CHAPTER 4

ECONOMIC ANALYSIS ON SOLAR PV ENERGY CONVERSION SYSTEM

4.1 INTRODUCTION

Energy economics is a broad area of science that covers energy supply and utilization. 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 markets to meet the increasing energy demands. Many initiatives are in progress across the globe to harness solar energy with cooperation from public, private and governments. However, the major obstacle in popularizing the solar energy utilization in India is the perception of high installation cost among the public and private sectors. 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 literature, studies were conducted predominantly assessing the technical performance of the installation, in terms of performance ratio and energy yield, leaving aside its economic aspects.

About 18% of the global populations do not have access to electricity. This is due to the absence of sufficient infrastructure like power grids. These people live in remote areas and find it difficult to live without electricity for their daily needs (Ghassan Zubi et al. 2016). From the year 2015, the utility-scale solar power plants are significantly growing in India. In
A study concluded by Saptak Ghosh et al (2015), Rooftop Photovoltaic (RTPV) systems not yet reached at the expected level. Hence, there is a need to standardize various policy incentives schemes for promoting RTPV in India. Though the growth of utility-scale solar power plant sector in India is high, most of the state governments now-a-days promote RTPV systems due to its multiple advantages such as non-requirement of ground-level land, reduction in gestation period and reduced Transmission and Distribution (T&D) losses due to decentralization in power generation and its consumption. Further replacement of huge Diesel Generator (DG) sets resulting in environmental benefits, reduced system congestion that leads to higher self-consumption and capacity buildings of local electricians are also added advantages. For instance, when 1 kWh is generated at a load center, it requires a generation of 1.5 kWh of fossil fuel-based plants (Muyiwa et al. 2015). Being a pilot project in India, the technological advancements in BIPV (Building-Integrated Photovoltaic) is still in nascent stage in terms of feasibility and viability.

A grid-connected system is effective and efficient for the residential electricity users since they are able to reduce their electricity consumption and independent from utility power. They can further generate electricity from environmental-friendly renewable energy resources as well. In this scenario, it is the need of the hour to evaluate the performance of an actual PV system installation to find out the potential for PV Energy production in an area.

In the Indian society, there are various myths and perceptions regarding economics of electricity generated through solar PV system. Therefore, this chapter will address the various LCCA and economic analysis for all types of consumers in the Indian electricity market. Various Life Cycle Cost (LCC) analyses and economics analyses are elucidated for the residential, industrial, commercial, institutional and all type of consumers in
India. 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 MCDM whereas AHP is applied to support the decision.

Furthermore, this investigation elucidates the strategies involved in
networking of stakeholder processes, policy measures, energy economics
evaluation, techno-economic analysis and grass root innovation using MCDM
method.

4.2 ENERGY ECONOMICS

Energy economics has explored various energy products and its
utilization by human beings followed by its consequences which focus on
how the economic driving force behaves and interacts. This branch of science
is broadly classified into microeconomics and macroeconomics in which the
former evaluates the behaviour of basic elements that includes markets,
individuals (such as households, firms, buyers and sellers), the interactions
between these two and the outcome of such interactions. While the latter
analyze the whole economy and the factors that impact it, such as inflation,
economic growth, resources unemployment (Labor, Capital and the Land) and
the public policies that address the above-mentioned issues (monetary, fiscal
and other such policies). Here the entire economy means the aggregated
production, its consumption, savings and the investment. This leads to rise in
need for strategies that emphasize the growth of solar energy sector through
National and State-level policy measures, targets and 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. This provides key insights about solar energy sector
followed by the bottlenecks in it and the obstacles present in harvesting the
solar energy.
4.3 ECONOMIC PARAMETER FOR SOLAR PV ENERGY TARIFF

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;

6) Architectural 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

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.
4.4 SPECIAL PURPOSE VEHICLE

In solar energy market, there are various stakeholders present such as investors, lenders, project developers, utility, Engineering Procurement Construction (EPC) contractors, service companies, management, and insurance companies who are grouped under Special Purpose Vehicle (SPV). SPV is the 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 either 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 MNRE and State Governments. 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 which the SPVs of project-specific self-financing companies possess tight project governance as shown in the Figure 4.1. 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 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.

Figure 4.1 Special Purpose Vehicles
4.5 METHODOLOGY OF LIFE CYCLE COST ANALYSIS

The LCCA studies aims at finding out mainly the cost-effective decision between various rival alternatives in terms of procure, build, own, operate, maintain and dispose of an object or process. Every stage is equally appropriate to be implemented on technical grounds. The utility to inspect projected LCC for competing investment capital; O&M project solutions and allows for appropriate comparison of alternatives of different capital values and time-span. Sieglinde K. Fuller et al (1995) and Priya D. Lavappa et al (2016) elucidate various LCCA for energy price indices and discount factors. Alex B. Lekov et al (2010) presented clear strategy chart and sequence process for LCCA. The LCCA diagram can be applied to address solar PV power plant projects in various processes such as cost of buying components, installing of plant and the operating costs.

(Source: Alex B. Lekov et al 2010)

**Figure 4.2 Workflow of Life-Cycle Cost Analysis**
Figure 4.2 shows the LCCA for entire installation cost and operating cost which are used to calculate for the payback periods and the LCC of each system as per the size of the project. Presently, India has different market structures for solar energy sector. Hence, provides an overview of Indian markets and analyses of cost of solar energy systems that range from 1kW to 1MW. Similarly various system configurations have been studied and the results are presented in the subsequent sections.

The flowchart represented in Figure 4.3 depicts the design, development and validation of various solar PV system configurations and respective system costing models for the payback period analysis.

(Source: Alex B. Lekov et al 2010, H. Islam et al. 2015 and own depiction)

**Figure 4.3 Used methodologies for Life Cycle Costing**
### 4.6 SOLAR (PV) SYSTEM COST

Solar PV plants can be broadly classified into large scale utility (>50 MW<sub>p</sub>), medium scale (50 kW<sub>p</sub>–1 MW<sub>p</sub>) and small scale rooftop system (1–50 kW<sub>p</sub>). The installation of a small scale rooftop system costs around INR 65,000–100,000 kW<sub>p</sub> for grid tied system and INR 85,000–125,000 kW<sub>p</sub> for off grid. For medium scale, the cost incurred is somewhere between INR 55,000–65,000 kW<sub>p</sub> for grid tied system. For larger farms and utility scale (MW<sub>p</sub>) projects, the market cost varies from INR 39,000 kW<sub>p</sub> to INR 55,000 kW<sub>p</sub>. The cost for installing a solar PV system (inclusive of its components and acquired land area) in India lies somewhere between INR 42.65367 W<sub>p</sub> and INR 120.89 W<sub>p</sub>. A number of suggestions and objections were received from various stakeholders with regards to benchmarking the capital cost for solar PV plant. CERC benchmarked the capital cost and the detailed breakdown of preliminary and pre-operative expenses combined with overall capital cost for FY 2012–2017 as listed in Table 4.1. For the FY 2016–2017, the EPC costs of INR 53.4769 W<sub>p</sub> for utility scale or large commercial in percentage is envisaged and displayed in Figure 4.4.

![Figure 4.4 EPC costs per MW in percentage for utility scale and large scale](image-url)
In Figure 4.4, 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. In Figure 4.5, 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 the available configuration in the market.

