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Solar Resource Assessment & Technology Roadmap Report: SEI-1

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CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

SERIIUS
Solar Energy Research Institute for India and the United States

Solar Resource Assessment & Technology Roadmap Report: SEI-1

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1 Introduction

India's per capita electricity consumption is less than one-third compared to the world average of about 2500 kWh and the country is placed at the bottom half of the Energy Development Index (IEA, 2012). Though power supply has witnessed rapid growth, it has not been able to keep pace with the rising demand. The total installed capacity from utilities and non-utilities has nearly doubled within a decade to reach 236 GW by 2012 (MoSPI, 2013). Of this, about 30 GW was added in the previous year alone. The total electricity generation in 2011-12 was 1050 TWh, growing at a CAGR of 6 per cent over the last decade. Yet, the country faces peak shortage of 9 per cent and energy deficit of 8.7 per cent.

The share of captive power in total electricity production is increasing gradually over time. In 2007, the total power generating capacity in the country was 155 GW, and the contribution of captive power was 22 GW. Captive power accounted for about 11 per cent of the gross generation of 752 TWh in that year (MoSPI, 2013). By 2012, the installed capacity under captive power had increased to 37 GW and accounted for a little over 12 per cent of the gross generation. This situation is not ideal as captive power is generally less efficient and more polluted than grid-based power.

Further, a significant share of diesel is used to compensate for unavailable or irregular grid supply. About 2.75 Million Tonne (MT), or 4 per cent of the total diesel consumption in India is attributed to diesel generator sets, while irrigation pumps are estimated to consume nearly 3 per cent[1]. In addition, more than one MT of diesel is used annually by mobile phone towers, over seventy per cent of which are located in rural areas with no grid supply. As the government subsidizes the fuel by about INR 8 per litre[2], this results in an annual subsidy burden of about INR 80 billion from these sectors.

The installed capacity of renewable energy sources has increased several-fold over the last decade. Yet, coal continues to account for bulk of the generation. In 2012, thermal power accounted for more than two thirds of the total installed capacity in the country and nearly 80 per cent of the electricity generation (Planning Commission, 2012). The installed capacity of renewable power had increased to 25 GW by March 2012, with wind power constituting about 70 per cent of the renewable capacity (MoSPI, 2013). However, due to the low base in 2007 and relatively lower capacity utilization factor, renewable energy contributes only about 6 per cent to the total generation from utilities.

To enable a GDP growth rate of 8 per cent, India will require about 2500-3500 TWh of electricity by 2030 – almost three times the current generation (Planning Commission, 2006; CEA, 2011). If it continues along the current trajectory, the country is likely to face several challenges in this sector, including the following:

- One in every three households in rural India – about 300 million people in all – does not have access to electricity. Even those with access to electricity report a per capita consumption of 8 kWh per month, one third of the per capita consumption in urban India. This is partly attributed to the poor quality of electricity supply. Improvement in

[1] http://www.business-standard.com/article/companies/commercial-vehicles-major-beneficiary-of-diesel-subsidy-114012800497_1.html
[2] Ibid.

coverage and quality of grid-based supply could take a long time to reach the entire population.

- The current installed capacity of hydropower, about 39 GW, represents only one-fourth of the total hydroelectric potential in the country. Yet, capacity addition since 2007 has been only about 5 GW against a planned capacity addition of 15 GW (Planning Commission, 2012). Social and ecological concerns have made it difficult to aggressively tap this resource. Further, most of the hydro potential is located in the Himalayan and North-Eastern part of India, which contribute a small share to the total electricity demand. This would make effective management of inter-regional transmission grid imperative.
- The gap between requirement and availability of coal is increasing rapidly. Today, the country meets about one-tenth of its coal requirement in the power sector through imported coal. The share of imported coal could go up to 25 per cent by 2017 (Planning Commission, 2012). This could affect energy security of the country and taxes on international coal could also reduce affordability of electricity supply.
- A recent study estimates that local pollution from thermal power plants resulted in more than 80,000 premature deaths and over 20 million cases of asthma in 2011-12 (Greenpeace and UrbanEmissions.Info, 2013). As coal continues to be the dominant source of power generation, health consequences are likely to only worsen over time.
- Thermal power accounts for over 85 per cent of the total industrial water use in India (FICCI). In the past, water shortages have reduced the effective Plant Load Factor (PLF) of several plants, causing losses in electricity generation.[3] As water scarcity worsens, electricity production may be adversely impacted.

Renewable energy, particularly from solar and wind, presents an opportunity to address these issues. As problems associated with coal power come to the fore, and large scale hydro and nuclear power face increasing public opposition, renewable energy could facilitate the transition to clean and affordable energy that India aims to achieve. Even in a conservative scenario, renewable energy is expected to supply about 15 per cent of the total grid-based electricity by 2030. This could imply an installed capacity of 75-100 GW of wind power and 58-84 GW of solar power.

Wind power already has an installed capacity of over 25 GW – the largest for any renewable energy source in the country (MoSPI, 2013). Further, several studies have attempted to assess resource potential and analyse the potential of wind power in India (Sudhakar, et al., 2013; TERI, 2012; Phadke, et al., 2012; WISE, 2012). However, the same cannot be said for solar power. Although there are resource maps developed at NREL and 51 stations (spread across the country) which gather real time solar irradiation data, an accurate analysis of the potential of solar power along with available land area is not available. Recently, KPMG released a report which analyses the possible pathways to achieve grid parity for solar power (KPMG, 2012).

The primary objective of the Solar Energy Research Institute for India and the United States (SERIIUS) is to enable the penetration of solar power in both the countries and achieve grid parity at the end of their respective solar missions i.e. Jawaharlal Nehru National Solar Mission and the SunShot Initiative. The Solar Energy Integration (SEI) thrust intends to develop technology roadmaps, policy analysis and assessment of solar energy integration and storage

[3] Over 6000 MW of thermal capacity was affected in the summer of 2010 due to insufficient water availability.

options. An important deliverable of the SEI-1 work package is an annual roadmap which covers these aspects. This report focuses on the development and evolution of solar energy in India. The current installed capacity is only about 2GW – and the transition towards 22 GW by 2021-22 (JNNSM target) will require further technological research and adequate planning to understand and deal with the challenges posed by solar energy.

This report starts with a preliminary roadmap assessment which includes projections of solar power capacity in India in 2031-32 (low carbon study, steady RPO growth and ICF International's Green Scenario), land and resource assessment using satellite data and an overview of the solar manufacturing industry in the country. The chapter following this validates the land and resource assessment using Geographical Information Systems (GIS) analysis and includes a generic framework to assess the potential of solar power in wastelands using this GIS analysis. A case study for Karnataka based on this framework has been presented. The next chapter provides a complete policy overview of solar energy in India and includes a review on central and state policies for grid-connected plants, rooftop PV systems, rural electrification schemes and decentralized solar applications. Based on these policies, the next chapter delves deeper into the policy and techno-economic assessment of solar energy applications, viz. grid-connected PV, rooftop PV and solar process heating in industries. Policy gaps have been identified in this chapter along with recommendations to bridge these gaps.

2 Preliminary Roadmap Assessment

India is a vast country with rich solar resource potential ranging from 4-7 KWh/m^2/day (2013). Due to excellent irradiation profiles in many parts of the country, solar technologies can significantly contribute in meeting the growing electricity demand of India. As of Oct 2013, the total installed capacity of solar grid-connected power is approximately 2079 MW (MNRE, 2013). The capacity was deployed under various projects, largely under Jawaharlal Nehru National Solar Mission (JNNSM); state regulated policies and other small schemes. The current roadmap towards the capacity addition is in compliance with yearly solar capacity addition model as per solar Renewable Purchase Obligations (solar RPO), which have been mandated to the states, beginning with 0.25% and rising upto 3% by 2022 (MNRE, 2013a) . A solar capacity addition of about 30 GW is envisaged by 2022 through RPO.

The solar technology roadmap which is constructed in this chapter is aligned with the existing policy targets envisaged through JNNSM under National Action Plan for Climate Change (NAPCC). The ***methodology*** adopts a ***top-down approach***; estimating the following,

a. **Forecasting yearly capacity additions:** The total energy demand projections till 2032 will be estimated and the percentage share of contribution from solar PV generation will be estimated based on the solar RPO targets set as per the NAPCC.
b. **Status and trend of Solar PV technology diffusion:** An assessment will be made on the current status and market trends based on technology performances, efficiency improvements, cost trajectories of technologies and the associated levelized cost of generation of different PV technologies. Also, progress on the evolving and novel R&D technologies and the expected timelines to reach commercialization will be assessed. Based on the demand projections and the likely PV technology penetrations into the market, the annual PV module requirements (both c-Si and Thin-Films) will be estimated.
c. **Cost of module and system per MW under PV technologies**
   An assessment of the global as well as domestic PV module price trends, production volume capacities and the market dynamics like demand v/s supply of the modules will be reviewed.
d. **Collector area –** An assessment of the cumulative area required by PV modules will be performed taking Global Horizontal Irradiance (GHI) and the efficiencies of conversion into account. Also, the land requirement based on the likely improvements in technological efficiencies of the modules will be estimated.
e. **Grid parity study**
   As per the Integrated Energy Policy, 2006, by the Planning Commission, imports of coal could increase to as high as 45% of the total coal requirement by 2031-32 (Planning Commission, 2006). The dynamics in global and domestic coal prices are bound to increase the cost of electricity generated from thermal power stations in India. The timeframe within which solar power will achieve grid parity considering these dynamics will be estimated and from that point on the roadmap will adopt an aggressive stance in terms of capacity addition of solar power.

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Currently the roadmap is being visualized in three pathways as mentioned below (Figure 2.1).

2.1 Path 1 Low Carbon Growth

CSTEP uses a TIMES based model to project low carbon growth scenarios in the power sector till 2031-32. It is a multi-region model considering India as 5 regions as demarcated physically by the electricity grid infrastructure. The primary objective of this model is to develop scenarios with 30% non-fossil fuel based energy by 2032. Total electricity demand projections lie in the range of 2700-2900 billion kWh (BU) taking 1000 BU in 2010 as the base value and a constant 0.8 elasticity of demand with respect to GDP growth rate (200-300 BU are deducted from the model estimates taking Demand Side Management (DSM) and energy efficiency measures into account).

The model takes solar resource potential calculated by MNRE as an input (analyzing the DNI/GHI data and identifying zones which receive suitable kWh/m^2 radiation). Filters of 1% for PV and 0.5% for CSP are applied while assessing land requirement and associated solar power potential. Current costs are taken for power technologies and are kept constant (no changes made based on future dynamics) and fed into the model as inputs. To factor in intermittency of solar and wind, load curves for both are taken into account. The model runs a cost optimization algorithm for choosing the right blend of power sources to reach 2700-2900 BU based on the following hard coded constraints:

- 15% RPO by 2020 with 3% Solar Purchase Obligation (SPO) by 2021-22 (no growth in SPO after 2021-22)
- 35 GW cap on nuclear and 80-85 GW hydropower by 2030
- minimum 25% coal imports by 2017 and 30% by 2020

With these inputs, the model shows 50 GW of solar power by 2030 and 64 GW by 2032.

2.2 Path 2 Strategic Policy

The demand for energy has been projected based on a conservative growth rate of 7%, thereby estimating energy requirement at around 1840 BU till 2022 and 3600 BU till 2032. At pan India level, the achievable RPO trajectory estimated under this scenario ranges from 0.25% in the current FY 2012-13 reaching up to 3% in FY 2021-22. This is as per the National Tariff Policy envisaged targets which requires a solar capacity addition of about 33 GW. Further to which, we assume a normative increase of 0.15% post 2022, reaching up to 4.5% till 2032 which requires solar capacity addition of 97 GW.

2.3 Path 3 Highly Aggressive

According to a report recently released by ICF International (ICF International, 2013), if the country adopts an aggressive clean energy policy approach (Green India Scenario) with higher penetration of renewable energy in the overall energy mix, a capacity addition of around 175 GW of solar power generation is achievable by 2031-32.

Figure 2.1 shows the possible capacity additions in solar power till 2031-32 taking these three paths into account.

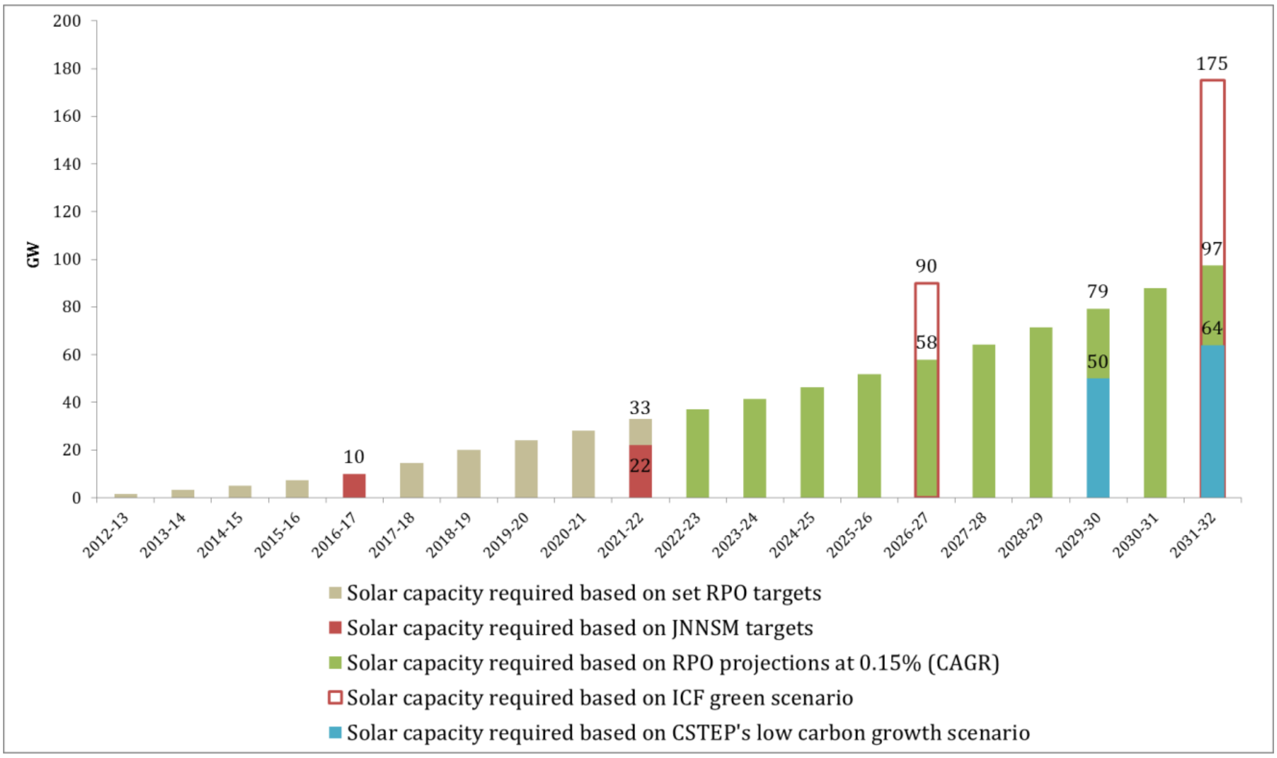


Figure 2.1: Preliminary roadmap assessment of solar power in India

Based on this initial roadmap, preliminary analyses of land availability, solar resource assessment, module requirements and manufacturing have been performed (refer to Appendix 2.4 below). In later stages of this project detailed analyses will be carried out based on the methodology as discussed above. The roadmap developed will be a work in progress and restricted to grid-connected PV and this will incorporate the evolution of PV technology (the ratio of thin film and c-Si, efficiency improvements, new technologies developed within the SERIIUS consortium), its impact on market dynamics - both domestic and global, the implications of policy and regulatory environments. These preliminary analyses will be updated to develop a detailed technology roadmap for solar PV in India.

In the next chapter, a detailed assessment of the solar resource potential for the state of Karnataka has been taken up as an illustration using GIS technology and the methodology will be extended to other states depending on data availability. The methodology for assessing solar resource potential based on both PV and CSP technologies has been discussed in detail (refer to chapter 3). Similarly, overall country wide solar resource potential assessments will be made in further studies as it will feed into developing the technology roadmap of solar PV in India.

2.4 Appendix: Preliminary Review and Assessments

Solar Resource Assessment

From DNI and GHI maps, it can be seen that around 1.3 million sq. km area in India receives a rich irradiation potential of 6 kWh/m^2 and 1.12 million sq. km receives 4.5 kWh/m^2/day (NREL, 2103). Figure 2.2 depicts the land area receiving typical solar radiation in India.

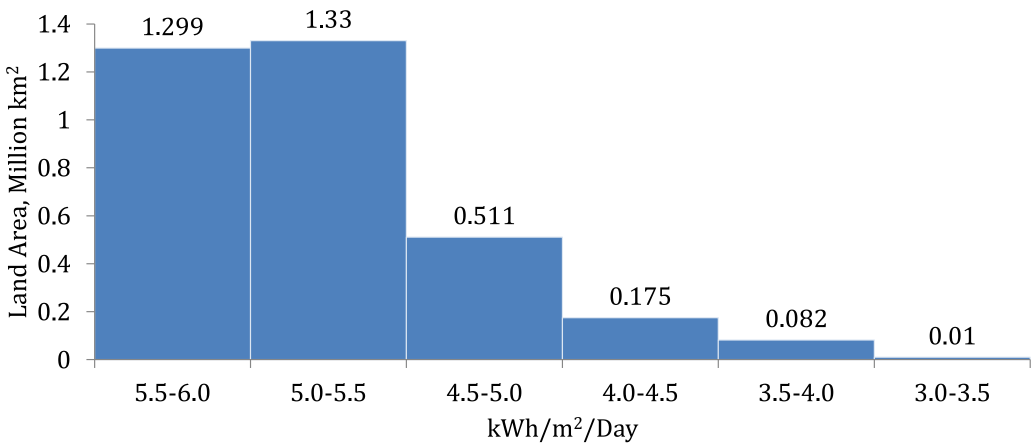


Figure 2.2: Land distribution of solar radiation in India

Land Availability

Recent land use statistics illustrated in Figure 2.3 highlight the availability of barren or uncultivable land in many states like Rajasthan, Gujarat, Andhra Pradesh, Maharashtra and others (Ramachandra, et al., 2011). In later stages of this roadmap assessment, the potential to utilize these areas in terms of solar power installations will be analyzed taking other infrastructural aspects into consideration (water, connectivity to grid, roads).

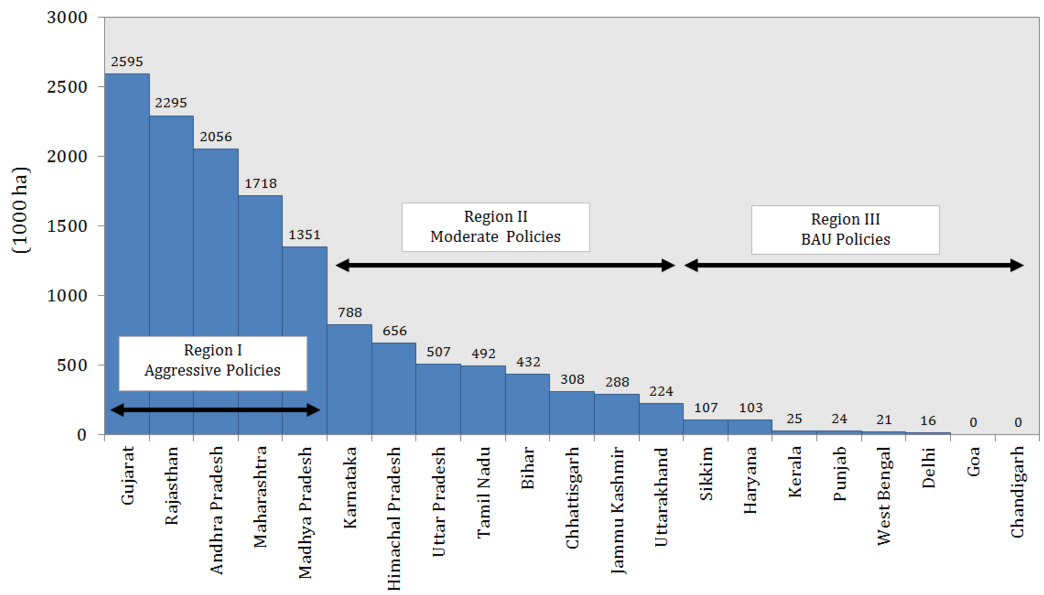


Figure 2.3: Barren and Uncultivable Land by states

From the above overview, it is clear that irradiation profiles and land are not an issue for this country and the key challenge is to develop a methodology and framework which will exploit suitable areas. Figure 2.4 below shows the holistic review of targeted collector area planned through JNNSM in reference to the waste/barren land available and India's geographical land area.

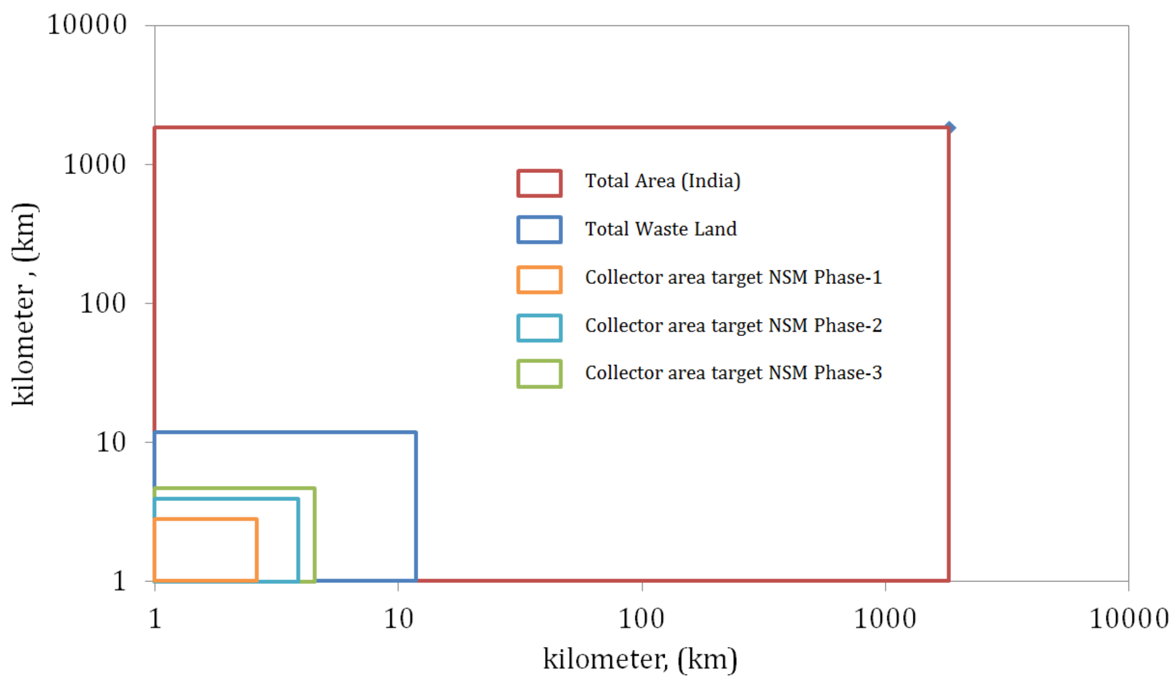


Figure 2.4: Land availability and target under JNNSM

Technology and Modules

Considering the projected capacity additions based on Path-2 (current strategic policy based), a scenario is constructed envisaging the business as usual condition with current technology adoption trend of solar PV with 45% engaging crystalline silicon and rest 55% uses thin-film (2012). The likely demand of modules is depicted in Figure 2.5 below. In this context, analysis of indigenous manufacturing of these modules along with other balance of system components is presented in the next section.

