution can be derived from a number of factors such as continuous process of system analysis, attention to performance details and design matching as per the site characteristics.

It is concluded that Solar Parks Development Cost with AD (Case 7) is more attractive than the other cases. Rooftop solar projects have not attained governments anticipated level in India. Due to demonetization, the rooftop solar project growth has been accelerated for availing Accelerated Depreciation (AD) benefits in India. Significantly, AD plays a vital role for Rooftop solar projects and captive solar projects. The LCOE of rooftop BOOT (Build, Own, Operate, and Transfer) model solar projects is calculated as INR 2.7928 kWh and the selling price is possible between INR 4.50 kWh to INR 7 kWh based on grid parity.

The current study contributes to the economic viability of PV-grid installation system in India based on the actual system performance data. MCDM based AHP method is used to analyze the best categories among the main groups and sub groups. The decision is made based on the rank priority mentioned in Table 5. AD impacts NPV and IRR and therefore AD will help those who invest their money into solar project for their own premises/project.

LCCA of the Photovoltaic system is dependent on material characteristics, equipment technology, overall system performance, labor cost, capital investment and variation of insolation levels. This analysis will be helpful for various stakeholders such as decision makers, policy makers, investors and customers to understand the existing position, obstructions and challenges for better development and execution in the field of solar PV.

Supplementary Materials: Supplementary materials can be found at www.mdpi.com/2071-1050/9/5/820/s1, Figure S1: Illustration of Global Horizontal Solar Irradiance in India, Figure S2: Classification of various Solar (PV) system models, Figure S3: Special Purpose Vehicle (SPV), Figure S4: Cost comparison between and grid tied and off grid system, 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, Figure S7: Comparison of Energy yield from 1 kW Grid Tied and Off Grid system, Figure S8: Comparison of Energy yield from Grid Tied and Off Grid system of various system sizes, Figure S9: Comparison of Solar Tariff and CERC Tariff considering major power consumers in LT, Figure S10: Comparison of Solar Tariff and CERC Tariff considering major power consumers in HT, Figure S11: Payback cost comparisons between Grid Tied and Off Grid system, Figure S12: Payback cost comparison between Central Inverter and String Inverter (10 kW, 50 kW, 100 kW), Figure S13: Levelised Cost of Energy (LCOE), Figure S14: Internal Rate of Return (IRR), Figure S15: Net Present Values (NPV), Figure S16: Profitability Index (PI), Figure S17: Cost benefits analysis of 1 MW solar energy project at interest 13% in India, Figure S18: Cost benefits analysis of 1 MW solar energy project at interest 6% in India, Table S1: State wise installed solar power capacity and proposed capacity in 2022, Table S2: Classification of various Solar PV system models and its suitability, Table S3: Realistic weights for the "Ideal Mode" and "Relative Mode".

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