![Cost comparison between grid tied and off grid system](image)

**Figure 4.5 Cost comparison between and grid tied and off grid system**

The consequence of supply side seems to be redundant since both module and inverter prices have been coming down faster than expected as shown in Figure s from Figure 4.6 to Figure 4.9.
Figure 4.6 Solar module price indexes from 2015 to 2017

Figure 4.7 Inverter price indexes from 2015 to 2017

Figure 4.8 EPC project price index from 2015 to 2017
The government of India has recommended mandatory rooftop solar installations for buildings exceeding specified size and/or power consumption thresholds under the model ‘Building Bye Laws’. The following states and union territories - Uttar Pradesh, Haryana, Chandigarh and Chhattisgarh have adopted these regulations so far. It is certain that there are EPC cost differences between utility scale solar projects and rooftop solar project. Figures 4.8 and 4.9 provide the details of both EPCs in India.

![Figure 4.9 Rooftop EPC project price index from 2015 to 2017](image)

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, but 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 4$W_p$ 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 cost, at utility scale, was observed to be 50-65% of the total costs in India, while it was only 25-30% in the US (CERC Survey, 2016).
Table 4.1 Central Electricity Regulatory Commission (CERC) benchmark capital cost and detailed breakup

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change in Cost over Past 5 Years</td>
<td>Cost in INR Lakhs/MW</td>
<td>% of Total Cost</td>
<td>Change from Previous Year</td>
<td>Cost in INR Lakhs/MW</td>
<td>% of Total Cost</td>
</tr>
<tr>
<td>1</td>
<td>PV Modules Cost</td>
<td>−4.68%</td>
<td>328.39</td>
<td>61.96%</td>
<td>7.10%</td>
<td>332.35</td>
</tr>
<tr>
<td>2</td>
<td>Land Cost</td>
<td>48.81%</td>
<td>25</td>
<td>4.70%</td>
<td>0.59%</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Civil and General Works</td>
<td>−62.96%</td>
<td>35</td>
<td>6.60%</td>
<td>−1.65%</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>Mounting Structures</td>
<td>−66.67%</td>
<td>35</td>
<td>6.60%</td>
<td>−1.65%</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>Power Conditioning Unit</td>
<td>−41.67%</td>
<td>35</td>
<td>6.60%</td>
<td>−0.82%</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>Evacuation Cost up to Inter-connection Point (Cables and Transformers)</td>
<td>−58.10%</td>
<td>44</td>
<td>8.30%</td>
<td>−0.78%</td>
<td>55</td>
</tr>
<tr>
<td>7</td>
<td>Preliminary and Pre-Operative Expenses including IDC and Contingency</td>
<td>−65.46%</td>
<td>27.63</td>
<td>5.21%</td>
<td>−2.79%</td>
<td>48.5</td>
</tr>
<tr>
<td></td>
<td>Total Capital Cost</td>
<td>−34.22%</td>
<td>530.02</td>
<td></td>
<td></td>
<td>605.85</td>
</tr>
</tbody>
</table>
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 PV plant need to generate electricity from the solar energy in wholesale level and wholesale price is applicable whereas for a home-scale solar plant, the price and the level need to be only a ‘retail’ in spite of using the same solar panel at both places. So, if a manufacturer is able to ensure the affordability of installed cost of retail solar PV 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 for utility scale or large commercial, which is the lowest across the globe. The presence of excellent and 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, starting 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 is 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/kWp/year (wholesale) and INR 11275 / kWp/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 kWp 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 Power Purchase Agreements (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 Internal Rate of Return (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.

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. The small-scale solar projects show less returns and IRR due to EBITDA and for large scale utility projects, the 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).

### 4.7 PERFORMANCE STUDY OF SOLAR PV 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. Padmavathi et al. (2013) investigated the efficiency of solar PV panel, inverter and overall system efficiency of grid-tied solar PV system in India. The results showed the actual performance and efficiency of the solar system.

In Figure 4.10, solar energy generated (kWh/MW) per month from both Crystalline and Thin Film technologies are compared for the year 2015 using the data collected from the Ministry of New and Renewable Energy (MNRE). The monthly Capacity Utilisation Factor (CUF) (%) for each technology is represented in Figure 4.11 which concludes that the average energy generation for both technologies is nearly the same. Figure 4.12 compares the month wise energy yield of a 1 kW Grid Tied and Off Grid system. Figure 4.13 discusses the units (kWh)/day generated by 1 kW, 2 kW, 3 kW, 5 kW and 10 kW Grid Tied and Off Grid systems.
Figure 4.10 Electrical energy generated (kWh/MW) using solar PV for both Crystalline and Thin Film technologies

Figure 4.11 CUF in (%) for each technology
Figure 4.12 Comparison of energy yield from 1 kW Grid Tied and Off Grid system

Figure 4.13 Comparison of Energy yield from Grid Tied and Off Grid system of various system sizes
4.8 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.

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. 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. 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.

4.9 GRID PARITY

Grid Parity is a simplification process that compares the LCOE with the marginal cost of electricity offset obtained from the grid. To calculate the payback period, financial analysis is performed utilizing Net Present Value (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 domestic and retail electricity prices are still low. 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 Wp installed) or else the policy for subsidy support should be achieved. According to the recent market updates, INR/Wp installed cost point has reached utility scale (INR 39–54.76 Wp 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 PV projects have already reached grid parity. Based on reference (www.bijlibachao.com) and Government Utility tariff compared with Solar Tariff, the major power consumers for the next 25 years for LT and HT connections is represented graphically in the Figure s, 4.14 and 4.15 respectively.
Figure 4.14  Comparison of Solar Tariff and CERC Tariff considering major power consumers in LT

Figure 4.15  Comparison of Solar Tariff and CERC Tariff considering major power consumers in HT
Various states have different SERC and they fix tariff for their utility. The Figure 4.16 is comparing solar tariff with government utility tariff for commercial and industrial consumers. The grid parity calculates variable tariff after adjusting fixed charges and Time of Day (ToD) charges. Rooftop solar power cost is calculated for 100kW system and the associated factors with an escalation of 2% per annum.

The Figure 4.17 depicts grid parity status for residential consumers. Solar power has not achieved grid parity with residential consumption less than 400kWh / month.
Figure 4.17 Comparison of grid parity status for residential consumers

Figure 4.18 Comparison of grid tariff with solar power cost considering the AD benefits for commercial consumers
Figure 4.19 Comparison of grid tariff with rooftop solar power cost for industrial consumers

Solar power has achieved grid parity with commercial tariffs in nine states and in another four states with Accelerated Depreciation (AD) benefits. The Figure 4.18 illustrated viable, non-viable and viable AD benefits for commercial consumers of solar power. Similarly, the Figure 4.19 compares rooftop solar power cost with grid power tariff for commercial consumers. From the result, it can be inferred that among the Indian states, 13 states are viable without AD benefits, 6 states are viable with AD benefits and remaining states are not viable at all.

Solar power has achieved grid parity with industrial tariffs in three states and in another eight states with AD benefits. The Figure 4.20 illustrated the viable, non-viable and viable AD benefits in solar power. Similarly, the Figure 4.21 compares rooftop solar power cost with grid power tariff for industrial consumers. From the result, it can be inferred that among the states, 14 states are found to be viable without AD benefits, 3 states are viable with AD benefits and 4 states are not viable at all.

Assumptions:
1. Additional charges (demand charges, fixed charges, Time of Day (ToD), Excise Duty (ED), Fuel Surcharges, etc.) for commercial consumers have been assumed as INR 1.00/unit in states where actual additional charges were not available.
2. Cost of solar power is calculated assuming tariff escalation of 3% per annum for 25 years.