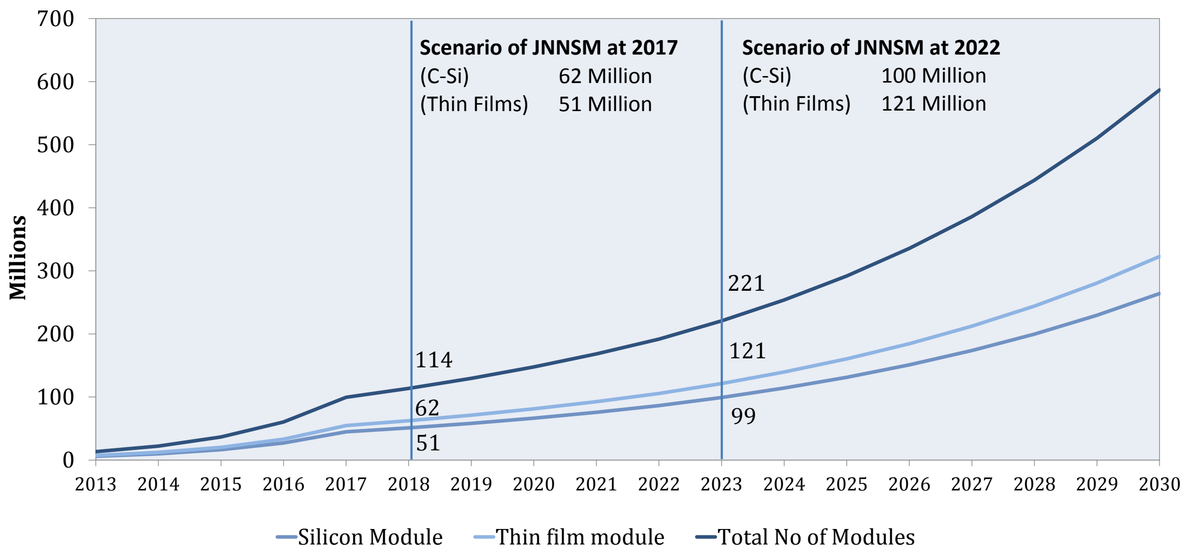


Figure 2.5: Estimated module demand

PV Manufacturing in India – The Future lies in 'Balance of Components'

JNNSM has a target of enhancing the domestic solar manufacturing capacity to 4-5 GW by 2017 (MNRE, 2012). In December 2012, India had approx. 848 MW of cell manufacturing capacity and

1,952 MW of module manufacturing capability (Subramaniam, 2013) (Kapoor, 2013). Figure 2.6 highlights the growth of the cell and module manufacturing in India. The cell and module manufacturing has grown at a CAGR of 67% and 73% respectively. Though the growth rates appear healthy, they still fall far short of the targets set by MNRE.

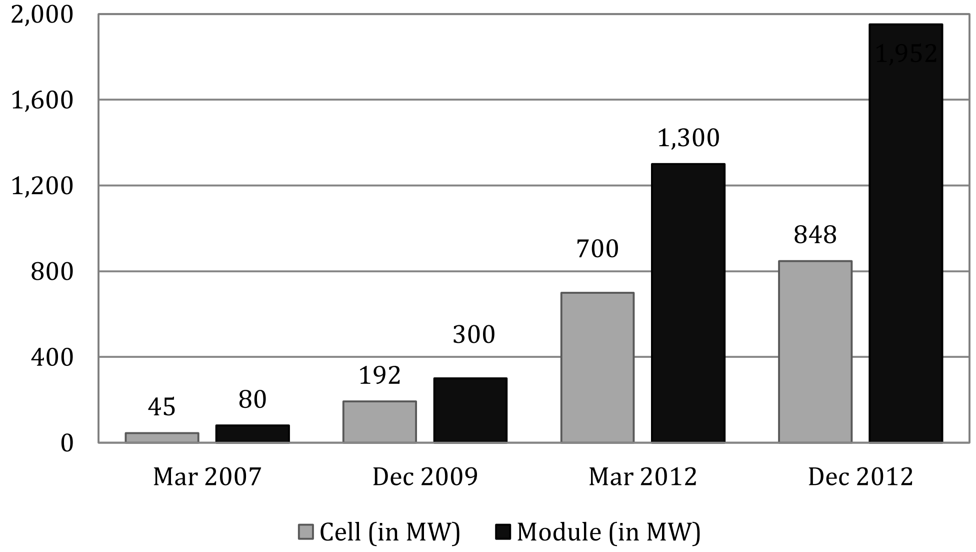


Figure 2.6: Domestic PV cell and module manufacturing capacity in India (ISA, 2008) (Subramaniam, 2013) (Ramesh, 2012) (Kapoor, 2013)

To accomplish the targets set forth, NSM Phase I had a Domestic Content Requirement (DCR) stipulation extending to two batches. In Batch 1, 100% of the modules for c-Si technology had to be procured from Indian manufacturers. In Batch 2, 100% of the cells and modules for c-Si technology had to be sourced domestically (CEEW/NRDC, 2012). Faced with this situation, developers and system integrators preferred to import Thin Film (TF) technology which was exempted from DCR obligation. Lower module price on Watt-peak basis and lower financing cost were the two attributes that favoured imported TF modules[4] (CEEW/NRDC, 2012) (Johnson, 2013).

Globally, over the last few years there is a glut of PV cell and module supply as against the demand (EPIA, 2013). This has allowed cheap imports from China. In the Indian market, five out of top 10 suppliers are Chinese. First Solar, an organization based out of USA, has the largest market share of 22%. In addition, 82% of the total installations in India used imported cells and modules (Agarwal, 2013). Figure 2.7 highlights the quantity of cells and modules imported to India between 2010 & March 2013. When the imported numbers are compared with the total commissioned we find low capacity utilization of indigenous production lines. Figure 2.8 highlights the imports as against the total PV commissioned from 2010-13. Thus, despite the DCR stipulation, the capacity utilization of domestic PV module production is in the range of 15-20% (Singh, 2013) (Subramaniam, 2013). It is even lower for cell production.

[4] Moser Baer is one among two large manufacturers of a-Si thin film module. The production capacity of the plant is 50 MW with a line efficiency of 7.3%. Whereas, the imported TF modules to India were mainly from First Solar and based on CdTe technology whose efficiency was around 12.7%. This was also the reason for preference for imported TF module.

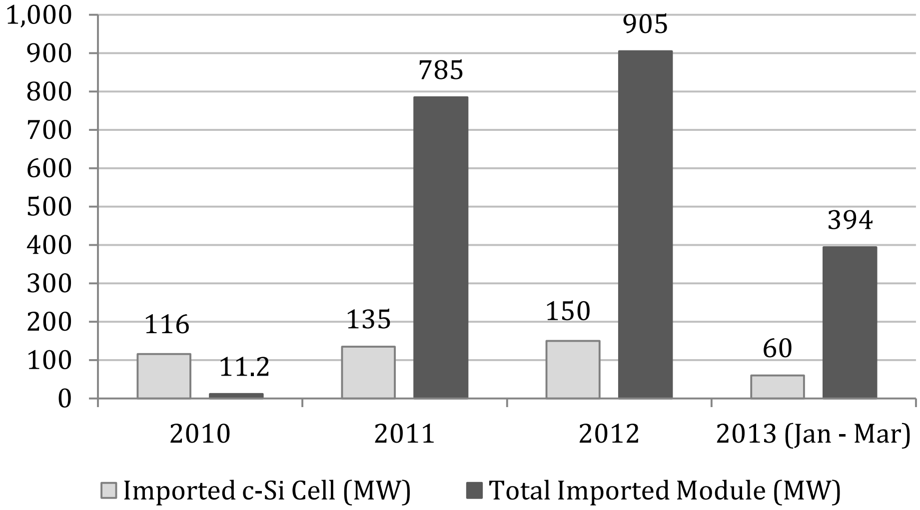


Figure 2.7: Import of solar cells and modules in India over the past three years (Singh, 2013)

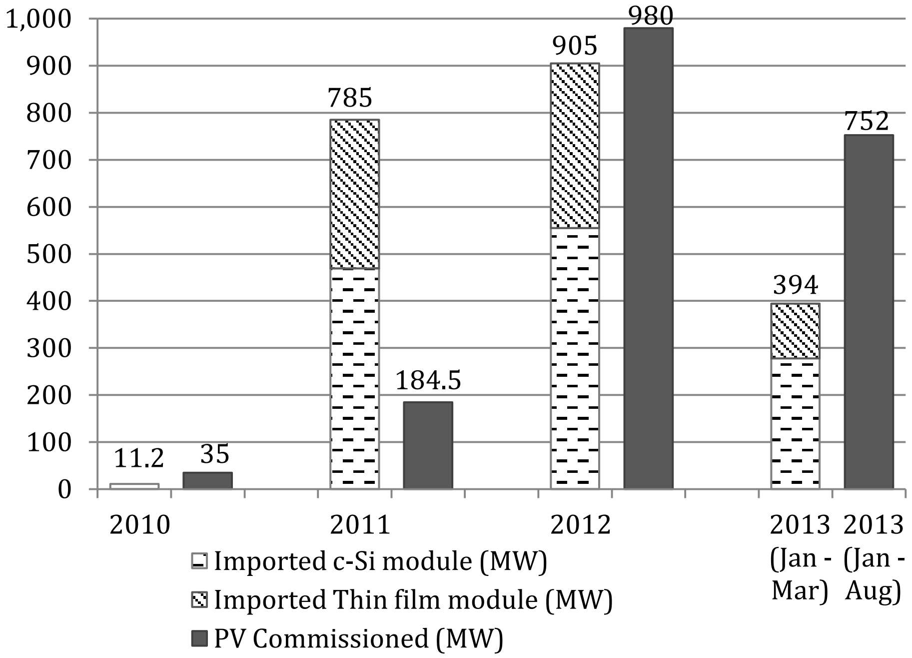


Figure 2.8: Import vs. Total PV commissioned from 2010-2013 in India (Prabhu, 2013)

3 GIS based solar (PV and CSP) potential assessment: Case study on Karnataka

3.1 Why Resource Assessment?

In recent years, there have been major concerns about the rising costs of fossil fuel, especially coal and its availability in the future. Considering factors such as environmental pollution and climate change and ever increasing energy demands, alternative methods for electrical power generation have taken a step forward. JNNSM was announced in 2010 to address India's energy security by exploring the immense potential of solar energy in the country. The objective of this mission is to achieve grid parity for solar by 2022. In this regard, locations of suitable sites play a vital role in achieving the targets. This helps to concentrate on the best available sites in India for solar technology deployment. So, potential assessment of solar energy in India using GIS plays a crucial role in planning and decision making.

3.2 Barriers of Site Selection

Selection of suitable site is usually a time consuming task, since a lot of factors such as good solar resource availability, availability of suitable and spacious land for installation, proximity to good water resource, and economics play important role. Forest lands have been restricted from any developmental activities in the recent years due to environmental issues. Usually agricultural lands are also not used for developmental activities.

3.3 Literature Survey

Concentrated Solar Thermal facilities: A GIS approach for land planning (Lehman, 2011) explains that several factors such as availability of spacious land plays a crucial role in selecting a site. The location of the site and information about electrical infrastructure, topography, insolation, flood information, environmentally sensitive area, federal lands, and land conservation units, are all critical factors when considering a potential site. GIS offers the ability to take these and other layers of information into account when searching for optimal regions for solar development.

Renewable energy mapping in Maharashtra, India using GIS (Renewable energy mapping in Maharashtra, India using GIS, 2011) explains that in order to tap the potential of solar energy, there is an urgent need to assess the potential first using geospatial techniques. This assessment is helpful in planning for the future and it helps in identifying potential areas where solar energy can be utilized intensively. This will be helpful for engineers and planners for decision making.

The San Bernando County, in USA, was taken as the study area for another GIS based study. A traditional rule used by planners equates eight acres of land being needed to produce one megawatt of electricity. This means roughly 800 acres would be consumed in the establishment of a 100 MW solar facility. In areas of high biodiversity, this becomes a sensitive issue.

U.S. Renewable Energy Technical Potentials: A GIS-based analysis (Anthony Lopez, 2012) has assessed the potential of solar energy in USA. This report discusses the state wise results of the GIS analysis which includes available land area, installed capacity and electrical generation for different solar technologies: utility-scale photovoltaic (both urban and rural), rooftop photovoltaic and concentrating solar power. Exclusions such as slope, restricted land and contiguous area were used to arrive at the suitable available area. Different state capacity factors were used to derive the potential (MW).

3.4 Aim and Scope of This Study

The aim of this study is to assess the potential of solar energy in India and also to find out locations suitable to harness different solar energy technologies. Due to limitations in availability of data, Karnataka has been taken up as an illustration and the methodology will be extended to other states depending on the data availability.

3.5 Data Sources Used for GIS Analysis

Table 3.1 shows the various data sources that have been used for the GIS study of solar power potential in Karnataka.

Table 3.1: Data sources used in GIS analysis

Name	Data Type	Resolution	Source	Available For	Comments
DNI/GHI map	Vector	10km x 10km cell size	NREL	India	• Free • Satellite derived data
Land use/Land cover data	Vector	NA	KSRSAC	Specific to Karnataka	• Commercial data
	Raster	300m	Bhuvan, NRSC	India	• Free • To be procured for other states • Satellite derived data
Sub stations	Vector	NA	KSRSAC	Only for Karnataka	• To be procured for other states • Data sources for other states to be determined
Water bodies	Vector	NA	KSRSAC	Only for Karnataka	• Commercial data
	Raster	300m	Bhuvan, NRSC	India	• Free • To be procured for other states • Satellite derived data
Roads	Vector	NA	KSRSAC	Only for Karnataka	• Commercial data
Other data (Ground water, dust etc.)	Yet to be determined				

3.5.1 NREL

The US based National Renewable Energy Laboratory (NREL) develops solar resource maps based on satellite data. In 2010, NREL released 10km resolution DNI resource maps for India. The high-resolution (10-km) solar resource data was developed using weather satellite data. The data is available in GIS format and as static maps.

3.5.2 Land Use/Land Cover data

Land Cover is defined as observed physical features on the Earth's Surface. When an economic function is added to it, it becomes Land Use (Food and Agriculture Organization of the United Nations, 2013). The definitions as per the NRSC LULC classification document (National Remote Sensing Centre, 2009) are reproduced in Annexure 1: Definitions of Land Use/Land Cover Classes.

Karnataka State Remote Sensing Application Centre (KSRSAC) has developed a detailed Land use Land Cover (LULC) mapping of Karnataka. This mapping is done at a scale of 1:50000.

Bhuvan, ISRO's Geoportal is an initiative to facilitate users to download thematic services such as LULC, soil information etc. Information on the spatial spread and monitoring the dynamics of the land use/land cover is the basic requisite for planning and implementing various developmental activities. National Remote Sensing Centre (NRSC) has carried out various studies on land use/land cover mapping. This mapping is done in two scales – 1:250,000 and 1:50,000. Currently, the 1:250,000 mapping is available for download in raster data format.

Land use GIS data for Karnataka was available from both, Karnataka State Remote Sensing Applications Centre (KSRSAC) and Bhuvan, NRSC. For the purpose of data comparison, initial analysis based on the framework above has been conducted for Karnataka and the results are presented.

3.5.3 Roads

The road data was available from KSRSAC. For the purpose of this analysis, the state highways, national highways and the metaled (tar) roads were considered.

3.5.4 Transmission lines

The transmission lines data was available with different types of substations and power lines such as 11kV, 33kV, 66kV etc. Only the substations were considered for conducting the proximity analysis.

3.5.5 Other Data

Sources for other data such as ground water, dust etc. are yet to be identified and data needs to be obtained.

3.6 Methodology Framework

The methodology for the site suitability was decided based on the literature survey which suggested that it is important to include constraints such as distance to roads, distance to the nearest substation and distance to water bodies (for CSP technologies) for potential assessment. The flowcharts in Figure 3.1 and Figure 3.2 show the methodology used for a generic estimation of potential of both PV and CSP technologies using GIS technology.

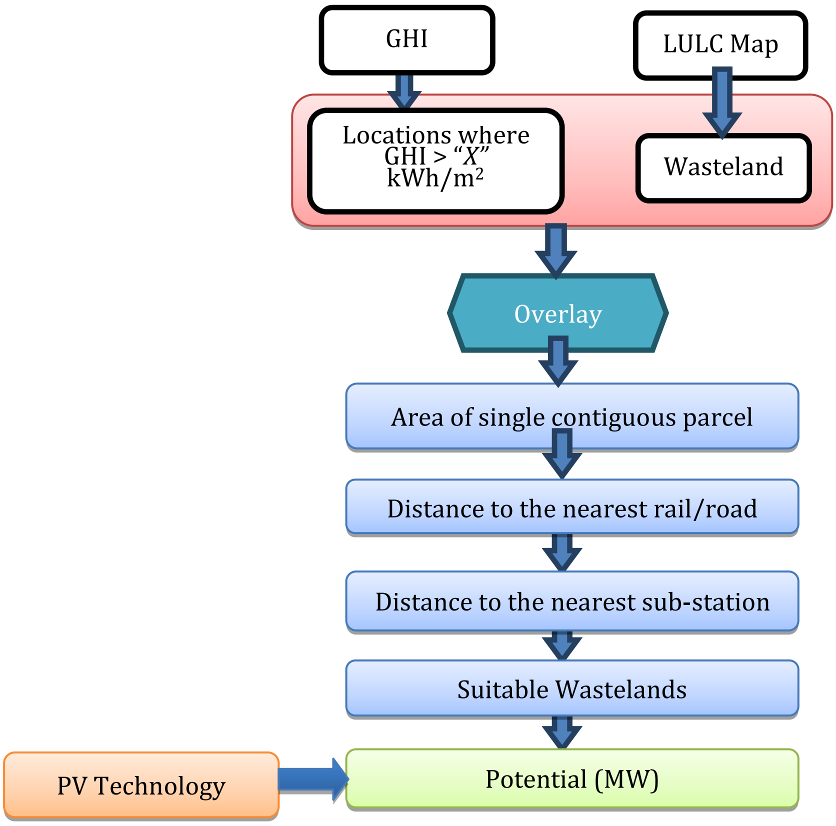


Figure 3.1: Methodology framework for site suitability and potential assessment of Photovoltaic (PV) technologies

This is a multi-criteria analysis where multiple criteria is used to select a suitable site and depending on whether the site meets the criteria listed will decide if the site is suitable or not.

As an illustration, locations with Direct Normal Irradiance (DNI) greater than 5.5 kWh/m^2 were taken up for analysis. This was intersected with the wastelands of Karnataka. Then the wastelands which have a contiguous parcel size less than 1 sq. km (For CSP) and less than 0.02 sq. km (For PV) were filtered out. Then the proximity criteria like distance to the nearest road, distance to the nearest substation was used to filter out wastelands which were far from these utilities. Water is an important source for CSP technologies so the "distance from the nearest water body" criterion was also included in the analysis for site suitability of CSP technologies. The water bodies in the GIS database consist of both, temporary and permanent water bodies. A similar methodology was followed for PV where Global Horizontal Irradiance (GHI) > 5.75 kWh/m^2.

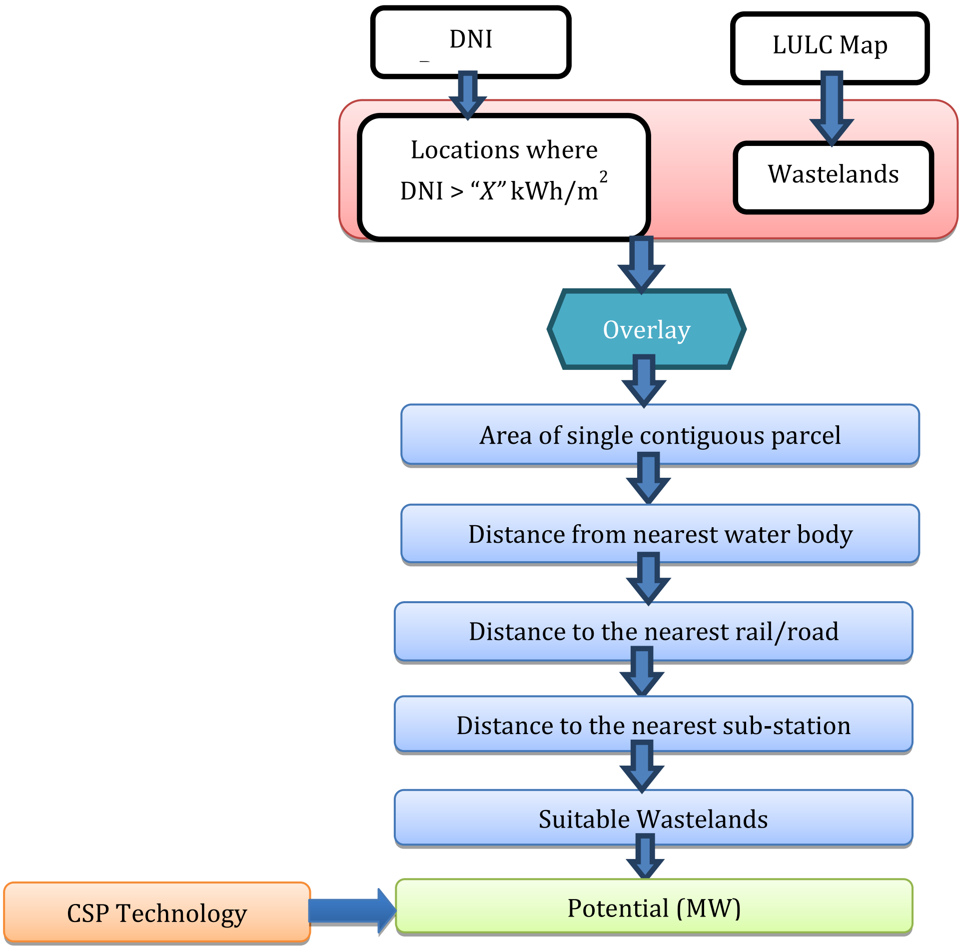


Figure 3.2: Methodology framework for site suitability and potential assessment of Concentrated Solar Power (CSP) technologies

3.7 Assessment of Solar Potential

Once the area (sq. km) of suitable wastelands has been calculated, this has to be converted into potential (MW). For this, the methodology depicted in Figure 3.3 was followed.

The different solar technologies were listed out and the solar to energy conversion efficiency of each solar technology was noted. It was assumed that there will be 300 days of sunshine and an annual average DNI/GHI of 5.5 kWh/m^2/day. Then for different CSP technologies and PV technologies, the efficiencies in Table 3.2 and Table 3.3 (Sharma, 2011) were considered. For all the CSP technologies, a capacity factor of 27% was used.

Table 3.2: Efficiencies for CSP technologies

CSP Technologies	Efficiency
Parabolic Trough (PT)	16%
Solar Tower (ST)	20%
Linear Fresnel(LFR)	10%

Table 3.3: Efficiencies for PV technologies[5]

PV Technologies	Efficiency
c-Si (Poly)	13%
c-Si (Mono)	18%
CdTe	9%
CIGS	11%
Perovskites	16%

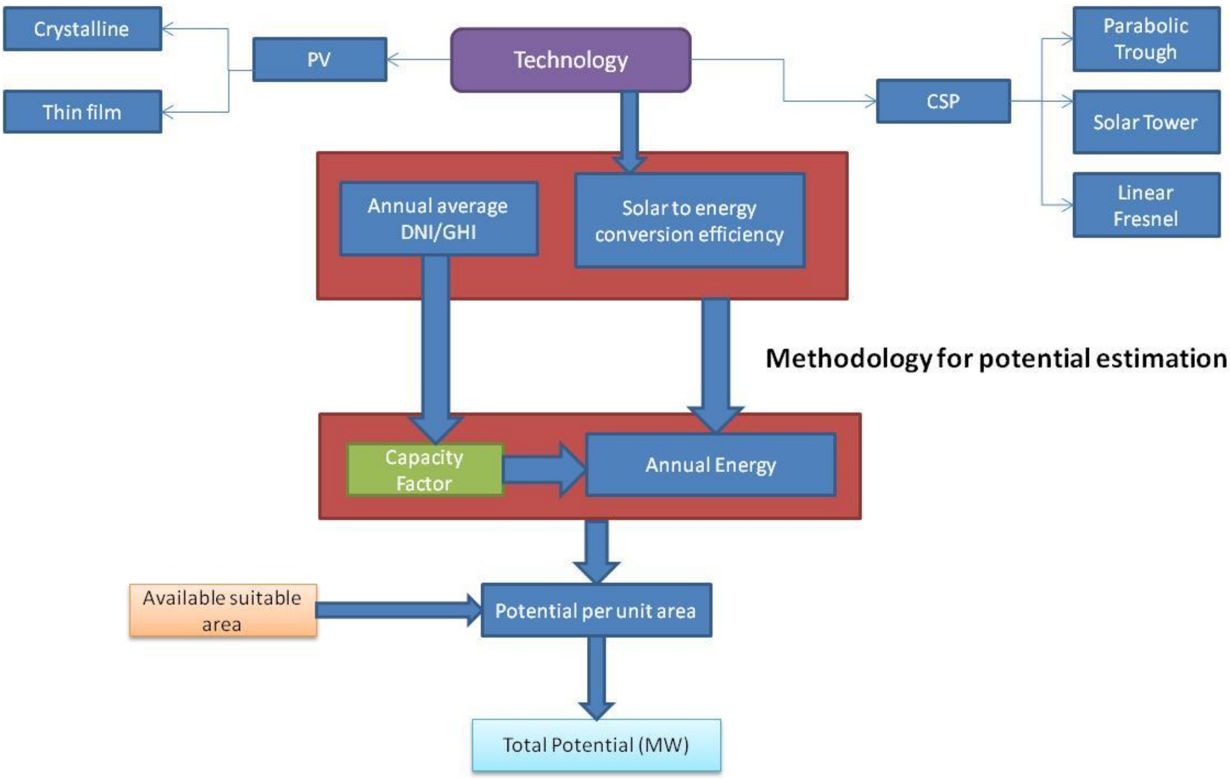


Figure 3.3: Methodology for potential estimation

Based on these assumptions and factors, the potential per unit area was calculated and then the suitable area (from GIS analysis) was used to calculate the total potential in MW for both PV and CSP separately.

3.8 Results

This section presents the results of solar potential in Karnataka using available wastelands for both PV and CSP technologies.

3.8.1 Comparison of Bhuvan LULC Data and KSRSAC LULC Data for Karnataka

[5] Based on calculations from solar plant data sheets and literature survey, conservative efficiencies have been used.

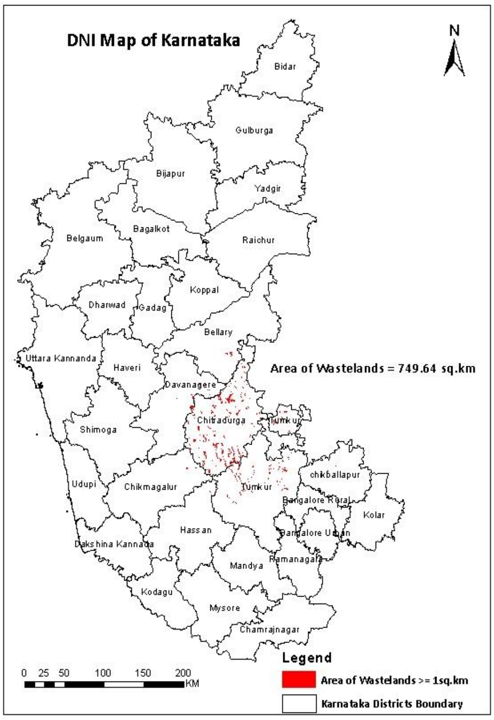
Since both data sources were available, this research first concentrated on comparing the two data sets. This is shown in Table 3.4

Table 3.4: Comparison of Bhuvan LULC data with KSRSAC LULC data

Bhuvan data land use classification (2012)	**Area in sq. km**	**KSRSAC data land use classification (2005)**	**Area in sq. km**
Agriculture	1, 38,119	Agriculture	1, 33,202
Forest	36,877	Forest	29,236
Natural/Semi natural grassland & Grazing land	178	Grassland	636
Wetlands/Water bodies	4,352	Wetlands/Water bodies	7,318
Built up	1,156	Built up	5,448
Wastelands	14,018	Wastelands	8,531
Total	1,94,700	Total	1,91,780

It was observed that there was discrepancy in the geographical area of land use classes. Importantly, the land use data were of two different dates, Bhuvan data (2012) and KSRSAC data (2005). So according to the comparison, the amount of wastelands in the state has increased from the year 2005 to 2012. There is also a discrepancy in the total geographical area of the state. So it was decided to use the KSRSAC, as it is more accurate because the data was validated with field visits by KSRSAC.

3.9 Results of GIS Analysis



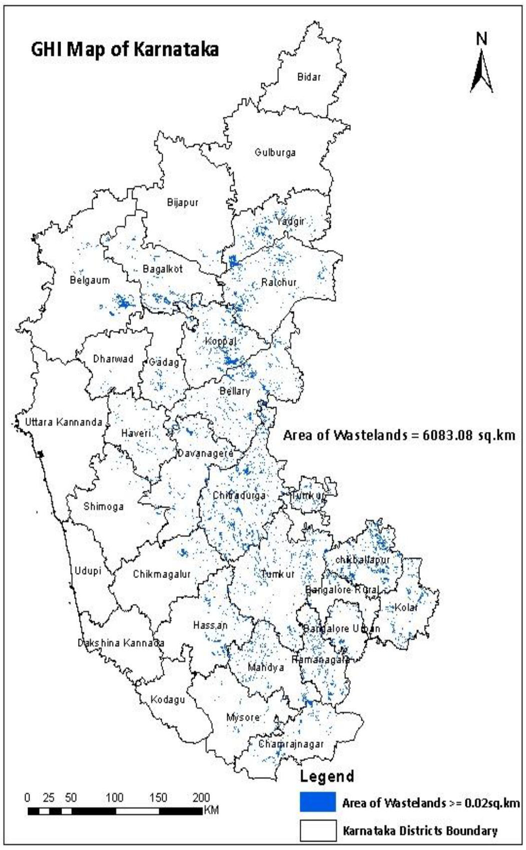
Total area of suitable wastelands in sq. km	749.64

Figure 3.4: Location of wastelands in Karnataka where DNI > 5.5 kWh/sq. km and area of single contiguous parcel is > 1 sq. km

Figure 3.4 shows the locations of wastelands in Karnataka where DNI > 5.5 kWh/sq. km and area of single contiguous parcel is > 1 sq. km and Table 3.5 show the area of suitable wastelands for CSP with distance sub stations/roads and water bodies between 1 and 3 km.

Table 3.5: Area of suitable wastelands for CSP using the given constraints

Distance of suitable wastelands from the nearest road/water body/sub station	Area of suitable wastelands (in sq. km)
Less than 1 km	109.12
Less than 2 km	173.92
Less than 3 km	319



Area of suitable wastelands in sq. km	6083.08

Figure 3.5: Location of wastelands in Karnataka where GHI > 5.75 kWh/sq. km and area of single contiguous parcel is > 0.02 sq. km

Figure 3.5 shows the locations of wastelands in Karnataka where GHI > 5.75 kWh/sq. km and area of single contiguous parcel is > 0.02 sq. km and Table 3.6 shows the area of suitable wastelands for PV with distance of the wastelands from sub stations between 1 and 3 km.

Table 3.6: Area of suitable wastelands for PV using the given constraints

Distance of suitable wastelands from the nearest road/water body/sub station	Area of suitable wastelands (in sq.km)
Less than 1 km	774.39
Less than 2 km	1491.11
Less than 3 km	2371

3.10 Assessment of Solar Potential

3.10.1 Assessment of Solar Potential for CSP Technologies

It is important to note that it may be practically impossible to use all the wastelands that are found suitable for solar power to establish solar CSP/PV infrastructure. From the land found suitable for solar power, the results have been presented assuming 5 to 10% of wastelands are available which may be usable for solar power.

The available potential if 5% and 10% of the suitable wastelands are considered is shown in Table 3.7 and Table 3.8 respectively:

Table 3.7: Potential of various CSP technologies in 5% of suitable wastelands

	Solar CSP Technologies (Potential in MW)		
Proximity	Parabolic Trough	Solar Tower	Linear Fresnel
< 1 km	434.9	360.1	525.1
< 2 km	693.2	573.9	837
<3 km	1,271.4	1052.7	1,535.2

Table 3.8: Potential of various CSP technologies in 10% of suitable wastelands

	Solar CSP Technologies (Potential in MW)		
Proximity	Parabolic Trough	Solar Tower	Linear Fresnel
< 1 km	869.8	720.2	1,050.3
< 2 km	1,386.3	1,147.9	1,674
<3 km	2,542.8	2,105.4	3,070.4

3.10.2 Assessment of Solar Potential for PV Technologies

Similarly, for PV technologies, the available potential if 5% and 10% of the suitable wastelands are considered is shown in Table 3.9 and Table 3.10 respectively.

Table 3.9: Potential of various PV technologies in 5% of suitable wastelands

	Solar PV Technologies (Potential in MW)				
Proximity	c-Si (poly)	c-Si (mono)	CdTe	CIGS	Perovskites
< 1 km	3,173.5	4,394.2	2,636.5	2,953.8	5,077.7
< 2 km	6,110.8	8,461.1	5,076.6	5,687.7	9,777.2
<3 km	9,716.7	13,453.8	8072.3	9,044	15,546.7

Table 3.10: Potential of various PV technologies in 10% of suitable wastelands

	Solar PV Technologies (Potential in MW)				
Proximity	c-Si (poly)	c-Si (mono)	CdTe	CIGS	Perovskites
< 1 km	6,347.1	8,788.3	5,273	5,907.7	10,155.4
< 2 km	12,221.5	16,922.1	10,153.3	11,375.4	19,554.5
<3 km	19,433.3	26,907.7	16,144.6	18,088	31,093.4

3.11 Solar Parks

In context to the Renewable Purchase Obligations (RPO) targets set for states by CERC and SERCs, the draft for Phase II of JNNSM makes a provision for solar parks. This option is intended to help state utilities to purchase a bulk amount of solar based electricity from a single location and fulfil a portion of their RPO targets. Around 5.4 GW of installations is expected to come from state level initiatives. MNRE will provide financial assistance to states and developers (to construct common evacuation infrastructure) within a solar park if the following criteria are met:

- Land area > 600 hectares (> 40 hectares for Karnataka)
- Receive annual average GHI greater than 5 kWh/m^2
- Avail 20,000 liters of water per MW of solar power installed
- State should have fixed RPO targets along with a fixed solar tariff

A GIS based site suitability analysis will be performed using the previously described methodology to identify locations of potential solar parks in Karnataka and other states depending on the availability of data. This will enable the government to strategize the bid processes for large centralized solar plants and allow project developers to compete on a more even field thereby ensuring performance over lifetime of plants.

3.12 Resource Assessment with a Policy Perspective

High quality resource assessments are the base for successful deployment of solar technologies. Their availability will lower the investors' uncertainty and risk about the availability of solar radiation. Hence, the Ministry of New and Renewable Energy (MNRE) has initiated a major project on Solar Radiation Resource Assessment (SRRA) station across the nation to assess and quantify the solar radiation availability along with weather parameters with a view to develop a Solar Atlas. With such detailed resource assessment potential, policy makers can optimize the support schemes by fine-tuning the necessary amount of financial support and therefore enhance the depth of market penetration of solar technologies.

This chapter shows that with proper resource assessment, even 5% of wastelands in Karnataka are sufficient to develop more than 6 GW of solar power in the state. Hence, land is not a constraint when it comes to solar power installations in the country. Other states will be analyzed in later stages of this research. To be able to reach the potential of solar power in India, proper policy measures need to be formulated. The next chapter provides an overview of the existing policy framework at the national and at various state levels which gives a background to evaluate the existing and potential barriers at the regulatory and institutional levels impeding the development of solar sector.

4 Overview of Policies and Regulations for Solar Power in India

Solar power is emerging as an important source of renewable energy in India with the government announcing various incentives to support the development of solar power. JNNSM and the Gujarat State Solar Policy are at the forefront in terms of the solar power projects deployment in India. Both, JNNSM and the various state solar policies, have encouraged investments in solar power leading to large scale grid-connected solar capacity additions in the country.

This chapter presents a comprehensive overview of the existing policies and regulations enabling investments in solar power and its growth in India. The first half of the chapter discusses about the policies related to grid-connected solar PV, solar thermal and rooftop PV systems under JNNSM. In addition, state-wise RPOs and highlights of state government initiatives and schemes for promoting solar power are discussed. The second half of the chapter presents an overview of central government schemes promoting the installation of off-grid and decentralized solar energy systems including rural electrification using solar power.

4.1 Jawaharlal Nehru National Solar Mission (JNNSM)

The Jawaharlal Nehru National Solar Mission (JNNSM), launched in January 2010, aims at generating 20,000 MW of grid-connected solar power by 2022 and work towards making India a global leader in solar energy. The mission aims at reducing the cost of solar power in the country through (i) long-term policy (ii) large-scale deployment goals (iii) aggressive R&D and (iv) domestic production of critical raw materials, components and products, as a result to achieve grid parity by 2022. The mission also intends to create an enabling policy framework to achieve this objective.

The mission also has other targets: 2000 MW of off-grid solar plants, and 20 million sq meters of solar collectors to be installed. In addition, 20 million solar lighting systems will be distributed in rural areas, saving about 1 billion litres of kerosene every year. The mission adopted a 3-phase approach, spanning the period of the 11th Plan and first year of the 12th Plan (up to 2012-13) as Phase-I, the remaining 4 years of the 12th Plan (2013-17) as Phase-II and the 13th Plan (2017-22) as Phase-III (Table 4.1) (MNRE, 2010).

Table 4.1: Solar Capacity addition targets under JNNSM

S. No.	Application Segment	Target for Phase-I (2010-13)	Target for Phase-II (2013-17)	Target for Phase-III (2017-22)
1.	Grid-connected Solar Power	1,000 – 2,000 MW	4,000 – 10,000 MW	20,000 MW
2.	Off-Grid Solar Power	200 MW	1000 MW	2000 MW
3.	Solar Collectors	7 million sq meters	15 million sq meters	20 million sq meters

4.1.1 Highlights of Phase-I of JNNSM (2010-2013)

As of 30/09/2013, the total installed capacity of grid-interactive solar power in India is 2,079 MW and off-grid/captive solar power (>1kW) is 138.99 MW (MNRE, 2013). The growth in installed solar power capacity over the last five years is shown in Figure 4.1 (till 31st March'13). There has been accelerated deployment of solar power with the announcement of national solar mission in January 2010. The installed capacity of solar power in India increased from 17.8 MW in March 2010 to 2,632 MW in March 2014.

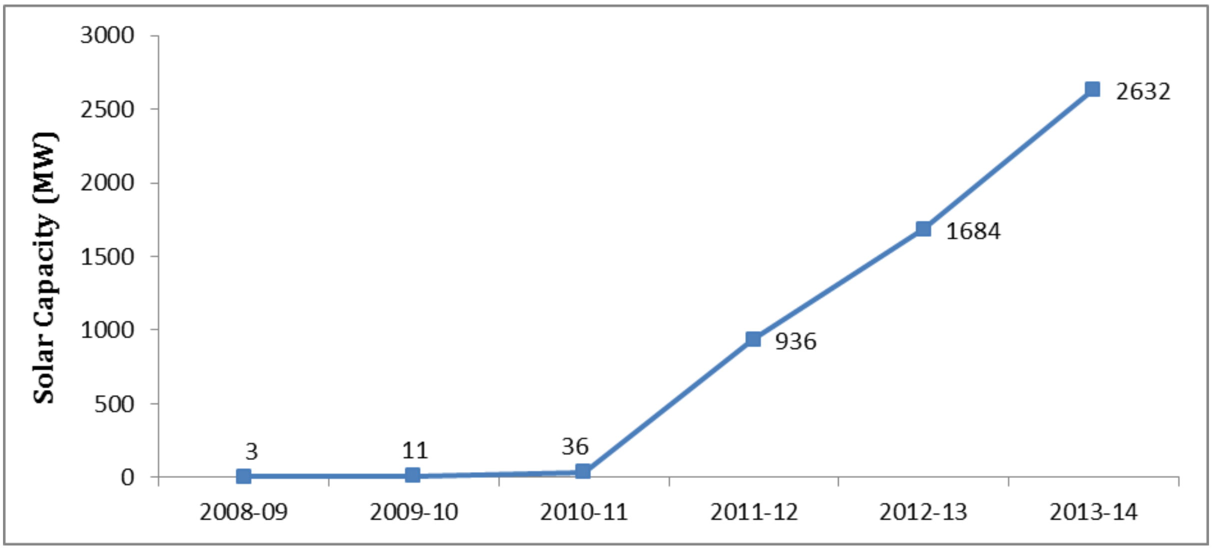


Figure 4.1: Solar power capacity growth in India

Phase-I of the JNNSM was mainly focused on large scale grid-connected projects. To install 500 MW of PV and an equal amount of CSP, the government conducted two batches of reverse bidding, which lead to achievement of least-cost solar power. The least-cost developers were incentivized in the form of financial security by providing long-term PPA with NTPC Vidyut Vyapar Nigam Limited (NVVN). NVVN was appointed as the nodal agency to purchase 1,000 MW of solar power. The purchased solar power is bundled with an equal capacity of unallocated coal based power available from NTPC. This "bundled" power is then sold to the distribution utilities at the Central Electricity Regulatory Commission (CERC) determined prices.

Phase-I of JNNSM was divided into two batches. In Batch-I, 150 MW of grid-connected solar PV and 500 MW of grid-connected CSP plants were targeted. In Batch-II the remaining 350 MW solar capacity was awarded. A Domestic Content Requirement (DCR) was mandated in phase-I of JNNSM wherein crystalline silicon cells and modules were required to be purchased from Indian manufacturers only.

Since there were many projects under planning and execution stages before the launch of JNNSM, a migration scheme was launched in February 2010 to provide these projects an opportunity to migrate to JNNSM to avail the benefits under national mission. However, this migration was subject to the consent of various stakeholders in their previous existing arrangements. A total of 84 MW (54 MW SPV and 30 MW CSP) solar projects migrated to JNNSM.

Apart from large scale grid-connected solar power plants, rooftop solar PV projects of less than 2 MW capacities each were also sanctioned under Rooftop PV and Small Solar Power Generation Programme (RPSSGP). Under RPSSGP, a maximum capacity limit of 20 MW per state was considered. MNRE provided a fixed Generation Based Incentive (GBI) to the state utilities at a rate equal to the difference of the CERC tariff for 2010-11 (Rs. 17.91 per kWh) and a reference rate of Rs. 5.5 per kWh. The projects were registered with IREDA, and 78 projects from 12 states were selected to set up 98 MW of capacity (Table 4.2).

Table 4.2: Status of Phase-I of JNNSM (MNRE, 2012)

Status of Batch - I							
Schemes		**Projects Allotted**		**Projects Commissioned**		**CERC Tariff (Rs./kWh)**	**Lowest Tariff discovered (Rs./kWh)**
		No.	MW	No.	MW		
PV projects through NVVN		30	150	25	125	PV – 17.91	PV – 10.95
CSP projects through NVVN		7	470	1	50	CSP – 15.31	CSP – 10.49
Migration Scheme	PV	13	54	11	48	-	-
	CSP	3	30	1	2.5	-	-
RPSSGP (PV)		78	98.5	62	76.55	-	-

Status of Batch – II							
Schemes	**No.**	**MW**	**Project Commissioned**	**Min Rs./kWh**	**Max Rs./kWh**	**Avg. Tariff Rs./kW h**	**% Reduction in tariff**
PV projects through NVVN	28	350	Schedule to commission by 2013	7.49	9.44	8.77	43%

Share of commissioned projects under different policy schemes

Table 4.3 shows the share of commissioned projects under different policy schemes with central and state governments.