Source: Bridge to India
Figure 4.20 Comparison of grid tariff with solar power cost considering the AD benefits for industrial consumers

Figure 4.21 Comparison of grid tariff with rooftop solar power cost for industrial consumers

Assumptions:
1. Additional charges (demand charges, fixed charges, Time of Day (TOD), Excise Duty (ED), Fuel Surcharge, etc.) for commercial consumers have been assumed as INR 1.00/unit in states where actual additional charges were not available.
2. Cost of solar power is calculated assuming tariff escalation of 3% per annum for 25 years.

Source: Bridge to India
4.10 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 (PPA) 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 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 even INR 1 lakh/kW_p (1–5 kW_p scale rooftop). If the annual operating expenses are calculated as 2% of CAPEX, the OPEX value would be INR 960 kW_p. The solar energy economics model considered from an Indian perspective will help to realize solar PV system of various capacities.

The Figure 4.22 compares the payback cost among the grid tied and off grid Solar Power Plant for 1 kW, 3 kW, 5 kW and 10 kW.
Figure 4.22 Payback cost comparisons between Grid Tied and Off Grid system

The Figure 4.23 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 decentralized connections in each sequence of solar panel as used in solar power plant. 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 which is presented in Figure 4.24. 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 compared to worldwide, which is refined in terms of scale, better supply chains and cheapest workforce.
Payback cost comparison between Central Inverter and String Inverter

**Figure 4.23** Payback cost comparison between Central Inverter and String Inverter (10 kW, 50 kW and 100 kW)

**Figure 4.24** Comparison between Central Inverter and String Inverter for 1 MW
A comparative study of Central and String Inverters, both in Industrial and Commercial applications, has been depicted in the Figure 4.25.

Figure 4.25 Comparison of payback Cost for 1 MW solar power plant utilizing Central and String Inverter in Industrial and Commercial applications

4.11 COST CONSIDERATION FOR MW SOLAR PV POWER PLANT

The project cost takes into consideration the various elements such as CERC benchmark of capital cost, preliminary and pre-operative expenses. 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.

4.11.1 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 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 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. But 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.

4.11.2 Subsidy and Accelerated Depreciation (AD)

The Accelerated Depreciation is determined by the government policy and is predicted to reduce up to 40% by 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 to pay regularly and on time. This can significantly improve economics to about (note: IRR computed for ≥15 years) 14–15% projected IRR for residential, 20–22% projected 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.
4.12 LEVELIZED COST OF ENERGY AND NET PRESENT VALUE

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 the different means of energy production which is done using LCOE. 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. LCOE was presented by Darling et al. (2011) whereas the Internal Rate of Return (IRR) and Net Present Value (NPV) (Source: http://www.immagic.com/eLibrary /ARCHIVES/GENERAL/WIKIPEDI/W120622I.pdf) equations were referred from literatures. 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.

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 (Adaramola, M.S 2015)).
LCOE remains to be the fairest comparison among the energy supply technologies, in which the energy produced in 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 possible to get greater insights on the projected costs for a solar energy project that can provide enriched information to the stakeholders.

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 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.

It can be represented as

\[
LCOE = \frac{\text{Lifecycle cost}}{\text{Lifetime energy production}}
\]  

\[LCOE = \frac{\text{Project cost} + \sum_{n=1}^{N} \frac{AO}{(1+DR)^n} - \frac{RV}{(1+DR)^n}}{\sum_{n=1}^{N} \frac{\text{Initial kWh} x (1-SDR)^n}{(1+DR)^n}} \]  

(4.1)  

(4.2)
The equation components are AO (Annual Operations cost), DR (Discount Rate), RV (Residual Value), and SDR (System Degradation Rate), whereas ‘N’ denotes the number of system operation years. The economic LCOE is computed by the equation (4.2) 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 (4.3). 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).

\[
\text{LCOE} = \frac{\text{PCI} - \sum_{n=1}^{N} \frac{\text{DEP+INT}}{(1+\text{DR})^n} \text{TR} + \sum_{n=1}^{N} \frac{\text{LP}}{(1+\text{DR})^n} + \sum_{n=1}^{N} \frac{\text{AO}}{(1+\text{DR})^n} (1-\text{TR}) - \frac{\text{RV}}{(1+\text{DR})^n} }{\sum_{n=1}^{N} \frac{\text{Initial kWh} \times (1-\text{SDR})^n}{(1+\text{DR})^n}} \tag{4.3}
\]

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. 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, 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.

\[
\text{Real LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1 + D \text{R}^\text{nominal})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1 + D \text{R}^\text{real})^n}}
\]

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\text{real} denote the Real Discount Rate (No inflation) whereas the DR\text{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.

\[
\text{Nominal LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1 + D \text{R}^\text{nominal})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1 + D \text{R}^\text{real})^n}}
\]

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 the PV cases.

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.
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. The results will be based on distribution and so the current research focused on assumptions on the basis of inflation, operating costs, (decoupled) sunlight variation and panel performance.

4.13 INTERNAL RATE OF RETURN

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.

\[ NPV = NET \times \frac{1}{(1+IRR)^{Year}} = 0 \] (4.6)

All cash flows (both positive and negative) from a particular investment should be equal to zero. 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”.

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. Theoretically, an individual or a firm should undertake, whatever may be the projects or investments, when the IRRs 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. 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.

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.

\[
NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}
\] (4.7)

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 there.

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. It is not possible always to find the value analytically. In such case, either graphical methods or numerical methods must be used.
If an investment may be given by the sequence of cash flows

<table>
<thead>
<tr>
<th>Year (n)</th>
<th>Cash flow (C_n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-53002000</td>
</tr>
<tr>
<td>1</td>
<td>9058972</td>
</tr>
<tr>
<td>2</td>
<td>9112578</td>
</tr>
<tr>
<td>3</td>
<td>9164697</td>
</tr>
<tr>
<td>4</td>
<td>9263950</td>
</tr>
</tbody>
</table>

Then the IRR 'r' is given by

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

Numerical solution

Since the above is a manifestation of the general problem of finding the roots of the equation \( \text{NPV}(r) \), there are many numerical methods that can be used to estimate ‘r’. For example, using the second method, \( r \) is given by

\[ r_{n+1} = r_n - \text{NPV}_n \left( \frac{r_n - r_{n-1}}{\text{NPV}_n - \text{NPV}_{n-1}} \right) \]  \( (4.8) \)

\[ r_{n+1} = r_n - \text{NPV}_n \left( \frac{r_n - r_{n-1}}{\text{NPV}_n - \text{NPV}_{n-1}} \right) (1 - 1.4 \frac{\text{NPV}_{n-1}}{\text{NPV}_{n-1} - 3\text{NPV}_n + 2C_0}) \]  \( (4.9) \)

where ‘\( r_n \)’ is considered as 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’. 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. 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.

**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 to put it differently, it is a quadratic function of the discount rate r/(1 + r); the highest NPV is −0.75, for r = 100%.

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.

**4.14 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 targets.

The benchmark capital cost norm for the FY 2016–2017 is INR 530.02 lakhs/MW. The break up details and guidelines put forth by CERC (Table 4.1) are considered for the analysis.

Based on the present market situation, project cost investment plan has been classified with covering all segments of consideration. The investigation descriptions are tabulated in the table 4.2. The capital cost differs (in lakhs) for various categories of investment (INR) and the analysis is presented in table 4.3.