Table 4.3: State wise solar power installed capacities under different policy schemes in India

Commissioning Status of Grid Connected solar Power Projects under JNNSM								
Sr. No.	**State/UT**	**Total MNRE Project**	**State Policy**	**RPO**	**REC Scheme**	**Pvt. Initiative (Roof - top)**	**CPSUs**	**Total Commissioned Capacity till 11 August 2014**
		MW	MW	MW	MW	MW	MW	MW
1	Andhra Pradesh	44.75	90.19	-	28.1	1.1	-	164.14
2	Arunachal Pradesh	0.025	-	-	-	-	-	0.025
3	Chhattisgarh	4	-		3.1	-	-	7.1
4	Gujarat	0	863.05	50	6	-	-	919.05
5	Haryana	7.8	-	-	-	-	5	12.8

6	Jharkhand	16	-	-	-	-	-	16
7	Karnataka	5	30	-	-	-	9	44
8	Kerala	0.025	-	-	-	-	-	0.025
9	Madhya Pradesh	5.25	224.05	-	75.78	-	50	355.08
10	Maharashtra	47	125	-	108.75	-	-	280.75
11	Orissa	12	5	-	2.5	-	10	29.5
12	Punjab	9	-	-	7.52	-	-	16.52
13	Rajasthan	484.5	23.1	40	190.35	-	-	737.95
14	Tamil Nadu	16	3	-	80	0.5	-	99.5
15	Uttar Pradesh	12	2	-	-	-	15	29
16	Uttarakhand	5	-	-	-	-	-	5
17	West Bengal	2.05	5	-	-	-	-	7.05
18	Andaman & Nicobar	0.1	-	-	-	-	5	5.1
19	Delhi	0.335	-	-	2.14	2.99	-	5.465
20	Lakshadweep	0.75	-	-	-	-	-	0.75
21	Puducherry	0.025	-	-	-	-	-	0.025
22	Chandigarh	2	-	-	-	-	-	2
23	Others	0.79	-	-	-	-	-	0.79
	Total	**674.4**	**1370.4**	**90**	**504.24**	**4.59**	**94**	**2737.62**

4.1.2 JNNSM Phase-II (Batch I)

While most of the solar thermal projects allocated in Phase-I of JNNSM were delayed, solar PV projects have been commissioned. Hence there is considerable learning in terms of technology, financing, and other aspects of solar PV. Therefore MNRE has decided to consider only solar PV in Batch-I of Phase-II of JNNSM.

After exploring various financial models for implementation such as Viability Gap Funding (VGF), Bundling scheme, GBI scheme, etc., MNRE has recently sought and approved bids for setting up 750 MW of grid-connected solar PV projects under with VGF support from the National Clean Energy Fund (NCEF) (MNRE, 2013). The total VGF requirement for this 750 MW after bids were opened was Rs. 1201 crores.

The scheme will be implemented through the Solar Energy Corporation of India (SECI) in close association with NTPC Vidyut Vyapar Nigam Limited (NVVN). The power generated will be purchased by SECI at a fixed levelized tariff of Rs. 5.45 per kWh for 25 years and sold to state utilities at a fixed price of Rs. 5.50 per unit for 25 years. In case, the benefit of accelerated depreciation is availed for a project, the tariff will be Rs. 4.95 per kWh. The upper limit for VGF is 30% of the project cost or Rs. 2.5 Crores/MW/project, whichever is lower. The VGF will be released by SECI to selected Solar Power Developers (SPDs) in six tranches as follows:

- 50% on successful commissioning of the full capacity of the project
- Balance 50% shall be paid progressively over the next 5 years, subject to the plant meeting requirements of generation

The selection of projects would be done through a process of open competitive bidding for their VGF requirement in order to enable them to supply the solar power to SECI. The bids would be invited in two separate categories: (i) 375 MW with Domestic Content Requirement (DCR) in respect of solar PV cells and modules (ii) 375 MW without any DCR requirement (MNRE, 2013).

4.1.3 Solar Renewable Purchase Obligations (RPO)

The Solar Renewable Purchase Obligation (RPO) mandates a DISCOM or any obligated entity to consume a certain percentage of their total electricity consumption from solar power. The National Action Plan on Climate Change and the National Tariff Policy envisages the increasing trajectory of Solar RPO from 0.25% in 2013 to 3% by 2022 at national level. Table 4.4 illustrates the solar capacity requirement at national level by 2022 on the basis of expected energy demand in India and solar RPOs, as envisaged in the National Tariff Policy (MNRE, 2013).

Table 4.4: Solar RPOs and Solar power capacity requirement by 2022

Year	Energy Demand (MU)(A)	Solar RPO (%) (B)	Solar Energy Requirement (MU) for RPO compliance (A) X (B)	Solar Capacity Requirement for RPO compliance (MW)[6]
FY-12	953,919	0.25	2,385	1,433
FY-13	1,022,287	0.25	2,556	1,536
FY-14	1,095,555	0.50	5,478	3,291
FY-15	1,174,074	0.75	8,806	5,291
FY-16	1,258,221	1.00	12,582	7,560
FY-17	1,348,399	1.25	16,855	10,127
FY-18	1,443,326	1.75	25,258	15,176
FY-19	1,544,936	2.25	34,761	20,885
FY-20	1,653,700	2.50	41,343	24,839
FY-21	1,770,120	2.75	48,678	29,247
FY-22	1,894,736	3.00	56,842	34,152

As per the provisions under Section 86(1) (e) of the Electricity Act 2003 and notified Tariff Policy, to encourage the development and consumption of solar power across all the states in India, State Electricity Regulatory Commissions (SERCs) have to specify solar RPO targets in their States, notify RPO regulations and ensure its compliance. The Solar RPO targets specified by various State Electricity Regulatory Commissions (MNRE, 2012) are summarized in Table 4.5.

[6] Assuming 19% CUF for Solar Power Plants

Table 4.5: State solar RPOs (%)

States	FY-12	FY-13	FY-14	FY-15	FY-16	FY-17	FY-18	FY-19	FY-20	FY-21	FY-22
Andhra Pradesh	0.25	0.25	0.25	0.25	0.25	0.25					
Arunachal Pradesh	No regulations issued for RPO by state regulator										
Assam	0.10	0.15	0.20	0.25							
Bihar	0.25	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.50	3.00
Chhattisgarh	0.25	0.50									
Delhi	0.10	0.15	0.20	0.25	0.3	0.35					
JERC (Goa & UT)	0.30	0.40									
Gujarat	0.50	1.00									
Haryana	0.00	0.05	0.75								
Himachal Pradesh	0.01	0.25	0.25	0.25	0.25	0.25	0.50	0.75	1.00	2.00	3.00
Jammu & Kashmir	0.10	0.25									
Jharkhand	0.50	1.00									
Karnataka	0.25	0.25									
Kerala	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Madhya Pradesh	0.40	0.80	1.00								
Maharashtra	0.25	0.50	0.50	0.50							
Manipur	0.25	0.25									
Mizoram	0.25	0.25									
Meghalaya	0.30	0.4									
Nagaland	0.25	0.25									
Orissa	0.10	0.15	0.20	0.25	0.30						
Punjab	0.03	0.07	0.13	0.19							
Rajasthan	0.50	0.75	1.00								
Sikkim	No regulations issued for RPO by state regulator										
Tamil Nadu	0.05										
Tripura	0.10	0.10									
Uttarakhand	0.03	0.05									

Uttar Pradesh	0.50	1.00									
West Bengal			0.25	0.30	0.40	0.50	0.60				

Table 4.5 indicates that many states are yet to notify the long-term solar RPO trajectory as envisaged under the National Tariff Policy. In the last financial year, no state except the solar power rich states of Gujarat and Rajasthan, complied with their RPO targets. All states are supposed to meet their RPO demand either through direct purchase of solar energy or by purchasing Solar Renewable Energy Certificates (RECs). RECs are very similar to carbon credits. The REC mechanism is similar to the international Clean Development Mechanism (CDM) market where countries that do not meet the emission reduction targets can purchase carbon credits in the designated market. Electricity distributors or other obligated entities in India who cannot buy the percentage of renewable energy required by RPOs, will have the option to fulfil their obligation by purchase of RECs that are traded at energy and power exchanges in India.

4.2 State Solar Policies

In addition to central government initiatives for development of solar power in India, there are a few states which have announced their own state solar policies in order to encourage solar project deployments in their states. Highlights of selected state solar policies are presented in this section (MNRE, 2013). The estimates of solar capacity requirement till FY-22 on the basis of expected energy demands[7] in the respective states and solar RPO targets of 0.25% in FY-13 and increased to 3.0% by FY-22, as envisaged in National Tariff Policy, is also shown for each state.

4.2.1 Karnataka

Government of Karnataka revised the existing state solar policy (2011-16) and announced its now policy, "Karnataka Solar Policy 2014-2021", with more ambitious targets and incentives for solar power development in the state. The cumulative target is to achieve 2,000 MW of installed solar power capacity by 2021, which includes 400 MW of grid connected rooftop PV systems by 2018. It also makes provisions for 200 MW off-grid installations by 2021.

Table 4.6: Solar power capacity requirement by 2022

Year	Total Energy Required (MUs)	Solar RPO (%)	Solar Energy Required (MUs)	Solar Capacity Required (MW)
2012-13	56620	0.25%	141.55	**85**
2013-14	59336	0.50%	296.68	**178**
2014-15	65179	0.75%	488.84	**294**
2015-16	77600	1.00%	776.00	**466**
2016-17	85660	1.25%	1070.76	**643**
2017-18	91267	1.75%	1597.17	**960**
2018-19	101165	2.25%	2276.21	**1,368**
2019-20	117308	2.50%	2932.70	**1,762**
2020-21	127452	2.75%	3504.93	**2,106**
2021-22	129709	3.00%	3891.26	**2,338**

4.2.2 Gujarat

Gujarat was the first state to launch a state specific solar power policy in 2009 and the same policy is operative till March 2014. All projects commissioned during this period will be eligible for benefits for a period of 25 years. Table 4.7 shows the expected capacity addition through the RPO route in Gujarat.

A total of 500 MW solar power projects shall be allotted under this policy with 5 MW as minimum capacity for each project. Power evacuation facility from the solar farms will be arranged by the Gujarat Electricity Transmission Corporation Limited (GETCO). Only new plants will be considered under the current policy and no hybridization shall be allowed for Solar Thermal Project under current state policy.

[7] CSTEP's estimates

Table 4.7: Projected solar power capacity requirement for Gujarat based on envisaged Solar RPOs till FY-22

Year	Total Energy Required (MUs)	Solar RPO (%)	Solar Energy Required (MUs)	Solar Capacity Required (MW)
2012-13	82,707	0.25%	207	124
2013-14	88,496	0.50%	442	266
2014-15	94,691	0.75%	710	427
2015-16	1,01,320	1.00%	1,013	609
2016-17	1,08,412	1.25%	1,355	814
2017-18	1,16,001	1.75%	2,030	1,220
2018-19	1,24,121	2.25%	2,793	1,678
2019-20	1,32,809	2.50%	3,320	1,995
2020-21	1,42,106	2.75%	3,908	2,348
2021-22	1,52,053	3.00%	4,562	2,741

4.2.3 Rajasthan

The government has allotted 66 MW of solar power in compliance with state electricity regulator's order and these projects were migrated to JNNSM to avail the benefits under Phase-I of the mission. The state will also develop 100 MW of solar power with equal contributions from CSP and PV and developers will be selected by competitive bidding process. In addition, the state government will also support commissioning of 100 MW SPV and 100 MW CSP under Phase-I of state solar policy 2011 and has plans to add 400 MW of solar power in Phase-II. The state also plans to develop solar parks of project capacities exceeding 1000 MWs. Table 4.8 shows the expected installations through the RPO mechanism in Rajasthan.

Table 4.8: Projected solar power capacity requirement for Rajasthan based on envisaged Solar RPOs till FY-22

Year	Total Energy Required (MUs)	Solar RPO (%)	Solar Energy Required (MUs)	Solar Capacity Required (MW)
2012-13	54,394	0.25%	136	82
2013-14	58,202	0.50%	291	175
2014-15	62,276	0.75%	467	281
2015-16	66,636	1.00%	666	400
2016-17	71,300	1.25%	891	535
2017-18	76,291	1.75%	1,335	802
2018-19	81,631	2.25%	1,837	1,104

2019-20	87,346	2.50%	2,184	1,312
2020-21	93,460	2.75%	2,570	1,544
2021-22	1,00,002	3.00%	3,000	1,802

4.2.4 Tamil Nadu

The Tamil Nadu government has announced its solar policy in 2012 and targets 3000 MW by 2015, including 350 MW of rooftop capacity in three phases of 100, 125 and 125 MW (per year) during the period 2013-2015. Out of 350 MW rooftop capacity, 50 MW will be from domestic consumers who will receive a GBI of Rs. 2/kWh for the first two years, Rs. 1/kWh for the next two years and Rs. 0.5/kWh for the subsequent two years for all solar and hybrid (solar & wind) rooftops being installed before 31 March 2014. 300 MW will be planned for government buildings and government schemes for rural and urban lighting. Table 4.9 shows the expected capacity installations through the RPO route in Tamil Nadu.

Table 4.9: Projected solar power capacity requirement for Tamil Nadu based on envisaged Solar RPOs till FY-22

Year	Total Energy Required (MUs)	Solar RPO (%)	Solar Energy Required (MUs)	Solar Capacity Required (MW)
2012-13	87,391	0.25%	218	131
2013-14	93,508	0.50%	468	281
2014-15	1,00,054	0.75%	750	451
2015-16	1,07,057	1.00%	1,071	643
2016-17	1,14,551	1.25%	1,432	860
2017-18	1,22,570	1.75%	2,145	1,289
2018-19	1,31,150	2.25%	2,951	1,773
2019-20	1,40,330	2.50%	3,508	2,108
2020-21	1,50,154	2.75%	4,129	2,481
2021-22	1,60,664	3.00%	4,820	2,896

4.2.5 Madhya Pradesh

The government of Madhya Pradesh announced its solar power policy in 2012. The following categories of projects will be considered for support under this policy:

Category I: Solar power projects will be selected based on bidding process and will sell power to DISCOMs.

Category II: Solar power projects will be commissioned for self-consumption or for sale to third party. However, individual projects will be limited to a maximum capacity as mentioned below:

- **Projects on Private Land:** There is no capacity limit for the projects installed on private land.

- **Projects on Government Land:** For solar power projects on government land, capacity limit is mentioned in Table 4.10

Table 4.10: Minimum and Maximum Capacity on Government land

Technology	Minimum Capacity (MW)	Maximum Capacity (MW)
SPV	0.025	100
CSP	1.00	100

Category III: Solar power projects of any capacity can be set up under REC mechanism as per the CERC guidelines**.**

Category IV: The solar power project capacity will be as per JNNSM guidelines.

Table 4.11 shows the total expected installed capacity through the RPO mechanism in Madhya Pradesh.

Table 4.11: Projected solar power capacity requirement for Madhya Pradesh based on envisaged Solar RPOs till FY-22

Year	Total Energy Required (MUs)	Solar RPO (%)	Solar Energy Required (MUs)	Solar Capacity Required (MW)
2012-13	46,178	0.25%	115	69
2013-14	49,410	0.50%	247	148
2014-15	52,869	0.75%	397	238
2015-16	56,570	1.00%	566	340
2016-17	60,529	1.25%	757	455
2017-18	64,766	1.75%	1,133	681
2018-19	69,300	2.25%	1,559	937
2019-20	74,151	2.50%	1,854	1,114
2020-21	79,342	2.75%	2,182	1,311
2021-22	84,896	3.00%	2,547	1,530

4.2.6 Andhra Pradesh

Andhra Pradesh solar power policy was announced in September 2012 and will remain applicable till 2017. The policy mainly supports large scale grid-connected solar projects. The following incentives will be applicable till June 2014 and will be in force for seven years from the date of commissioning of the project:

- No wheeling charges for sale of power within the state
- The power will be exempted from electricity duty charges

Table 4.12 shows the expected installed capacity in Andhra Pradesh through the RPO route.

Table 4.12: Projected solar power capacity requirement for Andhra Pradesh based on envisaged Solar RPOs till FY-22

Year	Total Energy Required (MUs)	Solar RPO (%)	Solar Energy Required (MUs)	Solar Capacity Required (MW)
2012-13	89,404	0.25%	224	134
2013-14	95,662	0.50%	478	287
2014-15	1,02,358	0.75%	768	461
2015-16	1,09,523	1.00%	1,095	658
2016-17	1,17,190	1.25%	1,465	880
2017-18	1,25,393	1.75%	2,194	1,318
2018-19	1,34,171	2.25%	3,019	1,814
2019-20	1,43,563	2.50%	3,589	2,156
2020-21	1,53,612	2.75%	4,224	2,538
2021-22	1,64,365	3.00%	4,931	2,963

4.2.7 Chhattisgarh

The Government of Chhattisgarh announced its solar power policy in November 2012 and it will be operative till 31st March 2017. This policy targets solar project capacity additions of up to 1000 MW by March 2017. This will be achieved in the following ways: This target will be achieved by deployment of large scale grid-connected solar power projects for self-consumption, sale to DISCOMs or sale to third party under open access within or outside the state along with projects under REC mechanism.

The government has extended incentives such as interest subsidy, fixed capital investment subsidy, exemption from electricity duty, etc. to the solar industry. Power evacuation facility from the solar plant will be provided by the Chhattisgarh Transco or DISCOM at the cost of project developer. Table 4.13 shows the expected solar capacity to be installed through the RPO route in Chhattisgarh.

Table 4.13: Projected solar power capacity requirement for Chhattisgarh based on envisaged Solar RPOs till FY-22

Year	Total Energy Required (MUs)	Solar RPO (%)	Solar Energy Required (MUs)	Solar Capacity Required (MW)
2012-13	17,693	0.25%	44	27
2013-14	18,932	0.50%	95	57
2014-15	20,257	0.75%	152	91
2015-16	21,675	1.00%	217	130
2016-17	23,193	1.25%	290	174

2017-18	24,816	1.75%	434	261
2018-19	26,553	2.25%	597	359
2019-20	28,412	2.50%	710	427
2020-21	30,401	2.75%	836	502
2021-22	32,529	3.00%	976	586

4.2.8 Uttar Pradesh

Uttar Pradesh announced its solar power policy in March 2013 with a target to reach 500 MW of solar power by March 2017. This policy will be effective till 31st March 2017. However, solar projects under JNNSM will not be considered under this policy. Selection of solar projects on government land will be done through a transparent competitive bidding process and a minimum capacity limit for each project under this policy will be 5 MW. Captive solar projects of greater than 5 MW capacities will also be eligible for benefits under this policy.

However, generation based incentives and capital subsidies available under this policy will not be extended to the projects willing to sell solar power to third parties under open access. Also, in future these projects will not be allowed to sign PPA with DISCOMs. Table 4.14 shows the expected installed capacity through the RPO mechanism in Uttar Pradesh.

Table 4.14: Projected solar power capacity requirement for Uttar Pradesh based on envisaged Solar RPOs till FY-22

Year	Total Energy Required (MUs)	Solar RPO (%)	Solar Energy Required (MUs)	Solar Capacity Required (MW)
2012-13	88,682	0.25%	222	133
2013-14	94,890	0.50%	474	285
2014-15	1,01,532	0.75%	761	458
2015-16	1,08,640	1.00%	1,086	653
2016-17	1,16,244	1.25%	1,453	873
2017-18	1,24,382	1.75%	2,177	1,308
2018-19	1,33,088	2.25%	2,994	1,799
2019-20	1,42,404	2.50%	3,560	2,139
2020-21	1,52,373	2.75%	4,190	2,518
2021-22	1,63,039	3.00%	4,891	2,939

4.3 Overview of Policies for Rural and Decentralized Solar Applications

4.3.1 Off-grid and Decentralized Solar Applications

The main objectives of this scheme initiated by MNRE in 2010 were to promote solar PV and solar thermal systems for off-grid applications and encourage replacement of kerosene and diesel based systems (MNRE, 2010). It supported solar PV applications up to a maximum of 100 kWp per site and off-grid/decentralized solar thermal applications. The scheme covered mini grids for rural electrification to a maximum of 250 kW per site. Implementation of the scheme was carried out by Renewable Energy Service Providing Companies (RESCOs), financial bodies and programme administrators. This scheme is currently in existence and guidelines for its implementation are revised every year. The subsequent schemes discussed in this chapter regarding off grid solar applications under the ambit of JNNSM are all continuing till date.

The central financial assistance (CFA) for the off-grid and decentralized solar application programme is summarized below:

- MNRE provided financial support through a combination of 30 % subsidy and 5 % interest bearing loans
- The benchmark price of various off-grid solar applications is shown in Table 4.15 (MNRE, 2013). However, according to JNNSM Phase-II guidelines, the annual benchmark price would be annually revised and the subsidy will be calculated accordingly (MNRE, 2012)

Table 4.15: Benchmark prices of SPV systems for off-grid and decentralized solar applications

SPV System		**Capacity**	**Benchmark Price (Rs/Wp)**
SPV power plants (with battery bank having more than 6 hours of autonomy)		>300 Wp – 1kWp	210
		>1kWp – 10 kWp	190
		>10 kWp – 100 kWp	170
SPV power plants (without battery storage)		Up to 100 kWp	100
		>100 kWp – 500 kWp	90
Micro Grid (DC)		Up to 10 kWp	350
Mini Grid		>10 to 250 kWp	300
Solar lighting system (street, home, lanterns)	**CFL**	Up to 300 Wp	270
	LED	Up to 300 Wp	450
Solar water pumps		Up to 5 kWp	190
Street lights through SPV power plants		Up to 100 kWp	300

- Capital subsidy of 90 % of the benchmark cost was available for special category states, which was however limited to 60 % for solar thermal systems
- 3 % of CFA was provided as service charge to programme administrators and an additional 10 % for projects involving poor strata of society
- The total budget allocated till 2013 was Rs. 1121.88 crores.

The Energy and Resources Institute (TERI) along with the support of Norwegian Ministry of Foreign Affairs demonstrated battery backed solar micro grids in Uttar Pradesh, India (MNRE, 2012). The system installation was typically of about 300 Wp catering to the lighting needs of about 40 households and commercial establishments specifically during evening hours. The entire infrastructure was set up by village level entrepreneurs and managed with the help of operators trained by TERI. By 2012, 17 micro grids had already been implemented. Humana People to People India has proposed to build 41 micro grids in Uttar Pradesh with 35 % project cost contribution by MNRE and remaining by local entrepreneurs (UNDP-MNRE, 2012). The net cumulative off-grid solar power installed in India by 31st June'14 is about 174 MW_{EQ} (MNRE, 2013).

However, the major threat to mini grids/ micro grids existing in India today is the extension of the national grid to remote areas which offers power at comparatively lower prices. Moreover, the existing mini grids today are not grid interactive due to a lack of regulatory framework; there is a chance that consumers might completely stop using decentralized power once three phase power from the national grid reaches their villages. To tackle such challenges, experts provide different opinions that can help scale up mini grid implementation. Small capital subsidies supported by feed in tariffs and generation based incentives is considered as a good solution by a few. While others feel that an Off-grid Distributed Generation Based Distribution Franchise (ODGBDF) model wherein the tariffs for consumers are kept at par with grid connected rates and the difference is taken care of by viability gap funding from the utility is a better model (Jamwal, 2014).

4.3.2 Rooftop PV and Small Solar Power Generation

Under Phase-I of JNNSM (started in 2010), both grid-connected and off-grid rooftop solar projects were encouraged (MNRE, 2010). For decentralized applications in rural areas, off-grid rooftop PV projects were found to have inherent advantages. Such installations reduced dependency on grid, were easy to install and required no stringent monitoring like grid-connected systems. However, off-grid PV installations required battery backup and were more expensive compared to grid-connected projects (Madhavanvee, 2012).