**Table 4.2 Project Cost Investment (INR) for different consideration**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Case No</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Case 1</td>
<td>Solar Panel costs expected to fall 5% from CERC Benchmark Cost with AD</td>
</tr>
<tr>
<td>2</td>
<td>Case 2</td>
<td>Solar Panel costs expected to fall 5% from CERC Benchmark Cost without AD</td>
</tr>
<tr>
<td>3</td>
<td>Case 3</td>
<td>Self Solar Project EPC Development Cost with AD</td>
</tr>
<tr>
<td>4</td>
<td>Case 4</td>
<td>Self Solar Project EPC Development Cost without AD</td>
</tr>
<tr>
<td>5</td>
<td>Case 5</td>
<td>Rooftop Solar Project Cost with AD</td>
</tr>
<tr>
<td>6</td>
<td>Case 6</td>
<td>Rooftop Solar Project Cost without AD</td>
</tr>
<tr>
<td>7</td>
<td>Case 7</td>
<td>Solar Parks Development Cost with AD (Lowest Price in India)</td>
</tr>
<tr>
<td>8</td>
<td>Case 8</td>
<td>Solar Parks Development Cost without AD (Lowest Price in India)</td>
</tr>
<tr>
<td>9</td>
<td>Case 9</td>
<td>CERC Benchmark with AD (2016–2017)</td>
</tr>
<tr>
<td>10</td>
<td>Case 10</td>
<td>CERC Benchmark Cost without AD (2016–2017)</td>
</tr>
</tbody>
</table>
The annual net cash flow, LCOE, IRR, NPV and Profitability Index (PI) for the solar PV projects are estimated using the equations (1)–(9) given in the reference. The Figure 4.26 represents the annual net cash flow (in INR) of ten categories (Cases 1–10) for a span of 25 years. Table 4.3 lists various categories of investment along with its project cost and metrics.

![Annual net cash flow (INR) of ten categories (Cases 1–10).](image)

Based on the above equation, it has to evaluate the performance of an actual solar PV system and investment LCOE, IRR, NPV, and Profitability Index were arrived for the considerations of about 10 cases which are depicted in the figures, 4.27, 4.28, 4.29 and 4.30 respectively.
Figure 4.27 Levelised Cost of Energy (LCOE)

Figure 4.28 Internal Rate of Return (IRR)
Figure 4.29 Net Present Values (NPV)

Figure 4.30 Profitability Index (PI)
Table 4.3 Various categories of investment with project cost (INR) in Lakhs and its metrics

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

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

4.14.2 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 got 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.
4.14.3 Sensitivity to PPA Term

With low PPA term of 10 years, the value of LCOE is found to be around INR 5.16 /kWh - INR 5.90 /kWh without the assumptions of residual value. Furthermore, it is interesting to note that there is a drop in the LCOE value to INR 4.1 /kWh - INR 4.76 /kWh for 20 years and to INR 3.86 /kWh - INR 4.50 /kWh for 25 years (implies a difference of 24-26 paise from 20 years to 25 years). Thus, for a term of 20–25 years, it is better to acquire a decent value of LCOE for the given capital cost.

4.15 MULTIPLE CRITERIA DECISION MAKING

During 1970s, Multiple Criteria Decision Making (MCDM) and Analytic Hierarchy Process (AHP) were developed to make mathematics-based decisions taking in account the optimum contribution from experience, intuition and heuristics.

![AHP method approach to support decision making process](image)

**Figure 4.31** AHP method approach to support decision making process
A research conducted by Saaty (2008); Bhushan et al. (2004), with the help of AHP provided easy understanding of decision-making process. 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. The AHP flow chart in Figure 4.31 demonstrates the implementation of this approach to problem applications.

Figure 4.32 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 4.2 and 4.4, respectively. The following assumptions are considered for estimating the rank with beneficial and non-beneficial sub categories.

**Table 4.4 Sub categories assumption (Beneficial and Non-Beneficial).**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Case</th>
<th>Beneficial or Non-Beneficial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Case A</td>
<td>Considered all cases are Beneficial</td>
</tr>
<tr>
<td>2</td>
<td>Case B</td>
<td>Considered all cases are Non-Beneficial (Ignored Accelerated Depreciation consideration)</td>
</tr>
<tr>
<td>3</td>
<td>Case C</td>
<td>Considered Case 1 and Case 2 are Beneficial and all the remaining cases to be Non-Beneficial</td>
</tr>
<tr>
<td>4</td>
<td>Case D</td>
<td>Considered Case 3 and Case 4 are Beneficial and all the remaining cases to be Non-Beneficial</td>
</tr>
<tr>
<td>5</td>
<td>Case E</td>
<td>Considered Case 5 and Case 6 are Beneficial and all the remaining cases to be Non-Beneficial</td>
</tr>
<tr>
<td>6</td>
<td>Case F</td>
<td>Considered Case 7 and Case 8 are Beneficial and all the remaining cases to be Non-Beneficial</td>
</tr>
<tr>
<td>7</td>
<td>Case G</td>
<td>Considered Case 9 and Case 10 are Beneficial and all the remaining cases to be Non-Beneficial</td>
</tr>
</tbody>
</table>
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-economic 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. At 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 (Ideal mode weights) is presented in Table 4.5 and Relative Mode weights are tabulated in Table 4.6 for all the ten categories and seven sub-

Figure 4.32 Classification of groups designed for a problem as per AHP method
categories considered. The Figures 4.33 and 4.34 represent graphical demonstrations of the data tabulated in Tables 4.5 and Table 4.6. Table 4.7 lists down the overall performance scores and rankings.

Table 4.5 Realistic weights for the “Ideal Mode”

<table>
<thead>
<tr>
<th>Years</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
<th>Case D</th>
<th>Case E</th>
<th>Case F</th>
<th>Case G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>0.0176</td>
<td>0.0206</td>
<td>0.0198</td>
<td>0.0167</td>
<td>0.0273</td>
<td>0.0177</td>
<td>0.0187</td>
</tr>
<tr>
<td>Year 2</td>
<td>0.0125</td>
<td>0.0345</td>
<td>0.0324</td>
<td>0.0253</td>
<td>0.0387</td>
<td>0.0266</td>
<td>0.0274</td>
</tr>
<tr>
<td>Year 3</td>
<td>0.008</td>
<td>0.0855</td>
<td>0.0799</td>
<td>0.0577</td>
<td>0.0867</td>
<td>0.0585</td>
<td>0.067</td>
</tr>
<tr>
<td>Year 4</td>
<td>0.0045</td>
<td>0.3516</td>
<td>0.3417</td>
<td>0.3187</td>
<td>0.1632</td>
<td>0.3217</td>
<td>0.2656</td>
</tr>
<tr>
<td>Year 5</td>
<td>0.0045</td>
<td>0.0957</td>
<td>0.0874</td>
<td>0.0502</td>
<td>0.0942</td>
<td>0.0887</td>
<td>0.0668</td>
</tr>
<tr>
<td>Year 6</td>
<td>0.0057</td>
<td>0.2931</td>
<td>0.2867</td>
<td>0.2748</td>
<td>0.1019</td>
<td>0.2901</td>
<td>0.2246</td>
</tr>
<tr>
<td>Year 7</td>
<td>0.0103</td>
<td>0.0332</td>
<td>0.0309</td>
<td>0.0257</td>
<td>0.0346</td>
<td>0.0318</td>
<td>0.02</td>
</tr>
<tr>
<td>Year 8</td>
<td>0.0149</td>
<td>0.0214</td>
<td>0.0203</td>
<td>0.0178</td>
<td>0.0254</td>
<td>0.021</td>
<td>0.0159</td>
</tr>
<tr>
<td>Year 9</td>
<td>0.0195</td>
<td>0.016</td>
<td>0.0156</td>
<td>0.0148</td>
<td>0.0222</td>
<td>0.0165</td>
<td>0.0145</td>
</tr>
<tr>
<td>Year 10</td>
<td>0.0242</td>
<td>0.0128</td>
<td>0.0129</td>
<td>0.0135</td>
<td>0.021</td>
<td>0.014</td>
<td>0.0141</td>
</tr>
<tr>
<td>Year 11</td>
<td>0.0288</td>
<td>0.0107</td>
<td>0.0112</td>
<td>0.0129</td>
<td>0.0209</td>
<td>0.0125</td>
<td>0.0143</td>
</tr>
<tr>
<td>Year 12</td>
<td>0.0335</td>
<td>0.0092</td>
<td>0.0101</td>
<td>0.0127</td>
<td>0.0213</td>
<td>0.0115</td>
<td>0.0149</td>
</tr>
<tr>
<td>Year 13</td>
<td>0.0382</td>
<td>0.0081</td>
<td>0.0092</td>
<td>0.0128</td>
<td>0.022</td>
<td>0.0109</td>
<td>0.0156</td>
</tr>
<tr>
<td>Year 14</td>
<td>0.0429</td>
<td>0.0072</td>
<td>0.0087</td>
<td>0.0131</td>
<td>0.023</td>
<td>0.0106</td>
<td>0.0164</td>
</tr>
<tr>
<td>Year 15</td>
<td>0.0476</td>
<td>0.0065</td>
<td>0.0082</td>
<td>0.0135</td>
<td>0.0242</td>
<td>0.0103</td>
<td>0.0174</td>
</tr>
<tr>
<td>Year 16</td>
<td>0.0524</td>
<td>0.0059</td>
<td>0.0079</td>
<td>0.014</td>
<td>0.0255</td>
<td>0.0102</td>
<td>0.0184</td>
</tr>
<tr>
<td>Year 17</td>
<td>0.0571</td>
<td>0.0054</td>
<td>0.0077</td>
<td>0.0146</td>
<td>0.0269</td>
<td>0.0102</td>
<td>0.0195</td>
</tr>
<tr>
<td>Year 18</td>
<td>0.0618</td>
<td>0.005</td>
<td>0.0075</td>
<td>0.0152</td>
<td>0.0283</td>
<td>0.0103</td>
<td>0.0206</td>
</tr>
<tr>
<td>Year 19</td>
<td>0.0666</td>
<td>0.0047</td>
<td>0.0074</td>
<td>0.0158</td>
<td>0.0298</td>
<td>0.0104</td>
<td>0.0218</td>
</tr>
<tr>
<td>Year 20</td>
<td>0.0713</td>
<td>0.0044</td>
<td>0.0074</td>
<td>0.0165</td>
<td>0.0314</td>
<td>0.0105</td>
<td>0.023</td>
</tr>
<tr>
<td>Year 21</td>
<td>0.0761</td>
<td>0.0041</td>
<td>0.0074</td>
<td>0.0172</td>
<td>0.033</td>
<td>0.0107</td>
<td>0.0242</td>
</tr>
<tr>
<td>Year 22</td>
<td>0.0808</td>
<td>0.0039</td>
<td>0.0074</td>
<td>0.0179</td>
<td>0.0346</td>
<td>0.0109</td>
<td>0.0254</td>
</tr>
<tr>
<td>Year 23</td>
<td>0.0855</td>
<td>0.0036</td>
<td>0.0074</td>
<td>0.0187</td>
<td>0.0362</td>
<td>0.0112</td>
<td>0.0267</td>
</tr>
<tr>
<td>Year 24</td>
<td>0.0903</td>
<td>0.0035</td>
<td>0.0074</td>
<td>0.0194</td>
<td>0.0379</td>
<td>0.0114</td>
<td>0.0279</td>
</tr>
<tr>
<td>Year 25</td>
<td>0.095</td>
<td>0.0033</td>
<td>0.0075</td>
<td>0.0202</td>
<td>0.0395</td>
<td>0.0117</td>
<td>0.0292</td>
</tr>
</tbody>
</table>
Figure 4.33 Weights chart for “Ideal Mode”

Table 4.6 Realistic weights for the “Relative Mode”

<table>
<thead>
<tr>
<th>Years</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
<th>Case D</th>
<th>Case E</th>
<th>Case F</th>
<th>Case G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>0.1935</td>
<td>0.0539</td>
<td>0.057</td>
<td>0.0633</td>
<td>0.1351</td>
<td>0.0572</td>
<td>0.0966</td>
</tr>
<tr>
<td>Year 2</td>
<td>0.137</td>
<td>0.0903</td>
<td>0.0876</td>
<td>0.073</td>
<td>0.1488</td>
<td>0.0793</td>
<td>0.1094</td>
</tr>
<tr>
<td>Year 3</td>
<td>0.087</td>
<td>0.2292</td>
<td>0.2136</td>
<td>0.1344</td>
<td>0.2666</td>
<td>0.1751</td>
<td>0.2139</td>
</tr>
<tr>
<td>Year 4</td>
<td>0.0489</td>
<td>0.584</td>
<td>0.5532</td>
<td>0.4705</td>
<td>0.4039</td>
<td>0.5279</td>
<td>0.4291</td>
</tr>
<tr>
<td>Year 5</td>
<td>0.0505</td>
<td>0.2488</td>
<td>0.2192</td>
<td>0.124</td>
<td>0.2651</td>
<td>0.2404</td>
<td>0.1971</td>
</tr>
<tr>
<td>Year 6</td>
<td>0.0647</td>
<td>0.4541</td>
<td>0.4321</td>
<td>0.4106</td>
<td>0.2719</td>
<td>0.4572</td>
<td>0.3093</td>
</tr>
<tr>
<td>Year 7</td>
<td>0.1152</td>
<td>0.0836</td>
<td>0.0791</td>
<td>0.0777</td>
<td>0.1198</td>
<td>0.0937</td>
<td>0.0793</td>
</tr>
<tr>
<td>Year 8</td>
<td>0.166</td>
<td>0.0544</td>
<td>0.0559</td>
<td>0.0671</td>
<td>0.1112</td>
<td>0.0702</td>
<td>0.0791</td>
</tr>
<tr>
<td>Year 9</td>
<td>0.217</td>
<td>0.0409</td>
<td>0.0465</td>
<td>0.0679</td>
<td>0.1179</td>
<td>0.0621</td>
<td>0.0862</td>
</tr>
<tr>
<td>Year 10</td>
<td>0.2683</td>
<td>0.0329</td>
<td>0.0419</td>
<td>0.0725</td>
<td>0.13</td>
<td>0.0592</td>
<td>0.0963</td>
</tr>
<tr>
<td>Year 11</td>
<td>0.3198</td>
<td>0.0276</td>
<td>0.0397</td>
<td>0.0789</td>
<td>0.1448</td>
<td>0.0589</td>
<td>0.1079</td>
</tr>
<tr>
<td>Year 12</td>
<td>0.3715</td>
<td>0.0237</td>
<td>0.0388</td>
<td>0.0862</td>
<td>0.1611</td>
<td>0.0599</td>
<td>0.1204</td>
</tr>
<tr>
<td>Year 13</td>
<td>0.4233</td>
<td>0.0208</td>
<td>0.0387</td>
<td>0.0942</td>
<td>0.1784</td>
<td>0.0619</td>
<td>0.1335</td>
</tr>
<tr>
<td>Year 14</td>
<td>0.4752</td>
<td>0.0186</td>
<td>0.0392</td>
<td>0.1026</td>
<td>0.1963</td>
<td>0.0645</td>
<td>0.147</td>
</tr>
<tr>
<td>Year 15</td>
<td>0.5273</td>
<td>0.0168</td>
<td>0.04</td>
<td>0.1113</td>
<td>0.2147</td>
<td>0.0675</td>
<td>0.1608</td>
</tr>
</tbody>
</table>
Table 4.6 (Continued)