The MNRE assistance for rooftop and small solar schemes is listed below:

- Financial aid at Rs. 100/Wp, subject to a maximum of 40 % of the cost of system was provided to non-profit making organizations. However, profit making organizations received only a maximum of 30 % of the cost of system (at Rs. 75/Wp), along with a provision to avail accelerated depreciation
- Support was extended to both grid and off-grid based systems in the range of 25-100 kWp. Systems with smaller capacity (not less than 10 kWp) were considered on case basis.

4.3.3 Solar Charging Stations (with lanterns)

This scheme started by MNRE in 2012, aimed to establish 6000 solar charging stations, in 100 villages of Left Wing Extremism (LWE) affected districts through respective State Renewable Energy Development Agency (SREDA) (MNRE, 2012). The scheme was implemented in Andhra Pradesh, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, Uttar Pradesh and West Bengal. Each station catered towards charging of 50 lanterns and 5-10 mobiles and was managed by local entrepreneurs.

The MNRE support for successful implementation of solar charging stations is mentioned in the bullets below:

- The benchmark cost was Rs. 1.5 lakh per station and a capital subsidy of 90 % was provided by MNRE. The total budget for the charging station was Rs. 81 crores (2012-2014)
- The State Nodal Agencies (SNAs) received 3 % of CFA as service charges for implementing and monitoring the charging stations
- The entrepreneurs earned revenue by renting lanterns and also maintained the charging stations. They also deposited 25% of the revenues in bank for replacement of batteries.

The MNRE scheme for Solar Charging Stations has been adopted from the highly successful 'Lighting a Billion Lives' (LaBL) initiative launched by TERI in 2008. The LaBL initiative provides lighting needs to the rural communities in India through solar lanterns charged in dedicated solar charging stations. The use of clean technology along with a sound replicable business model made this campaign international, transforming the lives of over two million people globally **(Dube, 2014)**. The LaBL scheme is currently being extended to the LWE districts in India and is under progress.

4.3.4 Solar Home Lighting and Other Small Solar Systems

Solar Home Lighting (SHL) systems essentially consist of a PV module, battery, charge controller and lighting loads such as DC light and fans (Raghavan, et al., 2010). The SHL scheme by MNRE (2009) aimed to assist financial bodies in providing loans to consumers for purchasing SHL systems and other small solar systems in remote un-electrified villages. The implementing agencies were also responsible for monitoring and inspecting solar systems. About 2,50,000 solar lighting and other small solar systems were proposed to be covered under the scheme by 31st March 2011 (MNRE, 2010).

Financial assistance for implementation of solar home lighting systems is summarized below:

- A provision of Rs. 1.5 crores was made for availing consultancies for monitoring and evaluation
- All NGOs or Self Help Group (SHGs) involved in capacity building and awareness generation was granted Rs. 5 lakhs. Cash prize of Rs. 1 lakhs was given to each bank or village panchayat wherein the village was completely electrified with solar energy
- During 2009-2010, funds for implementation were drawn from the Ministry's budget head under Renewable Energy. In 2010-2011, SHL funds were drawn from the total budget of Rs. 224 crores allocated for off-grid/ decentralized solar applications
- The funding limits are mentioned in Table 4.16 below:

Table 4.16: MNRE funding pattern for solar home lighting systems

The range of no. of systems	3000-6000	6001-12000	12001-20000	Above 20000
Minimum lending amount per year	Rs. 3 crores	Rs. 6 crores	Rs. 12 crores	Rs. 20 crores

Success stories related to implementation of SHLs under JNNSM and other existing schemes are covered in an MNRE report (MNRE, 2012). With its operations based in Kolkata and catering to the needs of people in West Bengal and Odisha, ONERgy has been able to impact 75,000 people with solar lighting solutions spanning across 300 villages. It offers customized solutions of SHLs with prices varying between Rs 1000- Rs 30,000 and payback period between 6 months to 5 years depending on the size of the project. Similarly, in the Sunderbans region of West Bengal, Ramakrishna Mission along with MNRE and NREL have been successful in installing about 1100 SHLs. IREDA along with a private organization developed a model to lease out SHLs in the Sunderbans using World Bank funds; a trial of 3000 SHLs has been approved till date. In a separate study highlighting the success of SHLs in Karnataka, the authors have highlighted the strong role of rural banks in acting as intermediaries between SHL manufacturers and consumers (Adoption of solar home lighting systems in India:What might we learn from Karnataka?, 2013). A well designed feedback loop by the banks helps ensure that the SHLs sold are well maintained and serviced; this in return also creates accountability on part of the firms selling SHLs. Karnataka's model of SHL system implementation shows that such schemes can be successful even in the absence of subsidies and in villages which are already electrified, but have poor access to electricity. In the year 2013-2014, the various banks have provided loans for about 61558 solar lighting systems (MNRE, 2014).

4.3.5 Solar Lantern Programme

The solar lantern programme started by MNRE in 2006, aimed at reducing kerosene consumption for lighting purposes in rural areas (MNRE, 2010). This helped in improving the quality of life and reduced the risk of heath and fire hazards. The scheme aimed at deploying about 30,000 solar lanterns during 2006-2007, with provisions for support towards the education of girl child. The scheme was implemented only through State Nodal Authorities (SNAs) and Akshaya Urja shops, with service centers set up by the manufacturer. The scheduled caste and scheduled tribe beneficiaries were provided at least 15 % and 10 % of the solar lanterns out of the allocated targets respectively with preference to centers meant for women. The benchmark price was set at Rs. 270/Wp for CFL based solar lanterns and Rs. 450/Wp for LED based solar lanterns (MNRE, 2010).

MNRE financial assistance for the solar lantern programme includes various subsidies and grants as summarized below:

- A subsidy of Rs. 2400 per lantern was provided by MNRE to non-electrified villages/ hamlets in special category states and Union Territory (UT) islands. In addition, a service charge of Rs. 100 per lantern was given to SNAs and Akshaya Urja shops. The SNAs received inspection charges of Rs. 100 per lantern for the sale of lanterns from Akshaya Urja shops

- Funds were drawn out of the Rs. 30 crores budget set aside for off-grid and decentralized solar applications in 2009-2010. In 2010-2011, the scheme was implemented under the same budget category out of a total Rs. 224 crores.

4.3.6 Solar Water Heating Systems

The scheme on Solar Water Heating (SWH) systems initiated by MNRE in 2008, aimed at promoting the use of solar water heaters in domestic, industrial and commercial sectors. A target of 1.4 million sq. m of collector area was set for 2008-2010 by accelerating implementation through capital/interest subsidy (MNRE, 2010). The capital subsidy was implemented through SNAs and interest subsidy via IREDA and other Financial Institutions (FIs), all involved in evaluation and performance assessment.

Solar water heating systems for various applications received interest and capital subsidies from MNRE as described below:

Interest subsidy

- Soft loans were provided to domestic users at 2 %, except in certain states wherein they were given interest free loans
- Loans at 3 % were provided to institutional users' not availing accelerated depreciation and at 5 % to industrial or commercial users availing accelerated depreciation
- The interest subsidy discounted at 6.5 % was released by IREDA to banks and financial bodies on a reimbursement basis after installation of systems

Capital Subsidy

- Capital subsidy at Rs. 1750 per sq. m and Rs. 1400 per sq. m of collector area was provided to non-profit making institutions and profit making bodies respectively for not availing soft loans
- For builders and housing developers, a capital subsidy was available for systems having a capacity of 2500 liters per day (lpd) or more at Rs. 1950 per sq. m for housing complexes, at Rs. 1700 per sq. m for institutional buildings and at Rs. 1400 per sq. m for commercial buildings
- Administrative charges were provided to SNAs at Rs. 100/ sq. m of installed collector area to a maximum of Rs. 5000 per system
- Grants up to Rs. 2 lakhs per event were given for conducting workshops, seminars and symposia. An additional assistance of Rs. 2 lakhs was provided for training programmes
- A one-time grant of Rs. 5 lakhs and Rs. 10 lakhs was given to municipalities and municipal corporations respectively for adopting the modifications in building by-laws and announcing rebate in property tax
- Grants up to Rs. 10 lakhs were given to State Electricity Boards for providing rebate in electricity tariff to users of SWH systems

- SNAs were given 1 % administrative charges by MNRE to help the municipalities/state utilities in the implementation of rebate schemes. All media campaigns organized by the SNAs/IREDA/Municipalities etc. in a year, were granted an annual amount of Rs. 10 lakhs
- Financial support was also given to industries on 50 % cost sharing basis up to a maximum of Rs. 5 lakhs to manufacturer associations for advertisement campaigns
- Technology up-gradation and related foreign visits for the SWH system manufacturers was supported by means of soft loans at 5 % interest through IREDA for 5 years.
- Financial grants up to Rs. 5 lakhs per project were provided to SNAs, NGOs, Consultants, etc. for technology/potential assessment and cost benefit analysis, etc.
- A total of Rs. 64.5 crores was allocated for the scheme till 2011, under the budget for Solar Thermal Energy Programme of the Ministry.

The net cumulative collector area installed for solar water heating systems by 31st July'14 is about 80.08 lakh square meters (MNRE, 2013).

4.3.7 Solar Thermal Systems, Solar Buildings and Akshaya Urja Shops

This scheme was initiated in 2005 and the major objectives of the scheme were to accelerate the use of solar thermal systems for air heating and steam generating applications. It also planned to use solar passive techniques for building designs and helped in the creation of retail outlets, namely Akshaya Urja for sale and service of solar and other renewable products (MNRE, 2010). The targets for the scheme in 2005-2006 was 6000 sq. m for collector area for Flat Plate Collector (FPC) based air heating system (minimum 25 systems), 4000 sq. m of dish area for solar concentrating systems (minimum 15 systems), 10 demonstration solar buildings in 8 states and 200 Akshaya Urja shops in 10 states. Implementation and performance evaluation of the scheme was carried out by SNAs, IREDA, technical institutions and reputed NGOs. The solar building component was removed and modified into a separate scheme for implementation from 2009 onwards. The scheme initially used funds from the Solar Thermal Energy Programme of MNRE and later received separate funds of Rs. 3.95 crores in 2009 and Rs. 10 crores in 2010.

MNRE financial support for solar thermal systems, solar buildings and Akshaya Urja shops are listed below:

a) Solar thermal systems for air heating and steam generation

- CFA for non-profit making institutions included 50 % of the cost of the system, whereas commercial organizations or those claiming depreciation were granted a CFA of 35 % of the cost of the system
- 3 % MNRE support was given to implementing agencies along with Rs. 10 lakhs grant per event for awareness campaigns and Rs. 2 lakhs per event for workshops/symposia. Training programmes at Rs. 2 lakhs per event was provided to installers or entrepreneurs
- Soft loans at 5 % interest were given for technology up-gradation. Rs. 5 lakhs per project was granted to conduct studies and surveys for assessing the feasibility of technology

b) Solar buildings

- CFA at 50 % of the cost of Detailed Project Report (DPR), a maximum of Rs. 2 lakhs was given
- Financial assistance up to 10 % of the cost of the project was provided, a maximum of Rs. 50 lakhs per project for demonstration of solar buildings
- Awareness generation through workshop/ seminars at Rs. 2 lakhs grant per event was supported. A grant of Rs. 2 lakhs per activity was given to encourage publications

c) **Akshaya Urja shops**

- Soft loan at an interest between 7 % - 8.5 %, to a maximum of Rs. 10 lakhs was given for setting up shops by banks, repayable over a period of 5 years
- A monthly grant of Rs. 5000 per month was provided towards manpower, electricity and other miscellaneous expenses
- An amount of Rs. 5000 per month was given as an incentive for turnover exceeding Rs. 50,000 per month in the first year and Rs. 1,00,000 in the second year.
- Service charges were provided to SNAs at Rs. 50,000 per shop, provided that 50 % of the amount is utilized for publicity purposes. 2 % service charge was given to IREDA on the interest subsidy given to banks and Rs. 5000 per loan disbursed to the banks.

4.3.8 Solar Thermal Energy Demonstration

This scheme was launched in 2006 with an objective to promote solar thermal technologies to meet cooking needs and thus reduce the need for biomass and traditional fossil fuels (MNRE, 2010). The scheme also supported applications such as solar drying, purification of water and solar buildings etc. Solar cookers of concentrating (dish and community) type and box type were promoted in the scheme. Solar dryers (direct and indirect type), solar distillation systems for pure water (single basin type solar stills, high efficiency solar stills) for use in villages were also included in the scheme. Solar water heating systems were encouraged at sites with high visibility and energy efficient solar buildings for rural areas were also supported. The schemes were implemented and evaluated by SNAs, government and semi-government bodies, recognized universities and reputed NGOs. A total target of 20,000 numbers of different solar cookers has been set for 2005-2006. Initially, the expenditure was met from the total budget allocated under solar thermal energy programme (a total of Rs. 4.43 crores). The scheme got a separate budget allocation of Rs. 10 crores in 2010.

The solar thermal energy demonstration programme received adequate financial support from MNRE for its implementation. The funding schemes are listed below:

- For dish type solar cooker, 30 % of the total cost, up to Rs. 1500 per cooker was given as CFA and Rs. 250 per cooker provided as service charge to the implementing agency. However, in the case of community solar cooker, 30 % of the capital cost limited to Rs. 30,000 per cooker was granted as CFA and the service charge was limited to Rs. 2500 per cooker

- The sale of box type solar cookers was promoted by means of financial incentives as mentioned in Table 4.17.

Table 4.17: MNRE funding pattern for box type solar cookers

Types of solar cooker sold	Incentive per cooker provided to SNAs for sale made	Incentive per cooker if the sale made by SNAs is through their associated promoters

	through their own outlet	SNAs	Associated promoters
ISI marked box solar cooker	Rs. 200	Rs. 100	Rs. 100
Non ISI box solar cooker but approved by SEC/ RTCs	Rs. 100	Rs. 50	Rs. 50

- Financial assistance up to Rs. 1.5 lakhs was provided for promotional activities like publicity, cooking demonstrations, seminars, workshops etc.
- Provision of reimbursement of 50 % of Bureau of Indian Standards (BIS) fee was facilitated by MNRE
- In support of solar dryers and solar stills, MNRE shared up to 50 % of the cost of the system
- In the islands and J & K, up to Rs. 4000 per sq. m of collector area was supported. However, in the NE and Sikkim, support was extended at Rs. 6000 per sq. m of collector area
- Solar buildings programme not only supported workshops/ seminars for the villagers, but also for orientation courses for architects and builders. The pattern of CFA is shown in Table 4.18.

Table 4.18: MNRE funding for solar buildings programme

National/ Model workshop/ Orientation course	Rs. 2,00,000
Seminar/ Workshop of one day duration	Rs. 40,000
Workshop/ Orientation course of 2 day duration	Rs. 65,000
Refresher/ Orientation course of 3 day duration	Rs. 80,000
A session in a major conference	Rs. 50,000

- Buildings with BIPV (Building Integrated PV) and solar passive features were supported with 50 % of the cost of DPR (maximum Rs. 1,00,000) or 1.5 % of the cost of the building
- Support up to 10 % of the cost of each BIPV structure (maximum Rs. 10 lakhs) was given towards construction. Financial grants up to Rs. 1,00,000 was given to housing organizations and village panchayats to formulate guidelines for energy efficient buildings
- Publications on solar buildings were supported and implementing agencies were provided with 10 % of CFA as service charges.

4.3.9 Large Area Solar Dish Concentrator (ARUN-160)

This programme was initiated by MNRE in 2007 to popularize and promote the use of a large area solar dish concentrator technology (ARUN-160), developed jointly by IIT Bombay and M/s Clique Development Private Limited (CPDL) (MNRE, 2010). The technology was successfully tested for industrial process heat applications and demonstrated a huge potential. This scheme basically supported installation and commissioning of ARUN-160 to test its performance under actual field conditions. A target of 10 numbers of technology evaluation projects and a maximum of 20 such projects were fixed for the year 2007-2008.

Financial assistance for solar dish concentrator programme is summarized below:

- A fixed grant of Rs. 12 lakhs was provided for each ARUN-160 (except private organizations)
- Implementing agencies received 2 % of the CFA as service charges
- The total budget allocated for the scheme in 2007 was Rs. 3 crores. Later in 2010, a budget of Rs. 64.8 crores was allocated again for the scheme

Since the inception of the scheme, Clique Solar has been successful in installing Arun concentrators for a host of applications that require heating in industries. Such concentrators have been immensely beneficial for applications such as milk pasteurization, effluent treatment, comfort cooling, laundry and cooking with efficiencies as high as 60-65 %. With significant oil saving potential, the ARUN concentrators have a payback between 3-6 years depending on the application (Bhatewara, 2013).

4.3.10 Remote Village Electrification

To achieve electrification in remote un-electrified villages and hamlets through renewable energy sources, this programme was initiated by MNRE in 2009. Only those villages/ hamlets identified to be remote for grid connectivity as per REC guidelines were given support (MNRE, 2011). The scheme intended to supply a minimum of 1 kWh/household/day. However, if there was a deficit, the basic lighting needs were met through solar PV home lighting systems. Installation of power plants based on small hydro, biomass, wind, biofuels and biogas were primarily encouraged. Solar PV power plants or hybrid renewable energy systems were extended support, only if found to be cost effective. Villages/hamlets not covered under any other scheme for lighting were covered under this scheme. Small hydro was given first priority based on availability of perennial resources, followed by biomass power plants and then biogas-based generation. If small hydro, biomass or biogas were found to be infeasible, they were combined with other renewable energy source such as wind. However, if the cost of solar PV power plants were justified, they were implemented. Preparation of initial surveys and state-wise plans, capacity building, monitoring, training and awareness programmes were all supported under this scheme. A budget allocation of Rs. 80 crores was made is 2009, followed by a subsequent allocation of Rs. 95 crores in 2011.

The funding schemes for remote village electrification undertaken by MNRE are summarized below:

- CFA up to 90 % of the cost of renewable electricity generation system (including the Annual Maintenance Contract (AMC)) was provided. CFA was limited to Rs. 18,000 per household

- The CFA for solar PV systems under this scheme was revised in 2011-2012 as shown in Table 4.19

Table 4.19: MNRE assistance under remote village electrification programme

Sl. No	Type of system	Amounts in Rs. (maximum)
1.	SPV home lighting system Model-II	8990
2.	SPV home lighting system Model-I	4370
3.	Street lighting systems with 74 W Module, 11 W lamp	17980
4.	Street lighting systems with 45 W Module and LED lamp	10935
5.	SPV power plant with battery storage	243/ Wp

- Activities such as initial surveys, preparation of state-wise master plans, monitoring schemes, training and orientation sessions received 100 % financial support
- The implementing agencies received a one-time service charge of Rs. 50,000/ village, limited to 10 % of the CFA per hamlet.

4.3.11 Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY)

RGGVY programme was the Rural Electrification (RE) scheme launched by the Ministry of Power (MoP) in April 2005 (Greenpeace, 2011). The major objectives of the scheme was to provide 100 % electricity supply to all villages, with free of cost electricity supply for Below Poverty Line (BPL) families. RGGVY has planned to electrify 1,25,000 un-electrified villages by the end of 12th five year plan (2012-2017) with 90 % capital subsidy (MoP, 2009). The scope of the RGGVY scheme was modified in 2009 to include Decentralized Distributed Generation (DDG) systems where grid connection was not cost-effective.

Decentralized Distributed Generation (DDG) scheme

The DDG scheme aimed to electrify remote villages/hamlets through locally available power generation technologies. A sum of Rs. 540 crores was allocated for DDG out of the total budget of Rs. 28,000 crores available for RGGVY in the 11th plan (MoP, 2009). DDG was carried out using conventional or renewable sources such as biomass, biogas, biofuels, mini hydro, solar etc for remote villages where grid connection was either not feasible or was not cost effective. REC was the nodal agency for implementation. Unsatisfactory implementation of scheme converted the capital subsidy to interest bearing loans. The state government owned the projects and decided SREDA, state electricity utility or a central PSU as the implementing agency. Priority was given to those villages which were unlikely to be electrified in the following 5-7 years. Conventional sources such as diesel generators were used mostly as back up for contingency situations. A decision chart for choosing the renewable technology was provided by MNRE according to which solar PV based power generation was given a 5th ranking for implementation after micro-hydro, biofuel, biomass and biogas based generation.

Financial Assistance

The capital cost of the project was given as a grant. Support was extended for revenue cost of spare parts excluding labor and for consumables for 5 years. The scheme also covered the cost of providing power for 5 years after recovering the tariff amount from village households. Soft cost for implementation of the scheme was also supported. 90 % of the total project cost was provided as subsidy to the implementing agency (Idam Infrastructure Advisory Private Limited, 2013). REC received 1 % of the project cost as service charge, whereas the state level agencies and central PSUs got 8 % and 9 % of the project cost respectively as service charges and also as a payment to be given to the developers for providing power for the following 5 years.

4.3.12 Major RE Schemes Prior to RGGVY

Some of the major RE schemes initiated by the Government of India are discussed below: (Bilolikar, et al.)

Minimum Needs Programme

This programme was initiated in the 5th five year plan (1974-1979) with State Electricity Boards (SEB) as the implementing agency. 100 % central assistance was given to states, particularly those where electrified villages were less than the national average. It was discontinued in 2004-2005 because of lack of response from several states.

Kutir Jyoti Programme

It was started in 1988-1989 with 100 % grant and SEB as the implementing agency. It aimed at single point light connection (60 W) to all BPL households - nearly 5.1 million households covered till date. Later, this scheme was merged with AREP in 2004.

Pradhan Mantri Gramodaya Yojana (PMGY)

It was launched during 2000-2001, with 90 % additional central assistance to special category states and 30 % to other states, implemented by SEBs and power utilities. The scheme was meant for providing minimum services (health, education, drinking water and electrification) in rural areas. Flexibility was provided for states to decide on inter-allocation of funds among various services. However, it was discontinued from 2005.

Accelerated Rural Electrification Programme (AREP)

This scheme was launched in 2002 with a 4 % interest subsidy to states from REC and other financial bodies; and was implemented through state electricity boards and power utilities. Rs. 560 crores budget was allocated in the 10th plan and a subsidy was availed only on loans from approved financial bodies like Rural Electrification Corporation (REC), Power Finance Corporation (PFC) and National Bank for Agriculture and Rural Development (NABARD).

Accelerated electrification of 1 lakh villages and 1 crore household

This scheme was started in 2004 with a 40 % capital subsidy and 60 % loan. The Kutir Jyoti and AREP schemes were merged with this scheme and later with RGGVY.

Rural Electricity Supply Technology Mission (REST)

This mission was initiated in 2002 with a vision to electrify all villages by 2012, with locally available renewable energy sources and decentralized solutions along with grid connectivity option. The scheme proposed an integrated approach to promote rural electrification by bringing together various ministries and implementing bodies.

Village Energy Security Programme (VESP)

This was launched in 2005 by MNRE to electrify remote villages, with a total budget of Rs. 225 crores and an objective to provide energy security (lighting, cooking and motive power). It focused mainly on biomass projects, with 54 test projects commissioned till date. During 2009-2010, the projects lay unutilized after grid connectivity was provided to the villages.

5 Application of Solar Technologies

This section of the report focuses on the various electrical and thermal applications of solar energy in an Indian context. India is large country and receives abundant solar radiation for more than 200 days a year with an average of 4-7 kWh/m^2 per day (MNRE, 2012). Figure 5.1 shows the global horizontal solar resource of various parts of India.

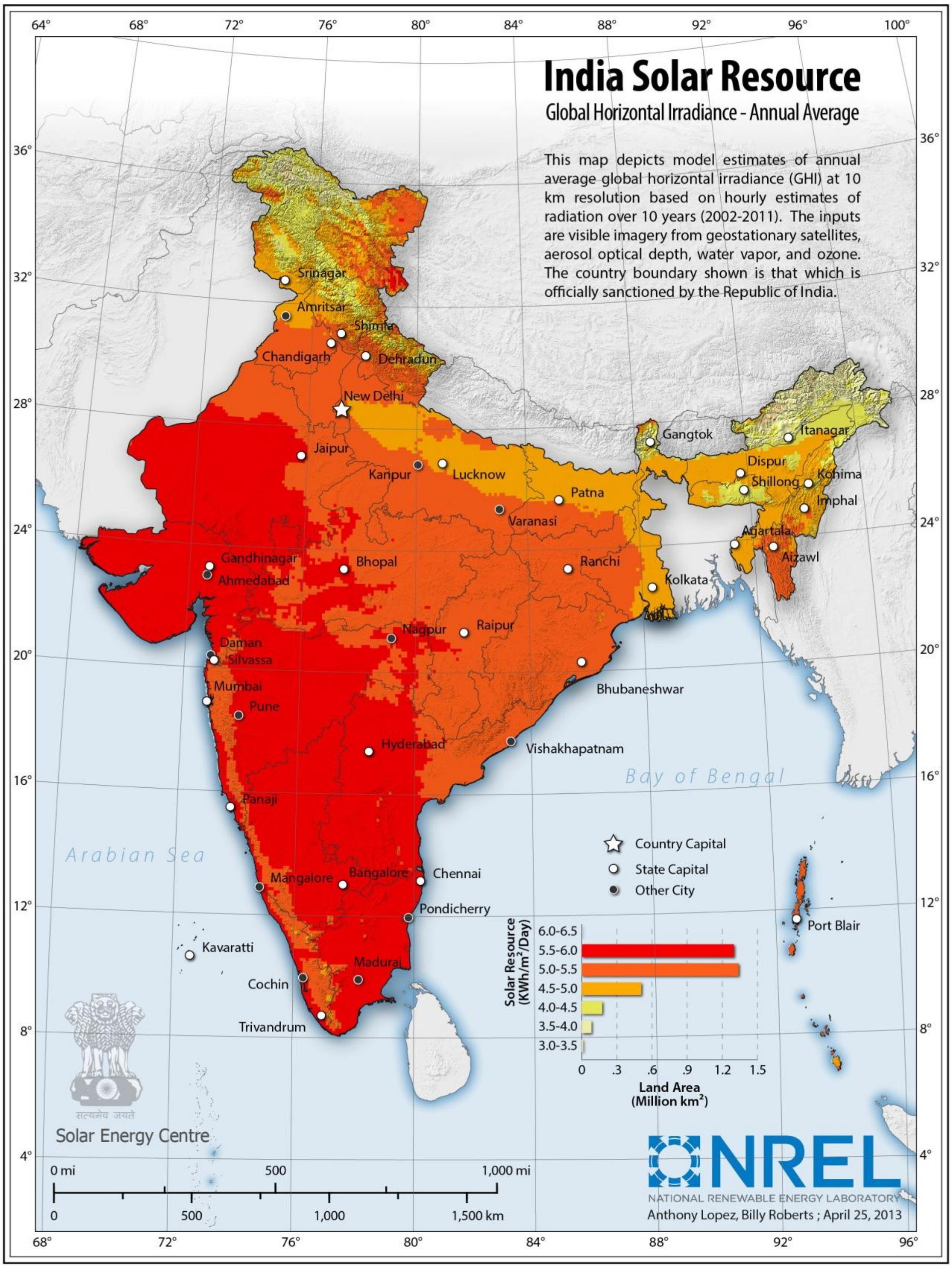


Figure 5.1: Global horizontal irradiance in India (Lopez, 2013)

It can be seen from Figure 5.1 that the irradiance varies across the country and this variance opens the scope for different conversion technologies in different places based on local climatic conditions and resources, dust and environmental factors, grid availability and pertinent regulations and policies. The following sub-sections elaborate on the range of solar technologies- their potential, techno-economics, and associated policy frameworks.

5.1 Utility Scale Grid-Connected PV Systems

India has witnessed steady growth in this sector in the last few years. Utility scale grid-connected PV systems (>1 MW) are installed in large areas of land and are connected to above 11 kV and 33 kV to the distribution grid. There is no storage associated with these systems and all the power generated is fed to the grid. Most of these installations fulfil RPO obligations for state utilities and are financially viable projects for developers owing to the proper incentive structures provided by the government. A typical installation is depicted in Figure 5.2 below. The inverters can be micro-inverters/string inverters/central inverters as decided by the developer.

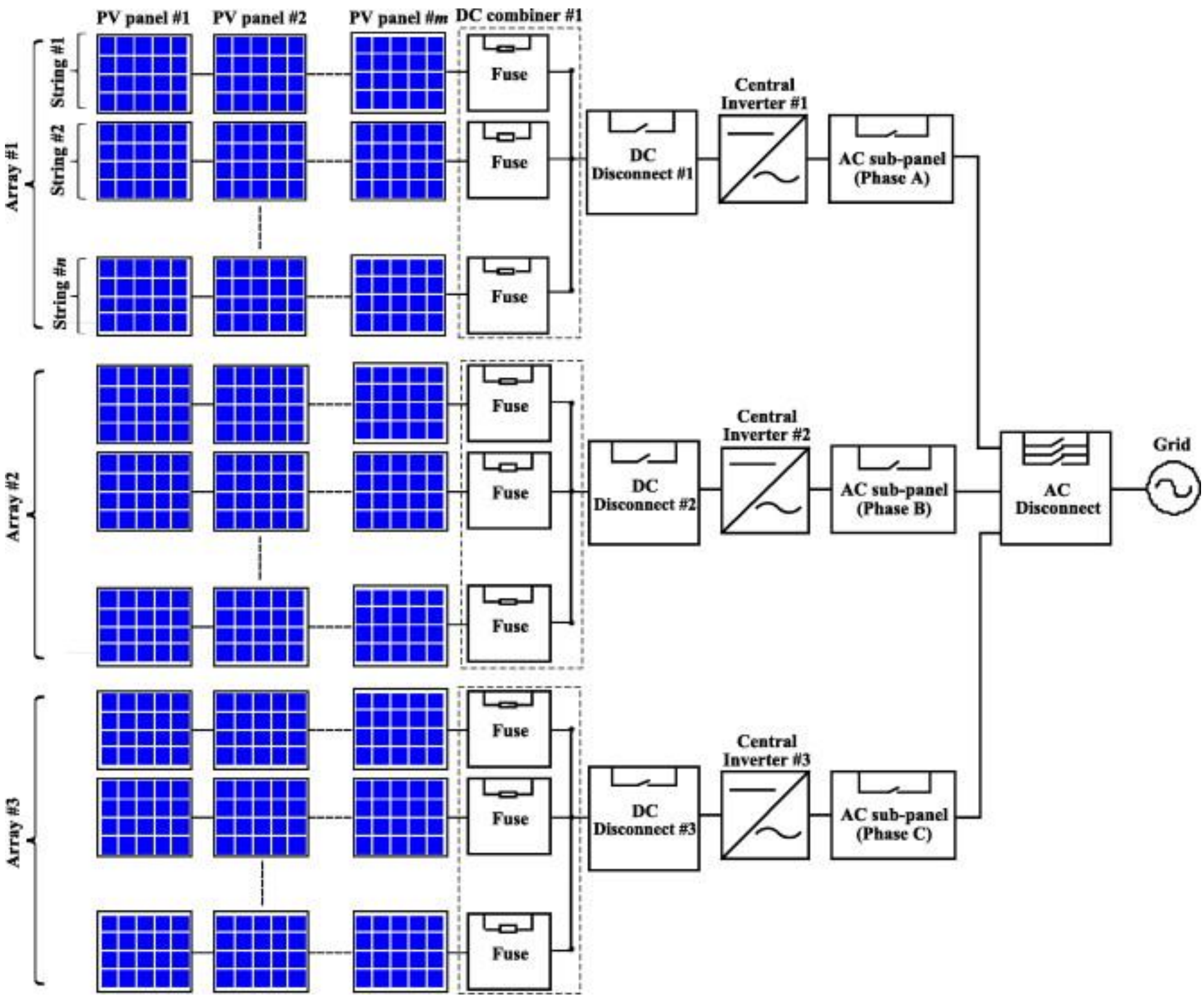


Figure 5.2: Schematic of a large grid-connected PV system

5.1.1 Policies Pertaining to Utility Scale Grid-Connected PV Systems

- ***NVVN bundling scheme***: In Phase I of JNNSM, the concept of bundling solar power with power generated from thermal power stations was introduced. In order to facilitate grid connection, NVVN (the financial arm of NTPC) is the entity which enters into a long term Power Purchase Agreement (PPA) with the project developer. NVVN buys power at a rate decided by a reverse bidding process from the developer. This rate is based on how much discount the developer offers on a pre-determined solar tariff (CERC regulation). The mechanism of bundling is to combine relatively expensive solar power with power generated from the unallocated quota of the NTPC's coal based stations, which is relatively cheaper and sell it to the Distribution Utility at weighted average price. This was a successful implementation strategy for Phase I and the lowest price discovered was around Rs. 7.49/kWh for solar PV. Project developers covered their risks by appreciating the single window buyer in the form of NVVN which assured timely payments for generation. However, due to unavailability of unallocated coal, Phase II of JNNSM will see minimal participation of NVVN. This is in spite of the fact that prices of solar PV power have gone further down to Rs. 6.20/kWh in certain states and the bundling ratio is no longer 1:1 but around 1:0.25 (solar : thermal). Calculations show that if the bundled price of power is kept at Rs.5/kWh, one MW of solar PV installation would need to be bundled with only 250 kW of a coal power station. Thus, the onus is on the government to allow NVVN to play a significant role in Phase II.

- ***Viability Gap Funding (VGF)***: In order to sustain the thrust provided by the bundling mechanism to utility scale project developers, MNRE introduced a new financial incentive known as VGF (tapped from the National Clean Energy Fund [NCEF]) for the second and third phases of JNNSM. The salient features of this mechanism are listed below (Solar Energy Corporation of India, 2013):

    - 30% of the project cost or Rs. 2.5 crores per MW (whichever is lower) can be availed as a capital subsidy from the Solar Energy Corporation of India
    - An equity contribution of at least Rs. 1.5 crores per MW needs to be injected by the project developer availing VGF
    - VGF will be disbursed in the following pattern:
        - Upon Commissioning (COD) – 50%;
        - End of 1st Year from COD – 10%;
        - End of 2nd Year from COD – 10%;
        - End of 3rd Year from COD – 10%;
        - End of 4th Year from COD – 10%;
        - End of 5th Year from COD – 10%;
    - In Batch 1 of Phase II of JNNSM, a total capacity of 750 MW (375 MW domestic content requirement) has been allotted. The amount of VGF utilized from NCEF on an annual basis for Phase II of JNNSM is depicted in Figure 5.3.
    - Projects availing VGF receive a tariff of Rs. 5.45/kWh (Rs. 4.75/kWh if Accelerated Depreciation [AD] is availed) for a period of 25 years (PPA with SECI)
    - Project developers should have a net worth of Rs. 2 crores per MW till a capacity of 20 MW and Rs. 1 crore for every subsequent 10 MW
    - If the project fails to generate any power continuously for 1 year within 25 years or its non-performing assets are sold or the project is dismantled during this

tenure, SECI will have a right to claim on assets equal to the value of VGF released.

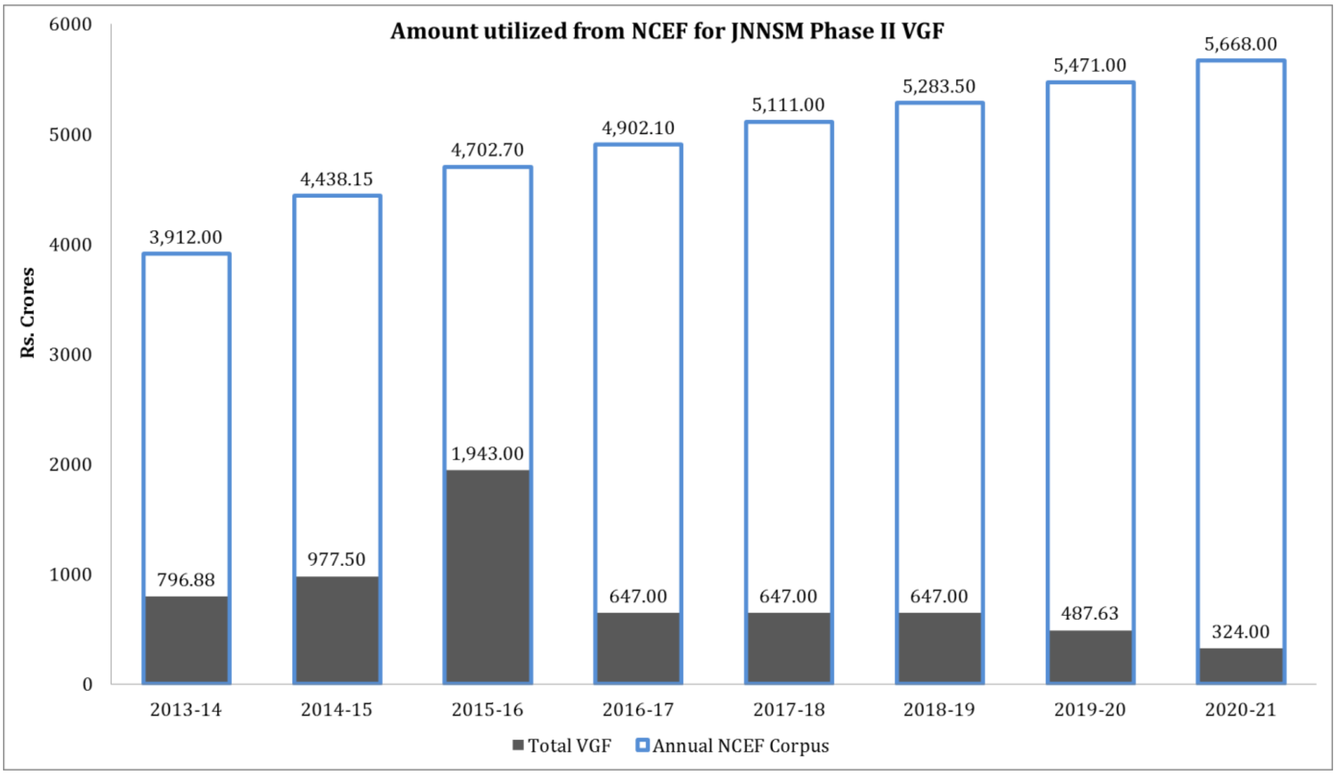


Figure 5.3: VGF utilization from NCEF for Phase II of JNNSM

- ***Renewable Purchase Obligations (RPO)***: Every state has a mandate to incorporate a certain percentage of renewable energy sources in their electricity mix. This is known as RPO. The solar RPO at the moment is 0.25% and is mandated to increase to 3% by 2022. In addition to RPOs, in some states the concept of SPOs has also been introduced. In this case, industries and other captive power consumers need to incorporate a certain percentage of solar power in their electricity mix. If the systems are to be grid-connected they are done at levels higher than 11 kV. The power generated from these systems can fulfil RPO obligations of these consumers. Under the Tamil Nadu Solar Energy Policy of 2012, approved by the Regulatory Commission, industrial and commercial power consumers have to meet 6% of their electricity requirement from solar power from January 2014. They can do this either from a captive solar power source, purchase from a third party, including the utility, or simply pay the solar tariff to the utility. However, due to the poor financial health of most distribution utilities in the country, RPOs have not been stringently enforced and because of this solar RECs accrued over the last two financial years have remained unsold in the market (Greenpeace, 2013). Unless there are policies to enforce the RPO mechanism, this scheme will not encourage developers to set up projects.

5.1.2 Techno-economics of Utility Scale Grid-Connected PV Systems

This section looks at different types of large grid-connected systems and assesses the economics associated with them in terms of initial investments, operation and maintenance (O&M) costs, payback periods, internal rate of returns (IRRs), diesel abatement and CO_2 savings, and

Levelized Cost of Electricity (LCOE). The systems taken into consideration are in accordance with the prevalent policies and incentives provided by state and central governments and JNNSM.

1. 5 MW with NVVN PPA (33 kV) – Loan from EXIM bank and from Indian financial institution
2. 5 MW with 30% VGF (33 kV) with AD – Loan from EXIM bank and from Indian financial institution (Project developers having sufficient net worth and parent companies which can avail tax benefits accrued due to AD are considered. This is because smaller players with low profits cannot appreciate the tax benefits owing to AD to the full extent. The tariff is fixed at Rs. 4.75/kWh for 25 years.)
3. 5 MW with 30% VGF (33 kV) without AD – Loan from EXIM bank and from Indian financial institution (Project developers who do not have sufficient net worth or parent companies with profits large enough to incorporate full tax benefits due to AD avail this option with a tariff of Rs. 5.45/kWh for 25 years.)
4. 10 MW with REC (33 kV) – Loan from EXIM bank and from Indian financial institution

The sources for financial data are kept confidential in this report. The following basic assumptions were made during calculations:

- discount rate – weighted average of Return on Equity and interest rate of loan
- lifetime of systems – 25 years
- inflation rate of components – 5%
- O&M costs for grid-connected PV systems – 0.5% of initial investment
- tax rate – 33%
- emission factors – diesel (0.7 $kgCO_2/kWh$), grid (0.8 $kgCO_2/kWh$), PV (0.03 $kgCO_2/kWh$) (CEA, 2011)

Based on these assumptions the financial analysis was made for the four systems. The salient features are shown in Table 5.1. The LCOE of different grid-connected systems is shown in Table 5.2 below. The IRR and payback periods of the various systems are depicted in Figure 5.4.

Table 5.1: Summary of techno-economic analyses of different grid-connected PV systems

	Financial assistance	Revenue model	Initial investment (Rs. crores)	Payback period (years)	IRR	CO_2 savings
5 MW (NVVN PPA) with EXIM bank loan (80:20)	Interest rate=8.18% Loan period 18 years	PPA with NVVN (Rs. 6-7.1/kWh)	45.065	5-6	13-18%	149998.5 tons
5 MW (NVVN PPA) with Indian bank loan (75:25)	Interest rate=13% Loan period 10 years	PPA with NVVN (Rs. 7-7.5/kWh)	45.065	9-10	14-17%	160198.5 tons
5 MW (VGF-30%) with AD & EXIM bank loan (80:20)	Capital subsidy (VGF-30%) Interest rate=8.18% Loan period 18 years	PPA with SECI (Rs. 4.75/kWh)	43.122	5	19%	149998.5 tons
5 MW (VGF-30%) with AD & Indian bank loan (75:25)	Capital subsidy (VGF-30%) Interest rate=13% Loan period 10 years	PPA with SECI (Rs. 4.75/kWh)	45.234	10	12%	160198.5 tons
5 MW (VGF-25%) without AD & EXIM bank loan (80:20)	Capital subsidy (VGF-25%) Interest rate=8.18% Loan period 18 years	PPA with SECI (Rs. 5.45/kWh)	43.122	6	16%	149998.5 tons
5 MW (VGF-25%) without AD & Indian bank loan (75:25)	Capital subsidy (VGF-25%) Interest rate=13% Loan period 10 years	PPA with SECI (Rs. 5.45/kWh)	45.234	11	11%	160198.5 tons
10 MW with REC mechanism for lifetime with EXIM bank loan	REC mechanism (Rs. 8000-12000/MWh)	PPA with utility (Rs. 3.5/kWh)	82.58	4-5	54-86%	312256 tons
10 MW with REC mechanism for lifetime with Indian bank loan	REC mechanism (Rs. 8000-12000/MWh)	PPA with utility (Rs. 4/kWh)	89.8	4-5	43-70%	320397 tons

Table 5.2: LCOE of different grid-connected PV systems

Type of grid-connected system	LCOE
<5 MW with EXIM bank loan with NVVN PPA	Rs. 8.6/kWh
<5 MW with Indian bank loan with NVVN PPA	Rs. 9.76/kWh
>5 MW with EXIM bank loan with 30% VGF	Rs. 6.82/kWh
>5 MW with Indian bank loan with 30% VGF	Rs. 7.48/kWh
>5 MW with EXIM bank loan with REC	Rs. 8.62/kWh
>5 MW with Indian bank loan with REC	Rs. 9.15/kWh

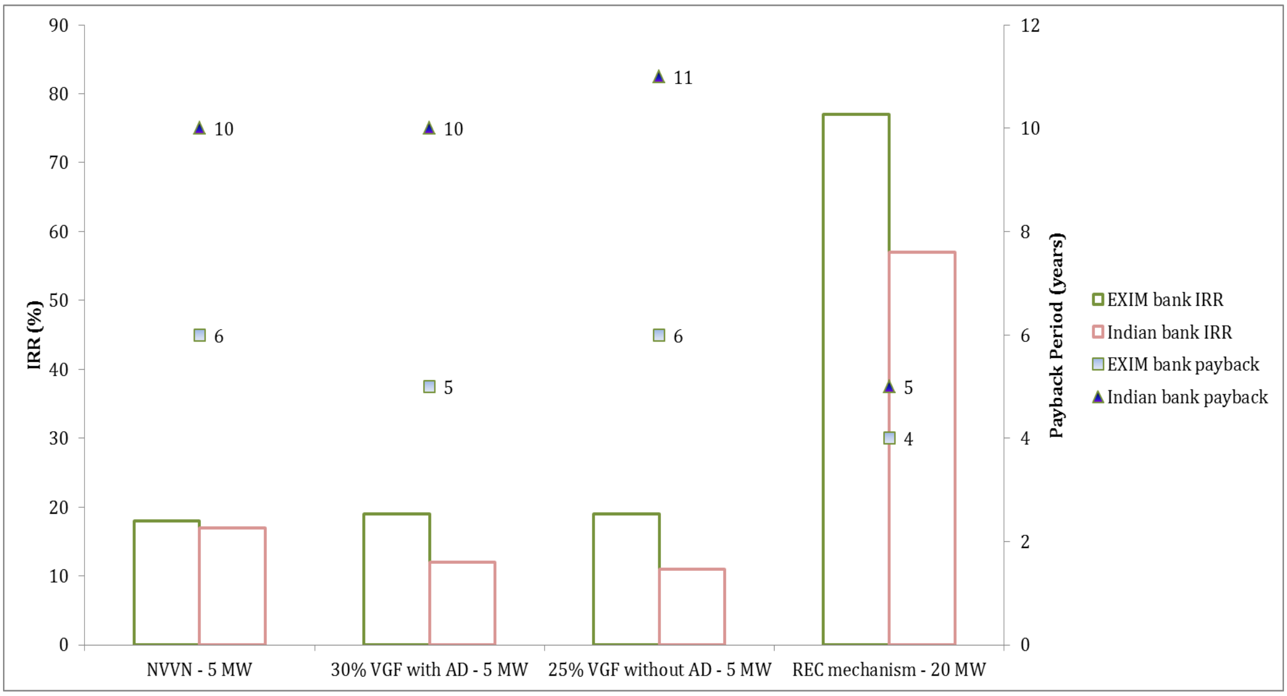


Figure 5.4: IRR and payback periods of utility scale PV systems

It can be seen from Figure 5.4 that project developers who use imported modules financed with EXIM bank loans (including a hedging component) have higher IRRs. than project developers who use indigenously manufactured modules with Indian bank loans. Policy mechanisms need to be structured in such a way that domestic manufacturers can compete with foreign manufacturers. Different financing schemes need to be explored which will allow indigenously manufactured modules to capture a larger share of the solar PV market in India in the future. The next stages of this report will analyse the potential of reducing excise duties and implementing public debt financing to support project developers availing Indian bank loans.