<table>
<thead>
<tr>
<th>Years</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
<th>Case D</th>
<th>Case E</th>
<th>Case F</th>
<th>Case G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 16</td>
<td>0.5795</td>
<td>0.0153</td>
<td>0.0412</td>
<td>0.1202</td>
<td>0.2335</td>
<td>0.0709</td>
<td>0.1749</td>
</tr>
<tr>
<td>Year 17</td>
<td>0.6318</td>
<td>0.0141</td>
<td>0.0425</td>
<td>0.1293</td>
<td>0.2525</td>
<td>0.0744</td>
<td>0.1891</td>
</tr>
<tr>
<td>Year 18</td>
<td>0.6842</td>
<td>0.0132</td>
<td>0.0441</td>
<td>0.1385</td>
<td>0.2717</td>
<td>0.0782</td>
<td>0.2035</td>
</tr>
<tr>
<td>Year 19</td>
<td>0.7366</td>
<td>0.0122</td>
<td>0.0458</td>
<td>0.1478</td>
<td>0.291</td>
<td>0.0821</td>
<td>0.218</td>
</tr>
<tr>
<td>Year 20</td>
<td>0.7889</td>
<td>0.0113</td>
<td>0.0475</td>
<td>0.1572</td>
<td>0.3105</td>
<td>0.0862</td>
<td>0.2325</td>
</tr>
<tr>
<td>Year 21</td>
<td>0.8413</td>
<td>0.0104</td>
<td>0.0494</td>
<td>0.1667</td>
<td>0.33</td>
<td>0.0903</td>
<td>0.2471</td>
</tr>
<tr>
<td>Year 22</td>
<td>0.8937</td>
<td>0.0095</td>
<td>0.0514</td>
<td>0.1762</td>
<td>0.3496</td>
<td>0.0945</td>
<td>0.2617</td>
</tr>
<tr>
<td>Year 23</td>
<td>0.9459</td>
<td>0.0086</td>
<td>0.0534</td>
<td>0.1858</td>
<td>0.3692</td>
<td>0.0988</td>
<td>0.2763</td>
</tr>
<tr>
<td>Year 24</td>
<td>0.998</td>
<td>0.0077</td>
<td>0.0554</td>
<td>0.1953</td>
<td>0.3888</td>
<td>0.1032</td>
<td>0.291</td>
</tr>
<tr>
<td>Year 25</td>
<td>1.05</td>
<td>0.0063</td>
<td>0.0575</td>
<td>0.2049</td>
<td>0.4083</td>
<td>0.1076</td>
<td>0.3056</td>
</tr>
</tbody>
</table>

Figure 4.34 Weights chart for “Relative Mode”

From the Figure 4.33 and Table 4.5, weights for ‘Ideal Mode’ can be realized each year. Similarly, from Figure 4.34 and Table 4.6, weights for ‘Relative Mode’ can be realized each year. From this interpretation, 4th and 6th
year show high significance compared to all cases. The analysis carried out using MCDM-AHP method from the Tables 4.3 and 4.7 inferred that there are several stages in the LCCA with various insights on investment planning and decision making. The Table 4.7 rank list exemplifies the decision making support. From the results, it can be inferred that the highest rank during $8^{th}$ year has been secured by Case B, Case C and Case F. Except Case A, for the first and second year, the ranks obtained are $4^{th}$ and $6^{th}$ respectively. These inferences will help provide support in decision making.

**Table 4.7 Various cases rank list exemplify for the decision making.**

<table>
<thead>
<tr>
<th>Years</th>
<th>Hierarchy Rank List for Different Cases with Respect to Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case A</td>
</tr>
<tr>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
</tr>
</tbody>
</table>
Table 4.7 (Continued)

<table>
<thead>
<tr>
<th>Years</th>
<th>Hierarchy Rank List for Different Cases with Respect to Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case A</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>18</td>
<td>1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>20</td>
<td>2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>21</td>
<td>7</td>
</tr>
<tr>
<td>22</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>23</td>
<td>6</td>
</tr>
<tr>
<td>24</td>
<td>5</td>
</tr>
<tr>
<td>25</td>
<td>4</td>
</tr>
</tbody>
</table>

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

4.16 FINANCIAL EFFECTIVENESS AND ECONOMIC GROWTH

This is about finance economic growth framework with regards to Indian solar project. 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, the Indian solar projects cost are added up to 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 change in the future when debt are less available. The financial market condition in India is the primary reason of
high interest rates in solar energy sector. This is fueled by growth, high inflation and other country risks. So, it is better to examine the design and implementation of funding mechanisms for long-term investment and low-cost debt (Gireesh Shrimali et al. 2013).

For the past several years in India, the need of energy has been increasing which has resulted in economic growth and modernization. There was a notable progression component observed in the Indian economy in the prospects for 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 at the rate of 6.6% per year, from the period of 2005 to 2012. As per the IEO 2016 report, India has the fastest growing economy in the world. Reference case, about averaging is 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 are to be achieved on long-term basis. According to IEO 2016 reference case, 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 during the projection period. To look at the preferable polices is cost effective and the government support can be leveraged.

To bring down LCOE of the baseline coal power plant, all renewable power plants are to be commissioned by 2022 whereas the cost effectiveness of different policy and the total cost in terms of NPV support is
to be calculated where both the analysis are determined accordingly. Probably, when the NPV of a policy support is less, the cost effectiveness of the policy is better from the complete subsidy standpoint which can be realized from the analysis. So, if the ratio is higher, the financial effectiveness of the policy will be also higher. The time value of money is considered which is to be mentioned in prior. But the actual time of the year at which money would be required is not considered.

4.17 TYPES OF DEBT SOURCE AND ARRANGEMENT

In this section, the Indian solar finance context is compared with financial contexts of developed markets. It already covers the basic level 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, and 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 the Debt or Equity ratio changes in accordance to the phase of the project. Mezzanine debt impacts their return on invested capital, and timing of cash flows 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 multi-lateral agencies might supply with 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 high levels of capital than others. This debt is also a high interest-rated debt that reflects high amount of risk. Mezzanine debt is also offered at a higher interest rate reflective of higher risk.

To keep the project success, the sponsors will have a strong incentives and the equity would be held by small set of parties (unlike a
public company with large dispersed holdings). The vendors (eg: 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 latter 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 than 5 years). So, the banks always lend this amount for shorter periods especially in the case of construction etc., It also tends to lend with a floating interest rate in which the interest rates tend to be higher than bonds. Despite, bank syndicate loans have the following flexibilities. In case of long 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 (eg: 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 don’t have secondary market for these loans. Insurance companies such as Life Insurance Corporation of India (LIC) are the 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 floats, these institutions also can
strike fixed interest rate deals for long term loans (eg: in the operating phase of a project).

4.17.1 Solar Project Fund from Public Sector Companies

In public debts, the project companies directly sell the bonds by approaching the markets 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’). If one owns a debt mutual fund, perhaps investing in a combination of government, private and project bonds is advised. However, all the public markets are subjected to greater degree of disclosure or transparency and regulatory scrutiny. The bonds (i.e. issue) and the issuer also need to be rated by rating companies like CARE, CRISIL which 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 investors with less knowledge. These ratings tend to change according to the time influenced 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 4.35 shows the analysis of cost 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 will increase the equity of leverage IRRs wherein it is assumed that the capital costs are low, leverage ratio is high (70 by 30 financing) and long term loans (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 home and convert the same into money; however, there is lack of visible secondary well-operating
markets for the utilized solar PV systems or assets of the system (for 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 with the emergence of secondary market for solar PV equipment, the flow of funds into solar loans will also increase.

![Cost benefits analysis of 1 MW solar energy project at interest 13% in India](image)

**Figure 4.35** Cost benefits analysis of 1 MW solar energy project at interest 13% in India

### 4.17.2 Solar Project Debt from International Capital Markets

#### 4.17.2.1 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 rely on LIBOR-based loan to generate solar electricity. The LIBOR rate of interest changes according to the credit rating of the borrower and amount of the loan.

4.17.2.2 External commercial borrowing (ECB) debt funding

As External Commercial Borrowing (ECB), it is possible to set up solar power projects at low interest rates with 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). For an external borrowing of infrastructure space that is provided with fully hedged (else the currency risks can be significant during market panics), norms have been relaxed by the Reserve Bank of India (RBI) for a 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- 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 due to which there are some discussions being held regarding the partnership with multi-lateral institutions for government's Clean Environment Fund (funded by the formerly named Coal Cess) so as to provide lower cost hedging solutions for renewable projects in India.

4.17.2.3 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 aiming
to enhance the solar power capacity to 100 GW which is approximately 16 times more than the current capacity of 8626.21 MW, India hopes to be funded by Asian Infrastructure Investment Bank, the newly founded one. 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%]) has increased the range in Levelised tariff and the 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. The solar projects executed with the minimal interest rate of 6% are shown in Figure 4.36 for illustration purposes. The analysis of cost benefits like savings per year, profit per year and loan repayment per year is performed considering 6% interest rate for 1 MW solar energy project in India. This suggests an innovation opportunity that, if beyond monitoring, escrow accounts (where the EMI slice of the bank comes directly from the escrow account) for which a secondary market in case if 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 rooftop systems.
Figure 4.36 Cost benefits analysis of 1 MW solar energy project at interest 6% in India

If the loans for solar PV systems are classified under the housing loan category, then regulations and funds 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. Furthermore, the renewable energy sector is also prioritized as a sector of great importance by the government of India wherein more than 40 per cent of a bank’s lending will be dedicated for the priority sector.

4.17.2.4 Leasing (or third-party ownership) for solar project

It is another model where the ability of the third party who can raise capital at lower costs, and claim tax shields (eg: depreciation benefits) can use this 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), and bilateral Export-Import Bank of India (EXIM) banks may provide ‘ecosystem’ stimulating finance (eg: solar park investments by Japan International Cooperation Agency (JICA), KfW Development Bank, Asian Development Bank (ADB) and United States Agency for International Development (USAID)).

The loans could be structured as ‘term loans’ (simple loans with bullet / balloon / amortized repayment), revolving credit similar to credit cards (for working capital, and phase-by-phase construction financing), Standby Letter of Credit (SBLC) (for exigencies governed by a board of lenders), Bridge Loan (bridging timing gaps between long term financing options). These options can be combined into a comprehensive credit facility. To establish the interest payback and principal payback (eg: 5 months of expected principal repayment held in cash) from the servicing view point, a buffer account is created as ‘reserve account’. Also the Debt Service Coverage Ratio (DSCR) i.e. ratio of revenues to debt service should be reasonable enough for the lenders to be comfortable. Upon the progress of the project and reduction of risks along the life cycle, soft or hard refinancing of the debt could be undertaken. The purpose, in general, is replacing one set of lenders with another (with different terms and conditions) and includes sourcing lower cost of capital, longer tenor of capital, replacing volatile floating rates with steady and fixed rates, allowing exit of one set of lenders and increasing or decreasing the equity and mezzanine content of capital. Project finance has become a presiding way of expanding finance availability to projects beyond what was practically possible with a single corporate balance sheet. This research has overviewed some of the project finance ideas from the Indian capital market or bank finance context. The current investigation does not cover the complex structured finance and packaging of tax incentives (eg: tax equity, YieldCo, etc).
4.18 BUSINESS MODELS OF SOLAR ENERGY SECTOR IN INDIA

This part covers business models in solar energy sectors such as third-party ownership, solar-as-a-service (solar PPA, lease), solar loans, solar securitization, peer-to-peer financing, Yield-Co and solar financing for the poor to develop basic needs of electricity through off grid. It also briefly covers other possibilities of e-Commerce driving solar.

The broader structure of the solar market (from upstream to downstream) involves: (a) solar technology players and equipment makers (including solar PV cells, module manufacture, film technology providers, inverter & power electronics companies), (b) solar Engineering, Procurement and Construction (EPC) companies, solar installers and operations service providers, (c) solar financiers and financial intermediaries and (d) system owners (end-user owners or third party owners).

The Indian market has its utility-scale segment such as banking, corporate, institutions, industrial, commercial segment, and off-grid segment either which are not yet electrified or face frequent power failure of residential segments where the markets around are yet to be examined. Let’s examine each in turn.

In the future, some governments (minority) stake in project equity is possible to be included by the Independent Power Producer (IPP) model that evolves as in BOOT model (i.e. Build-Own-Operate-Transfer, i.e. transfer the asset at the end of the term to the government which can capture the long term residual value). Some multilateral agencies may participate via mezzanine debt or via loan guarantees. Innovative ideas like dollar-tariffs or a centrally-managed hedging fund are also proposed.
Repowering of plants (i.e. replacement of old panels with newer technology) is allowed; and excess generation via solar yield-improvement schemes up to certain evacuation limits is also being accepted. The developers might build a farm where solar parks facilities are organized. These solar parks are often co-financed at low capital costs by multi-lateral infrastructure ecosystem financiers (like world bank, IFC, KfW, JICA, ADB, USAID etc) who have land, evacuation facilities (to the nearest transmission grid) and other services arranged.

The commercial and industrial segment is not just rooftop solar, but also "open-access" solar where the actual solar plant (of at least 1MW) may be in a solar park or at a remote facility several hundreds of km away (typically in the same state, but can be inter-state as well), organized as captive, group-captive or lease-model with a ‘wheeling and banking’ arrangement facilitated by the utility. A Power Purchase Agreement (PPA) is contracted with the solar PV developer by the end user to off-take a minimum amount of units each month (and up to the maximum produced by the plant and banked). The ESCOM state meets the excess need that goes beyond the tariff rate. The government or a private entity could also aggregate the rooftop spaces on their facility and award a project development contract for rooftop solar.

A captive model in an open-access solar (i.e. where the solar PV plant is remote) is the one in which the project equity majority stake is held by the end-user. Usually there is a high leverage debt arrangement (eg: 70:30 Debt: Equity) when the developer has minority stake, over the past 10+ years. All the output of the farm is earmarked and offset against the electricity meter bills of the end-user. The sizing of the plant is done to be well within the expected consumption profile of the customer. Excess generation can be ‘banked’, i.e. credited with the utility and used within a year (i.e. offset
against the subsequent bills). As a new emerging trend, a real estate developer could also be the owner/promoter/developer of the solar farm and sell the energy to their lessee tenants. Embassy energy is one such example of a real-estate developer where the company plans to sell the output of their 100 MWp plants to their large tenants in their STPIs (Software Technology Parks of India), SEZ (Special Economic Zone) and industrial zones. A typical building in business parks may have about 2 MW of connected loads.