It can also be seen that project developers availing the option of REC trading have much higher IRRs (and lower payback periods). This is because in the calculations, the RECs have been assumed to be sold at a floor price of Rs. 8000/MWh for the entirety of the project (i.e. 25 years). Presently, the REC market is volatile because of the lack of enforcement of the RPO mechanism. Most state utilities are financially weak and other obligated entities are asking for more time to fulfil their RPO targets. However, some states like Maharashtra and Punjab have recently issued orders to all obligated entities to fulfil the set targets by 2014 (MERC, 2013) (PERC, 2013). In later stages of this report, an analysis of the evolution of the REC market will be carried out and more accurate techno-economics of solar projects using this mechanism will be presented.

5.2 Decentralized Rooftop PV (RTPV) Systems

RTPV systems are PV systems which are installed on rooftops of residential, commercial or industrial buildings. The various kinds of RTPV systems are described briefly below:

• ***Grid-connected RTPV systems:*** These installations are connected directly to the local grid with the help of an inverter and transformer unit (the latter is required if the installed capacity is high). Any system less than 3 kWp is connected to a single phase 220V line whereas systems greater than 3 kWp are connected to 11 kV or 440 V, 3 phase lines depending upon the installed capacity. The electricity that is generated from RTPV systems can be fed to the grid in two ways:

1) **Feed-in Tariffs (FiT)**: Entire generation fed directly to the grid at **regulated FiT** as per norms set by the Central Electricity Regulatory Commission (CERC) or by the respective State Electricity Regulatory Commission (SERC). A typical RTPV system with FiT is depicted in Figure 5.5. FiT is a common norm in European countries like Germany and Italy.
2) **Net metering mechanism**: In this scheme there are two meters installed for the RTPV system. One meter measures the monthly domestic consumption of the consumer while the other measures the total monthly generation from the RTPV system. The difference between the two is considered for monetary compensation. If the domestic consumption is more than the monthly generation, then the consumer pays the difference to the utility and vice-versa. There is a lobby which pushes for policies to have a preferential rate for the PV generation since the investment costs for the consumer are higher, thereby leading to higher returns. However, owing to the ailing financial health of Distribution Companies (DISCOMs), various states are contemplating suitable rates for such systems. A typical RTPV system with net metering mechanism is depicted in Figure 5.6. The net metering mechanism is deployed widely across USA, Spain and Brazil.

• ***Off-grid RTPV systems:*** There are some parts of the country which do not have access to the grid and rely on local resources for meeting local energy needs. RTPV systems with battery storage or hybridized with fuel cells or wind energy are options that can be considered to provide clean electricity to these places at a household level.

In some cases, industrial units which need reliable electricity supply for smooth operation of processes, construct captive power plants within their premises to reduce dependence on the grid. RTPV systems can provide reliable power to these units at lesser costs as compared to diesel based generation. These systems may or may not have battery backup or other storage options depending upon the kind of loads being serviced in the industrial unit. A typical off-grid RTPV system with battery backup is depicted in Figure 5.7.

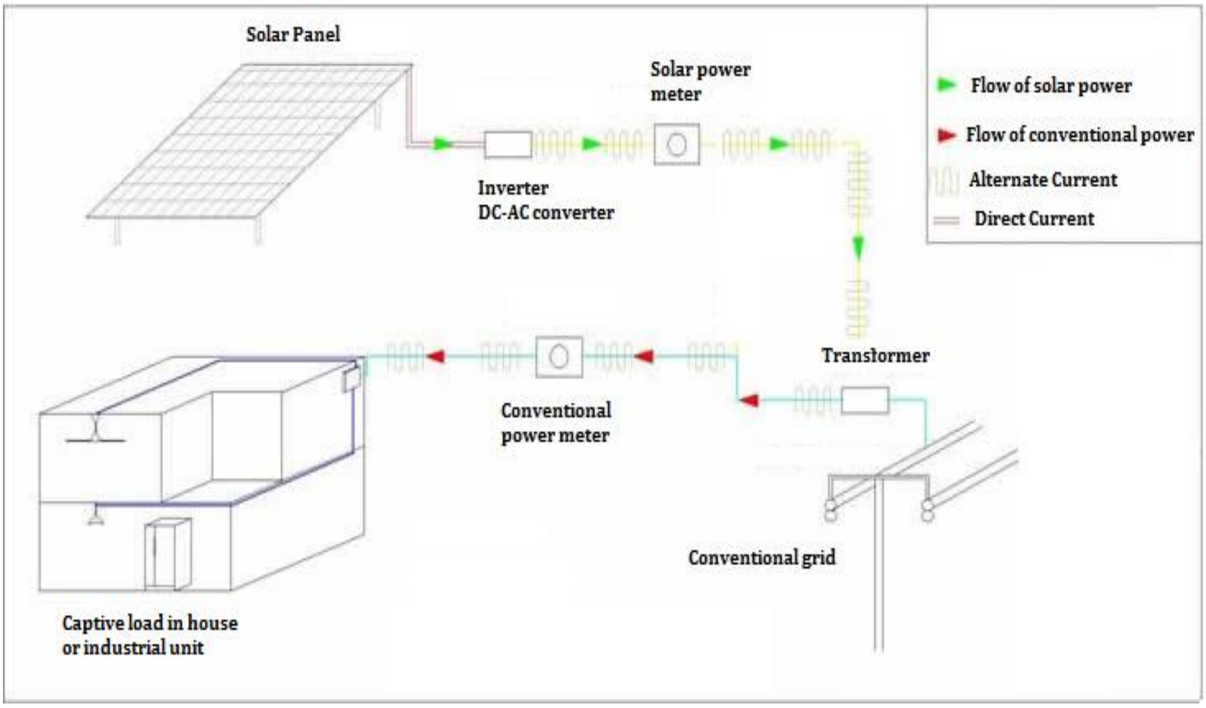


Figure 5.5: Typical grid-connected RTPV plant with FiT mechanism

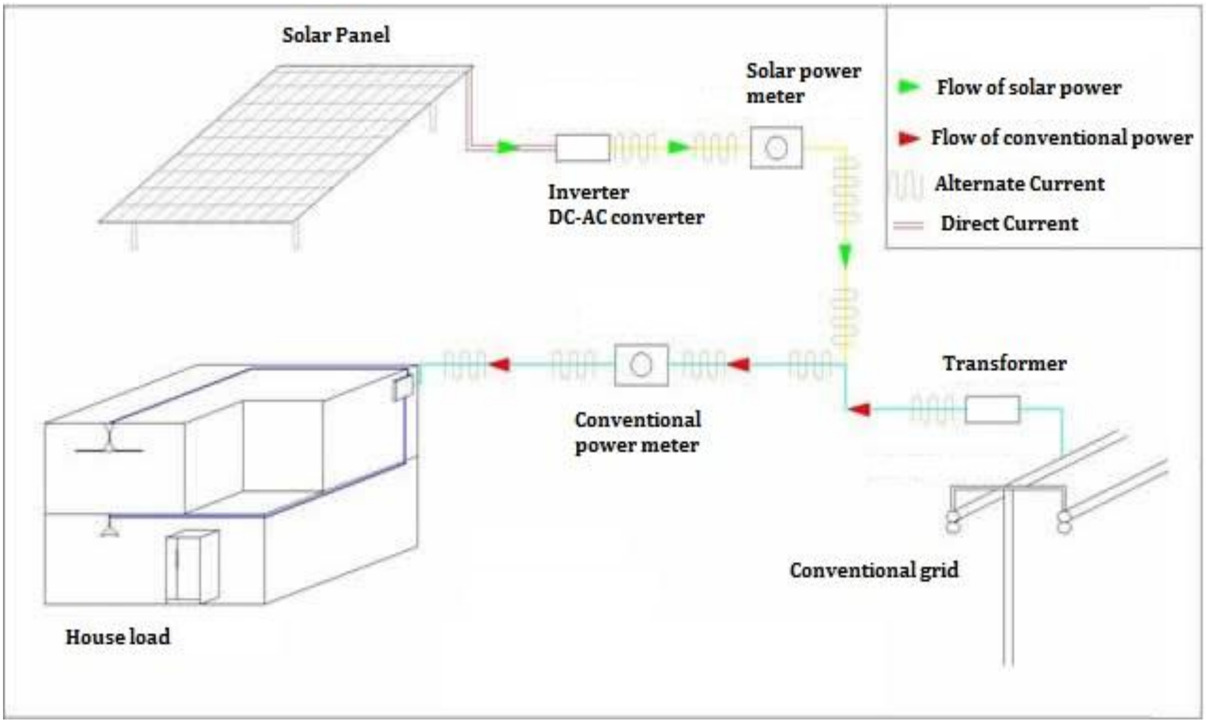


Figure 5.6: Typical grid-connected RTPV plant with net metering mechanism

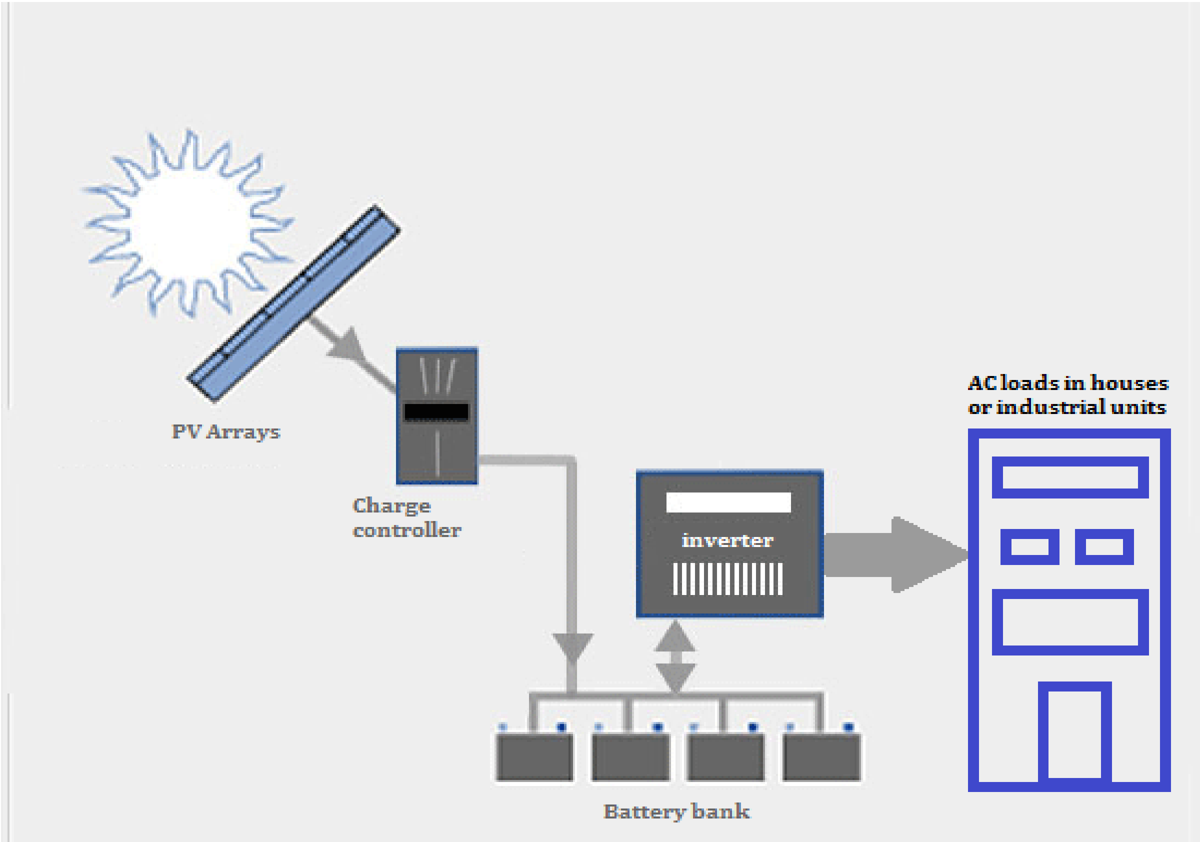


Figure 5.7: Typical off-grid RTPV system with battery backup

All these RTPV systems are applicable in an Indian context. The advantages of RTPV systems are as follows:

- Significant savings in Transmission and Distribution (T&D) losses because of the decentralized nature of power generation and usage
- Low gestation time
- No requirement for additional land or leases
- Considerable environmental benefits because of displacement of diesel based power generation by consumers
- Improvement of tail-end grid voltages and reduction in system congestion with higher self-consumption of solar based power
- Local employment generation

A major challenge faced by proponents of grid-connected RTPV systems is the weakness and instability of the grid and inability to import fluctuating power. However, reliable inverters are now entering the Indian market and mitigating the risk to both the consumer and the utility. A challenge faced by consumers opting for off-grid RTPV systems is the lack of financial viability considering the high capital costs involved in setting up such systems.

There are different schemes associated with RTPV systems when it comes to central and state policy initiatives. The next section of this report highlights the potential of RTPV in India and the most pertinent policies and incentives provided by the central government as well as by some state governments to deploy RTPV systems across the country to achieve the potential.

5.2.1 Potential of RTPV in India

It is difficult to assess the exact potential of RTPV systems in India owing to the large size of the country and the complexity of social engineering associated with the diversity in the country. However, recent studies have shown that the potential lies anywhere between 20-100 GW. A detailed description is given in Table 5.3 below.

According to the recently published Census data, India has around 247 million households with roofs (167 million rural and 79 million urban) (Ministry of Home Affairs, 2012). Taking a conservative approach, it is assumed that an average rural household has a demand of 1 kW and an average urban household has a demand of 3 kW in 2021-22. If 1% of rural households and 3 % of urban households install RTPV systems by 2021-22, the installed capacity would be around 8.8 GW. It is assumed that the demand will rise to 1.5 kW and 3.7 kW by 2031-32 in the rural and urban contexts respectively. Also if 2 % of rural households and 5 % of urban households are assumed to install RTPV systems by 2031-32, the installed capacity would be around 19.7 GW. Similar calculations performed on commercial, official, industrial and transport infrastructural rooftops show that the potential is around 16 GW in 2021-22 and around 41 GW in 2031-32. If a structured approach is taken to deploy RTPV systems in five year timeframes by giving the utilities enough scope and time to adapt, then by 2031-32 over 100 billion kWh can be generated from these systems alone. The central and state governments and the MNRE recognize this potential and have formulated certain policies to incentivize the growth of RTPV in India. An overview of these policies is given in the next section of this report.

Table 5.3: Estimated RTPV potential in India from various rooftop types (Gupta, 2011)

	Description of building/location or areas for RTPV	Comfort Level Potential (GW)	Remarks
1	All central govt. building rooftops, residences of MPs, Ministry buildings	15	Estimate based on 1000W/m^2 and availability of sun for 310 days annually
2	All cantonment boards, defence department factories and buildings, civil aviation department buildings, offices and all above residential roofs	11	This area covers many manufacturing units of defence production, residences of employees and similarly for other ministries
3	Indian Railways having 22,500 small and big stations (rooftops), residences of employees and their subsidiaries and related undertakings	2.2	Indian Railways have to take the initiative to go green like other countries and utilize all of their rooftop area for RTPV
4	All central govt. undertakings and their factories and manufacturing units like SAIL, BHEL, etc., Educational institutions, crude oil products dispensing stations, etc.	13.5	An exhaustive list prepared adopting figures from public websites and their documentaries circulated to the press

5	All states for their Roadways Corporations and Metro Roadways, all state govt. secretariat buildings, primary & secondary educational institutions in rural & urban areas, state industries & misc. building roofs	12	States have large roadways networks and each station has large rooftop area, similarly for schools and generating stations across states
6	All developed and operational industrial areas and SEZ in India having roofs of different styles	14.5	There are more than 200 developed industrial areas in India
7	All big house and MNCs and pharmaceutical plants (TATA, Reliance, etc.)	12.5	All estimated figures are taken from public domain and annual reports
8	Domestic rooftops of 1.2 billion people	12	On an avg. 1 m^2 is a standard rooftop area for 1.2 billion people
	TOTAL	**92.7**	

5.2.2 Policies Pertaining to RTPV in India

In order to encourage the growth of RTPV and other small solar power plants connected at distribution network at voltage levels below 33 kV envisaged under Phase I of JNNSM, MNRE launched a programme on **Generation Based Incentives (GBI)** in June 2010. The programme is referred to as **'Rooftop PV & Small Solar Power Generation Programme' (RPSSGP)**. This programme focuses on strengthening the tail end of the grid and allows DISCOMs to purchase power from any RTPV or small scale PV system based on the tariff approved by the respective SERCs. A cap of a maximum 20 MW capacity projects per state was stipulated. The project size was limited to a maximum of 2 MW to be connected to the grid. The role of the Ministry was limited to providing a fixed GBI to the DISCOMs at a rate equal to the difference of the CERC tariff for 2010-11 (Rs. 17.91 per kWh) and a reference rate of Rs. 5.5 per kWh. The projects were registered with nodal agency Indian Renewable Energy Development Agency (IREDA) through a web-based process, and 78 projects were selected to set up 98 MW capacity projects from 12 States. The exact amount of RTPV systems set up under this scheme is uncertain (MNRE, 2012) (MNRE, 2012a).

In Phase II of JNNSM, the target is to deploy 1,000 MW of rooftop projects both at off-grid and grid-connected levels. However, the extension of this GBI scheme has been restricted to only 60 MW spread over states which were not included in the previous phase. The size of the eligible projects is to be in the range of 500 kW to 2.5 MW (MNRE, 2012). MNRE is in the process of formulating new guidelines for RTPV systems based on net-metering and capital subsidy along with a rent-a-roof concept wherein an owner may rent the roof to the project developer, who in turn would sell the electricity to the utility (Ministry of New and Renewable Energy, 2012) (Prayas Energy Group, 2012). For residential RTPV systems, MNRE has a capital subsidy scheme of 30% of initial investment which can go up to 90% for remote inaccessible areas.

The state level initiatives that have come up in the recent past are summarized in Table 5.4 below:

Table 5.4: Overview of state policies for RTPV

State	Salient features of RTPV policies
West Bengal	• net-metering model promoting self-consumption

	• under WBERC regulations, RTPV allowed only for institutional consumers like government departments, academic institutions, etc., with the system size limited to 2-100 kW (Commission, 2013) • connectivity is allowed at Low Voltage or Medium Voltage (6 kV or 11 kV) of DISCOM • Solar injection is permitted only up to 90% of the annual electricity consumption • the net energy supplied by the utility would be billed as per existing slab tariffs, i.e. solar generation would first offset consumption in the highest tariff slab and then the lower slab • under the West Bengal Renewable Energy Policy, buildings with a certain minimum load will have to meet some electricity needs through RTPV (Prayas Energy Group, 2012) • policy targets 16 MW of RTPV and small PV by 2017
Gujarat	• Gandhinagar has initiated a 5 MW rooftop PV programme based on a FiT/sale to utility model (Gandhinagar Solar Rooftop Programme, 2012) • 4 MW to come up on government buildings, while 1 MW is to be installed on roofs of private homes • GERC rooftop tariff of Rs. 12.44/kWh acts as a ceiling • 5 more cities in Gujarat will also be following the rooftop model, namely Bhavnagar, Mehsana, Rajkot, Surat and Vadodara (International Finance Corporation, 2012) along with Ahmedabad (Prayas Energy Group, 2012)
Karnataka	• under the new Karnataka Renewable Energy Policy 2009-14, the state seeks to promote RTPV with net-metering • allowable system size range to be 5-100 kWp, and interconnection at 415 V, 3 phase or 11 kV • maximum energy injection is allowed only up to 75% of the customer's energy usage from the DISCOM (beyond that no consideration) • Solar Karnataka Programme is targeted for 25000 Solar Roof Tops of 5-10 kW with net-metering, which will be taken up with a 250 MW potential during the next 5 years with a generation potential of 350 MU (Karnataka Renewable Energy Development Limited, 2009)
Tamil Nadu	• target of 350 MWs of RTPV to be installed in three years from 2013-15 has been approved in state solar policy • 50 MW of RTPV would be supported through a GBI of Rs. 2/kWh for the first two years, Re. 1/kWh for the next two and Rs. 0.5/kWh for the subsequent two years will be provided for all solar installations completed before 31st March, 2014 (Tamil Nadu Energy Development Agency, 2012)
Maharashtra, Andhra Pradesh, Odisha, Chattisgarh and Rajasthan are also in the formulating stages of their respective state level RTPV policies in the near future (Prayas Energy Group, 2012)	

The next section of this report deals with the techno-economics of different ranges of RTPV systems and assesses the scope to provide financial incentives to consumers and developers.

5.2.3 Techno-economics of RTPV Systems

To be able to understand how RTPV systems can be rapidly deployed over the next 10 years in India, developers and consumers need to have an idea about the economics of these systems.

This section looks at certain types of RTPV systems with a focus on Karnataka and calculates the economics associated in terms of initial investments, O&M costs, payback periods, IRRs, diesel/kerosene abatement and CO_2 savings, and LCOE. The systems taken into consideration are in accordance with the prevalent policies and incentives provided by state and central governments and JNNSM.