The debt equity ratio is high in the project finance structure, when the group of end user is a variant and holds joint equity stakes with a minimum off-take commitment and appropriate automatic settlement mechanism. When the solar generation use goes beyond the minimum commitment, it is known as the “group captive”.

In residential or small-scale commercial solar, the simplest setup is where the end-user buys the PV system, and has a maintenance contract with the solar installer. The local state may have a policy such as net metering and Feed in Tariff whereas different states and market segments have different levels of financial attractiveness.

Financial loan originators (eg: Oorjan) help in arranging the finance at low interest rates and for long term basis (than personal finance loans) from banks or infrastructure financing sources (eg: IDBI etc). The interest rate may be not too far off from home loan rates with a good financial intermediary. The collateral required in such financing could vary from unsecured (for small loans) to secured by the solar PV system alone (non-recourse financing) or may require this to be linked or rolled into the housing loan (i.e. home as collateral in addition to the system). The counter-party is usually the consumer; but if there is an escrow account coupled with gross-metering, it may be possible to directly deduct the interest payment from the PPA payment from the ESCOM and utility. In order to help the ongoing credit risk
analysis, some degree of production is monitored and the data analysis is
presented to the bank. Insurance is also necessary for the larger PV systems
(and could be waived if there is adequate security in the home or apartment
complex).

The next model is Third Party Ownership (TPO) (typically for
residential, small or medium commercial) where the solar PV system is
owned by a third party, but the roof space is that of the end user (or their land
lord). An operating lease or Power Purchase Agreement (PPA) is signed
between the TPO and the end user. The end user, in turn, gets a PPA from the
utility. Sometimes these two PPAs may be combined into a single agreement
between the ESCOM (utility), the Third Party Owner (TPO) and the end-user.
An escrow account may be set up in this case to reduce credit risks, and the
payments to the TPO may go directly as a fraction from the ESCOM PPA
payments to the end user.

Without any upfront investment (i.e. zero-down), the solar PV is
provided "as-a-service" (i.e. "solar-as-a-service" or "solar lease") to the end
user which is attractive and similar to the utility electricity service or cloud
Virtual Machine (VM) /web services. Sometimes the term "operating lease" is
used to indicate a fixed monthly charge to the user, whereas a PPA implies
that the user pays for the actual solar production at a charge usually linked to
their tariffs (if there is net metering). In India, Solar Town is an example of
such a PPA provider (amongst other options it provides). The Third party
Owner (TPO) can avail Accelerated Depreciation (AD) benefits if they have
enough other revenue as discussed in prior section.

Sometimes, if the TPO is not just an installer or owner, but also a
financing entity (eg: a Non-Banking Financial Institution (NBFC)), it can
raise capital from private financing partners (eg: banks, a syndicate of banks,
insurance companies, pension funds or other institutional investors as public
bond market (eg: solar bonds, green bonds, climate bonds etc)), or aggregate a portfolio of solar PPAs, securitize it and sell it to the public markets directly.

The final option is aggregation of a portfolio of operating and yielding solar PPAs and creating a financial security against it which is called ‘solar securitization’. Both solar bonds and securities are similar in the way that they are offered in public (or private) markets, and have to be rated by bond rating agencies. Someone has to take responsibility for the collection of revenues and administering the distribution to security holders. A key difference between solar bonds and solar securities is that the solar bonds may have a lien on the corporate entity; whereas the solar securities depend on the pass through of the cash flows from individual PPAs.

Like other securitization (eg: home or auto loan receivables etc), there can be tranches which are rated differently by rating agencies. Solar City, in the USA, is an example of such a player which has raised finance from all these mechanisms. Solar securitization is perhaps more appropriate to the rooftop sector (but could also be applicable to a collection of medium-sized ground mounted farms) and is therefore new or not very prevalent in India yet. It is important that the veracity of the cash flow (and any impediments) should be assessed by the rating agencies along with the robustness of the diversification offered by the aggregation (eg: the same ESCOM defaulting could affect all solar cash flows securitized from a single state).

Due to the presence of tax subsidies (eg: Investment Tax Credit), in US markets, these are packaged and passed through tax equity investors who plan to save their profits from being taxed. Financial institutions of huge turn-around and some industrial players like Google do perform this way, otherwise called equity financing. But this could not be applied in India as
there are no tax subsidies and it is tough to pack and sell any such subsidy to third parties who finance the projects.

The peer-to-peer solar financing can be utilized in case if the solar PV plant has debts or equity part. But the idea is to pool peer-to-peer finance into a debt pool alike securitization. When it comes to Indian markets, investors are protected through various acts due to experience from chit scams and other debt markets. Peer-to-peer finance is only confined for single projects, but in this case, the projects details need to be shared to all investors (i.e. pure match making) who must be convinced to finance the project diligently. The mechanism to retrieve the payments from the defaulted counterparties (especially the consumers) and peer investors (either NRIs or the High Net-worth Individuals-HNIs) is limited and there are no much resources allotted in debt recoveries. This kind of financing method will be suitable when the escrow accounts are present, in which the payments are received from a single reliable source, and specific projects by TPOs (Third Party Owners) who can be matched with specific peer investors. But the interest rate demanded by the TPOs and peer-investors are higher compared to that of the banks (or whatever financial institution that could lend) where no bank-based debt capital is easy to be allotted.

Some companies like SELCO, which are socially-focused and innovative in their operations, customized their payment terms to poor for off-grid solar PV in order to match their opportunistic cash flow. In order to accommodate this variable cash flow, the companies possess some equity-like characteristics. Companies combined the solution as a package that contains solar PV, batteries, DC appliances (lights, fans etc.) along with the contract for Operations and Maintenance. In accordance to the micro-finance entities, the interest rates are pretty high. One more growth area is solar pumps and related microgrid business for irrigation purposes.
Recently, ‘YieldCo’ mechanism was popularized and of course met a spectacular fall in which the business design is developed based on the simple observation that in spite of risks present in development phase, once the solar PV plants are established in addition to long-term PPA and credit-worthy off-taker as counterparty, there are no pitfalls found in terms of cash flows. The basic idea is to separate the developmental phase from the operational phase (or otherwise called yield phase) with two companies (a development company ("DevCo") and a financial holding or yield company ("YieldCo")) involved. Based on 100% reliability on sunrise and sunsets, the average production (accounting for average cloudiness and equipment performance reliability) and the average conversion of kWh to yield consistent and predictable cash flows as per the contracted PPA, can be worked out.

According to finance laws, during predictable cash flows which are of low risk, the capital cost would be lesser. In YieldCo, the low-risk cash flows are financed with dual sources of low-cost capital such as low-cost debt, and possibly low-cost equity (organized similar to real-estate trusts) in which the cash flows to equity move in the form of dividends thus are restricted from being retained within the entity. The cost of capital can be theoretically low when the cash flows to both debt and the equity portions can be predicted. The development company, DevCo, focuses on acquisition of good pipeline of high quality projects (at reasonable costs). Once the projects are developed, it can pass it on to YieldCo at lower capital costs, i.e. at higher price realizations. When some of the YieldCos were listed on the public equity markets, their pricing reflected very low dividend yields (Note: When risk-free rates rise, the cost of capital of both the equity (dividend) and debt part of the yield co rises.)
4.19 CONCLUSION

This chapter offers new contributions and comparisons of the Indian electricity markets after investigating the 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 the anticipated level as per the prediction by government of 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 4.7. 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 solar PV 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, challenges for better development and execution in the field of solar PV.