1. An urban villa with a rated load of 7 kW and a RTPV system of 5 kWp capacity with and without storage; revenue model of net metering
2. A sub-urban villa with a rated load of 7 kW and a RTPV system of 5 kWp capacity without storage; revenue model of net metering
3. A cluster of five industrial units with RTPV systems of 50 kWp capacity each amounting to 250 kWp without storage; revenue model of REC mechanism
4. A warehouse rooftop with a RTPV system of 30 kWp capacity without storage; revenue model of FiT for the IPP
5. An off-grid hut with a RTPV system of 350 Wp with storage

The sources for financial data are kept confidential in this report. The following basic assumptions were made during calculations:

- *Cost of modules*: Rs. 53-57/Wp (Since available rooftop area is a constraint in RTPV systems, only high efficiency crystalline silicon cells have been considered and the market prices are comparatively higher)
- *discount rate* – weighted average cost of capital (WACC) for debt financed cases and 10% for other cases
- *lifetime of systems* – 25 years
- *inflation rate of components* – 5%
- *O&M costs for RTPV systems* – 0.5% of initial investment
- *tax rate* – 33%
- *emission factors* – diesel (0.7 $kgCO_2/kWh$), grid (0.8 $kgCO_2/kWh$), kerosene (2.53 $kgCO_2/liter$), PV (0.03 $kgCO_2/kWh$) (CEA, 2011)
- *battery reserve time* – 4 hours with 70% depth of discharge
- *degradation factor* of cells: 0.5% per annum (Outdoor PV Degradation Comparison, 2010) (Central Electricity Regulatory Commission, 2011)

Based on these assumptions the financial analysis was made for the four systems. The salient features are shown in Table 5.6. The LCOE of these RTPV systems is shown in Table 5.5 below.

Table 5.5: LCOE of various RTPV systems

Type of RTPV system	LCOE
Grid-connected without storage (with and without capital subsidy from MNRE)	Rs. 5.38-7.25/kWh
Grid-connected with storage (with and without capital subsidy from MNRE)	Rs. 6.24-8.37/kWh
Off-grid with storage (with and without capital subsidy from MNRE)	Rs. 9.3-12.88/kWh

Captive plant without storage (without capital subsidy from MNRE)	Rs. 9.29/kWh

Initial investments of RTPV systems (per kWp) are considerably higher than utility scale grid-connected systems because economies of scale are not applicable in this context. Also RTPV systems are constrained by space requirements. Hence, most efficient crystalline PV modules are used which are more expensive than thin film modules. Also, there are barriers to actually receiving the capital subsidy from MNRE and recent reports suggest that it will be a while before capital subsidies for RTPV systems are disbursed through correct channels in the country (Bridge to India, 2013). Hence, this report looks at both cases for techno-economic analyses i.e. with and without capital subsidy. Table 5.6 summarizes this analysis with the different revenue models associated with each case in Karnataka. Later stages of this report will focus on such systems in other states incorporating respective policy measures prevalent in those states.

Table 5.6: Summary of techno-economic analyses of different RTPV systems

Description of RTPV system	*Revenue model*	*Initial investment (Rs. lakhs)*	*Payback period (years)*	*IRR*	*Type of fuel saved*	*Government subsidy saved*	*CO_2 savings*
30 kW grid-connected (415 V or 220 V) without MNRE subsidy	FiT/GBI (Rs. 9.56/kWh)	27.65	7	13%	-	-	999.6 tons
5 kW grid-connected (75% of domestic load) with MNRE subsidy for urban residential villa	Net metering (Rs. 3.5/kWh – utility rate; Rs. 7.2/kWh for solar power)	3.69	8	10%	Diesel	Rs. 55,239	162.46 tons
5 kW grid-connected (75% of domestic load) without MNRE subsidy for urban residential villa	Net metering (Rs. 3.5/kWh – utility rate; Rs. 9.56/kWh for solar power)	5.26	13	5%	Diesel	Rs. 55,239	162.46 tons
5 kW grid-connected (75% of domestic load) with MNRE subsidy for semi-urban residential villa	Net metering (Rs. 3.5/kWh – utility rate; Rs. 7.2/kWh for solar power)	3.37	8	10%	Diesel	Rs. 6362	165.84 tons
5 kW grid-connected (75% of domestic load) without MNRE subsidy for semi-urban residential villa	Net metering (Rs. 3.5/kWh – utility rate; Rs. 9.56/kWh for solar power)	4.82	8	9%	Diesel	Rs. 6362	165.84 tons
350 W off-grid with battery storage with capital subsidy	-	0.305	-	-7%	Kerosene	@Rs. 30/litre – Rs. 39,735	9.1 tons
250 kW captive system for SME sector	REC mechanism (Rs. 8000/MWh base rate and declining 5% annually)	227.5	2	41%	Diesel	@Rs. 8.4/litre – Rs. 9 lakh	7907 tons

Some important inferences can be made from the findings in Table 5.6:

- The FiT scheme allows a customer to develop a feasible business case. However, BESCOM's poor finances will not allow them to actually pay the consumers a rate of Rs. 9.56/kWh. To reach the figure of 250 MW in 2014 using FiT, the total corpus required to support this scheme would be Rs. 397.8 crores. Taking into account that the average pooled price of electricity for BESCOM is around Rs. 3.5/kWh, an additional amount of Rs. 252.16 crores is required. The State Clean Energy Fund (SCEF) can be tapped to avail this amount.

- If net metering is to be used for RTPV systems, then the concept of a cap of 75% of rated load does not make the business case viable. This is because the net metering rate of Rs. 7.2-9.56/kWh for solar power will never come into being since the electricity generated from the RTPV system will never exceed the consumption of a residential consumer within city limits and the only monetary savings arise from net electricity bill reduction and diesel savings. However, if such a RTPV system is installed in the country/semi-urban residential villas which are used only during weekends and holidays, a feasible business case can be constructed.

- If the cap is to be removed in context to net metering, then the total corpus required to reach 250 MW (taking 40% excess generation from RTPV systems) in 2014 would be around Rs. 139.8 crores. As in the case of the FiT scheme, BESCOM would require an additional amount of around Rs. 81.6 crores to support this scheme. Again, this money can come from the SCEF.

- In the case of an off-grid RTPV system with battery storage, the economics do not make sense because there is no revenue generated from the generation or consumption of electricity. Social engineering aspects need to be linked with this business case taking into account the growth of GDP due to energy access for the consumer. Later stages of the report will incorporate this analysis.

- A captive RTPV system feeding power to a private industrial unit is the most profitable of all business cases in this analysis. Since the consumer can avail the REC mechanism, there is added incentive for captive power consumption. Similarly commercial establishments in the city which are heavily dependent on diesel generators to meet their electricity needs can benefit to a great extent using RTPV systems for captive use. However, due to lack of data, this analysis has not included quantitative economics for this sector.

- Later stages of this project will include techno-economic analysis of RTPV systems for large apartment complexes and commercial establishments, along with similar systems mentioned above for other states in the country.

5.3 Solar Process Heating in Industries

India is consuming over 100 million tonnes of oil every year which is about one-fourth of the total primary energy consumption. Out of this, 80% is imported (Bhatewara, 2012; EIA, 2013). The industrial sector in India alone consumes 40% of the total oil consumption. Out of this, 40-50% is consumed in the form of thermal energy in terms of pressurized hot water, steam and hot air in the temperature range of 40-250°C. This is equivalent to about 15 million tonnes of fuel oil per year (MNRE, 2013).

Solar energy utilization in industries can play a significant role in meeting the thermal energy requirements mentioned above and in reducing the consumption of oil. Integration of solar energy for industrial process heating application is a challenging task because it requires constant heat load but solar is intermittent. Also, some industries require heating throughout the day and night. Therefore, solar energy alone will not be able to meet the complete requirements and it can penetrate to only about 20-40% of total energy requirements. However, the fuel savings through the interventions of solar energy is significant. For example, a 100 liters per day (LPD) solar water heater system can save 1500 kWh of electrical energy (by replacing the geyser) and can prevent 1.5 tonnes of CO_2 per year (SWH, 2013).

The current study focuses primarily on solar thermal collectors that are suitable to replace or to integrate to the existing systems in various industries. The study also examines the impact on capital cost, monetary savings and environmental benefits by replacing the conventional power sources.

5.3.1 Overview of Solar Collectors

Solar energy collectors can be classified based on the range of temperatures used for different applications as Low Temperature Collectors (LTC), Medium Temperature Collectors (MTC) and High Temperature Collectors (HTC). The operating temperatures of LTC, MTC and HTC are less than 80°C, 80-250°C and greater than 250°C respectively. LTCs are mainly used for water heating and space heating applications. MTCs are used for generating hot water, steam and hot air in industrial process heating and cooling applications. HTCs are used mainly for power generation but these collectors can also be used for supplying hot water/steam.

The classification of collectors can also be based on whether the collectors are tracking (movable) or non-tracking (stationary). The tracking collectors are further classified as single axis tracking and dual axis tracking. Table 5.7 gives various types of solar collectors and their range of operating temperature with suitable heat transfer fluids (Tchanche, 2006).

Table 5.7: Different type of collectors and their operating temperatures range

S. No	Collector type	Tracking	Temperature
1	Air collector	-	30-50
2	Pool collector	-	30-50
3	Reflector collector	-	50-90
4	Solar pond	-	70-90

5	Solar chimney	-	20-80
6	Flat plate collector (FPC)	-	30-80
7	Advanced flat plate collector	-	50-150
8	Combined heat and power solar collector	-	80-150
9	Evacuated tube collector (ETC)	-	50-150
10	Compound parabolic collector (CPC)	-	70-240
11	Linear Fresnel reflector (LFR)	1-axis	Up to 300
12	Parabolic trough collector (PTC)	1-axis	Up to 400
15	Power tower	2-axis	Up to 600
16	Dish	2-axis	Up to 1000

Most of the industrial processes require temperatures in the range of 40-250°C. The interventions for process heating by CSP technologies are capital and space intensive. Therefore, solar collectors which require lesser space to install or roof top based are addressed in this study.

Therefore, we have restricted the assessment only for the collectors which are:

i. Able to meet temperature in the range of 40-250°C and
ii. Indigenously available such as FPC, ETC and ARUN 160 dish.

In this section, the data used to make the solar energy assessment in various industries are based on literature, secondary research and interaction with experts and solar component manufacturers.

5.3.2 Inputs and Assumptions for the Assessment

Figure 5.8 shows the variation of efficiency with the operating temperature for various solar collectors (Shireesh Kedare, 2012; POSHIP, 2013; Lauterbach C., 2013; Study of medium temperature solar thermal applications, 2013). In the figure, T_{op} and T_a represents operating temperature and ambient temperature respectively.

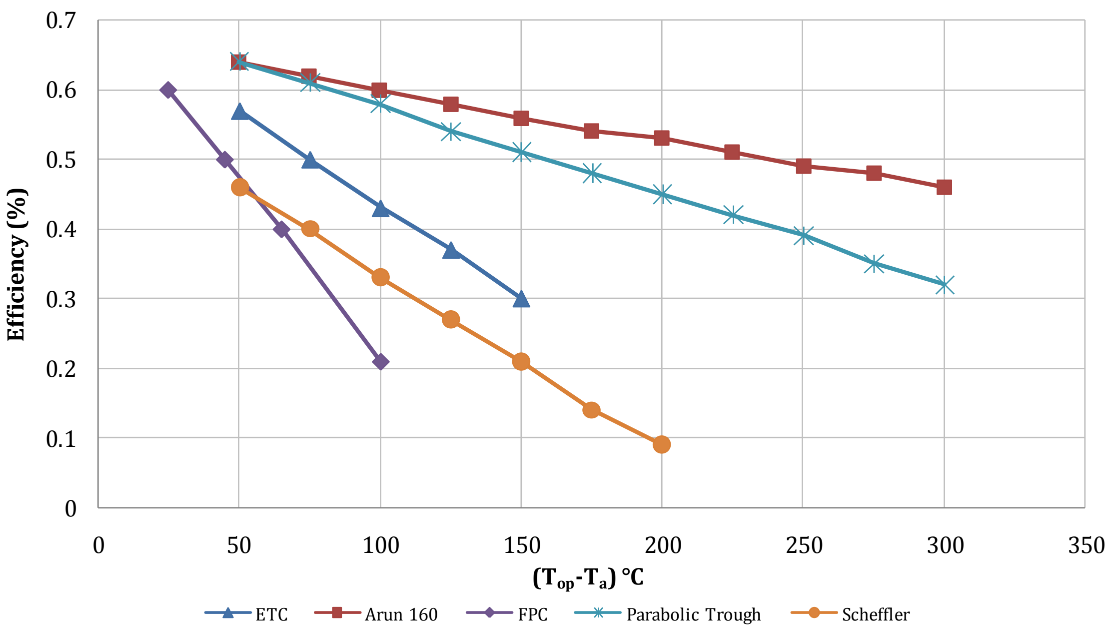


Figure 5.8: Efficiency variation of various collectors with operating temperatures

The efficiency trend followed in Figure 5.8 is utilized for the technical assessment. The assumptions taken for the techno-economic assessment of these collectors for Indian conditions are:

i. Ambient temperature is 25°C.
ii. The Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) for India vary from 4.5-6.5 kWh/m²/day. Therefore, an average value of 5.5 kWh/m²/day is taken as both GHI and DNI.
iii. Solar energy availability in a year is 260 days.
iv. Tilt factor of both FPC and ETC is taken as 1.1.
v. Radiation reflected from the ground surface to the collector is not considered.
vi. The suitable solar collectors for each industry are suggested purely based on the operating temperature of the process.
vii. Cost of the FPC and ETC are 11000 Rs/m² and 10000 Rs/m² respectively. Cost of one ARUN 160 dish (aperture area of 169 m²) is Rs. 37, 80,000 (MNRE, 2013).
viii. Operating & Maintenance (O&M) cost per year for both FPC and ETC collectors are taken as 2% of the capital cost. In case of ARUN 160 dish, the O&M is taken as 3.5% of capital cost.
ix. Plant life for FPC, ETC and ARUN 160 dish are 20, 15 and 25 years respectively.
x. Furnace oil is most likely to be used as fuel for process heating in the industries.
xi. The boiler combustion efficiency varies from 85 to 95% (TESPL, 2013). Hence, it is taken as 90% for estimating the energy equivalent in terms of furnace oil.

xii. Cost of furnace oil Rs. 55/kg (2013; MCF, 2013).

Note that the cost of FPC and ETC are taken based on the 100 LPD systems and it will significantly reduce for higher capacity systems. All the aforementioned assumptions have been taken into account for estimating the solar collector area, energy generation, oil savings, capital cost, payback period and cost of energy generation for FPC, ETC and ARUN 160 dish with respect to the operating temperatures of different processes in various industries.

5.3.3 Industries

The energy intensive industries which have the potential for integration of solar energy are textile, pulp & paper, dairy, food processing, automobiles, leather, wine, painting, pharmacy and hospitals etc. Many of these industries require heat for applications such as cleaning, drying, evaporation/distillation, pasteurization, sterilization, cooking, preheating, cooling etc. Some of the potential industries are considered for doing the assessment study.

5.3.3.1 Textile Industry

Overview

The textile industry contributes 14% to the total industrial production, 4% to the GDP and 11% to the country's export earnings. It is the second largest provider of employment (about 35-45 million). This industry is extremely varied and comprises hand-spun & hand-woven sector, sophisticated mill sector and decentralized power looms sector. The major sub-sectors of the textile industry are organized cotton/man-made fibre textiles mill industry, man-made fibre/filament yarn industry, the wool and woolen textile industry, handlooms, handicrafts, the jute and jute textile industry and textile exports. The production of handloom sector alone is 6900 million sq. meter in the year 2011-12. The raw material for the textile industry is natural fibre or synthetic fibre. The fibre production in India is 9.6 million tonnes in 2012-13 (textile, 2013; magazine, 2012).

Processes involved for the scope of solar energy

There are wide processes involved in the textile industry from fibre to fabric production. Fibre undergoes preparatory process before spinning (to yield yarn), weaving (to yield fabric) and finishing. However, the major processes involved in the textile industry which has the potential for solar energy are de-sizing, scouring, bleaching, mercerizing, dyeing and finishing. The operating temperature of these processes, conventional fuels being used for heat generation and the potential solar collectors to replace the existing conventional system are given inTable 5.8 (Bhide, 2012).

Table 5.8: Operating temperatures and suitable solar components for various processes in the textile industry

Process	Energy being used	Temperature (°C)	Fuel sources being used	Suitable solar component
De-sizing	Thermal	60-90	electricity, petroleum, coal and	ETC
Scouring	Thermal	90-110		ETC

Bleaching	Electrical	-	other fuels	PV
	Thermal	90-95		ETC
Mercerizing	Electrical	-		PV
	Thermal	60-70		FPC
Dyeing	Thermal	70-90		FPC
Finishing	Thermal	40-100		ETC

Potential for solar integration and expected savings

The production capacity of fabric in the textile industry is about 9.6 million tonnes. In the total production, 20% of the fabric will undergo the processes mentioned earlier. The thermal energy requirement for all these processes can be met through FPC, ETC and ARUN 160 solar collectors.

The potential of solar penetration using FPC and ETC in the textile industry for various processes at the national level is estimated and given in Table 5.9. From this table, it can be seen that the total energy demand is 83×10^6 GJ/year. Of that, solar component can supply 17×10^6 GJ/year based on the assumption of 20% solar penetration. This requires the total FPC and ETC collector area of 6.2 million m^2. The capital cost of these collectors without subsidy and with subsidy are Rs. 6538 crore and Rs. 4577 crore respectively. The summary of oil demand, savings in terms of furnace oil, monetary savings and payback period without subsidy and with subsidy with FPC and ETC are given in Table 5.10. It is found that the textile industry has the potential for saving fuel oil of about 395 ktoe and annual CO_2 reductions of about 1300 ktonne.

Table 5.9: Potential of solar energy in the textile industry by FPC and ETC

Operation	Operating Temp (°C)	Suitable solar collector	Hot water required (kL/tonne)	Energy required (MJ/litre)	Energy required$\times 10^3$ (MJ/tonne)	Energy required $\times 10^6$ (GJ/year)	Energy from solar – 20% of the demand $\times 10^6$ (GJ/year)	Collector area (million m^2)	Capital cost without subsidy (crore)	Capital cost with subsidy (crore)
Sizing/ Desizing	60-90	ETC	15.5	0.21	3.24	6.23	1.25	0.40	402	282
Scouring	90-100	ETC	21.5	0.29	6.30	12.1	2.42	0.87	865	606
Bleaching	60-100	ETC	15.5	0.23	3.57	6.85	1.37	0.45	455	318
Mercerizing	60-70	FPC	15.0	0.17	2.51	4.82	0.96	0.34	373	261
Dyeing	70-90	FPC	90.0	0.23	20.7	39.8	7.96	3.29	3619	2533
Finishing	40-100	ETC	12.0	0.19	2.26	13.02	2.60	0.82	824	577

Table 5.10: Overall benefits for textile industry using FPC and ETC

Description	value
Total oil required (ktoe)	2197
Total oil saved by solar (ktoe)	395
Annual CO_2 reduction (ktonne)	1300
Gross annual monetary benefits (Rs. crore)	2175
Annual O&M cost (Rs. crore)	131
Net annual monetary benefits (Rs. crore)	2044
Payback period without subsidy (years)	3.2
Payback period with subsidy (years)	2.2

A similar analysis is also done using ARUN 160 dish. It can be noted that the energy requirement from solar component will not change whether it is ARUN 160 or any other solar collector. This is because of the assumption that the solar penetration is only 20%. Note that the collector area and economic parameters will change depending on the type of technology chosen. These details are given in Table 5.11. From this Table, it is found that the total number of ARUN 160 dishes required in the textile industry is about 30,000. This would require capital cost without subsidy and with subsidy of about Rs. 11,367 crore and Rs. 8,318 crore respectively. A summary of oil demand, savings in terms of furnace oil, monetary savings and payback period without subsidy and with subsidy with ARUN 160 dish are given in Table 5.12. It can be seen from Table 5.10 and Table 5.12 that, the ARUN 160 would require more O &M cost and its payback period is higher than that of FPC and ETC. However, ARUN 160 dish is able to supply process temperatures up to 250°C.

Table 5.11: Potential of solar energy in the textile industry by ARUN 160 dish

Operation	No. of units of ARUN 160	Capital cost without subsidy (Rs. crore)	Capital cost with subsidy (Rs. crore)
Sizing/ De-sizing	2251	851	623
Scouring	4470	1689	1236

Bleaching	2490	941	689
Mercerizing	1724	652	477
Dyeing	14456	5465	3999
Finishing	4679	1769	1294

Table 5.12: Overall benefits in textile industry with ARUN 160 dish

Parameter	Value
Total oil required (ktoe)	2197
Total oil saved by solar (ktoe)	395
Annual CO2 reduction (ktonne)	1300
Gross annual monetary benefits (Rs. crore)	2175
Annual O&M cost (Rs. crore)	398
Net annual monetary benefits (Rs. crore)	1777
Payback period without subsidy (years)	6.4
Payback period with subsidy (years)	4.7

5.3.3.2 Pulp & Paper

Overview

Pulp & paper industry is one of the most energy intensive industries. Most of the process operations in this industry require temperatures below 250°C (O. Edenhofer, 2011). There are about 515 companies engaged in manufacture of paper and its related by-products in India. India produces only 2% of paper and paperboard in the world. The energy cost in terms of fuel requirement account for nearly 25% of the overall manufacturing cost. The total annual energy consumption of the Indian paper industry is about 52 Million Giga Cal, which is equivalent to about Rs. 15000 million (IREDA, 2010).

Processes involved and the scope of solar energy

There are variety of processes used in the paper industry depending on the type of raw material (Wood based or Agro-based or waste paper based) and product desired (Paper/Paperboard etc). The most popular processes are Sulphate (Kraft) process, Suphite process and Semi-mechanical process. The processes which have scope for integration of solar technologies are debarking, pulp making, bleaching, stock preparation and paper making. The processes utilize heat mainly for cleaning, boiler feed water heating and drying. The operating temperatures of these applications, fuels being used and suitable solar technology are given Table 5.13.

Table 5.13: Operating temperatures and suitable solar components for various processes in pulp & paper industry

Process	Temperature (°C)	Existing fuel source	Recommended Solar technology
Cooking, drying	60-80	Furnace oil, Pet coke, rice husk and coal	FPC
Boiler feed water	60-90		FPC
Bleaching	130-150		ETC

Potential for solar integration and expected savings

Since the data on energy process wise is unavailable, the solar potential estimation is done based on the gross production and its energy requirements available in the literature (IPMA, 2013; GIZ, 2011). The details are given in Table 5.14.

Table 5.14: Solar energy potential in pulp & paper industry

Description	Quantity
Total Production of Paper & paperboard (Million Tons/year)	10.11
Hot water requirement for preheating of boiler feed water @70°C (tonnes/ton of paper)	6.5
Joules constant (kJ/kg°C)	4.186
Operating temperature of boiler feed water (°C)	70
Energy required to heat water up to 70°C (kJ/kg)	188.4
Total amount of hot water required (Million tons/year)	65.7
Total energy required $\times 10^6$(GJ/year)	12.4
Solar energy potential (%)	20
Total Energy from solar $\times 10^6$(GJ/year)	2.48
Total energy savings (ktoe)	59
Collector area required (million m^2)	0.915
Capital cost without subsidy (Rs. Crore)	1006
Capital cost with subsidy (Rs. Crore)	704

From Table 5.14 it can be seen that the total thermal energy from solar component is 2.48×10^6 GJ. It can also be seen that the total collector area is 0.9 million m^2 and the capital cost without subsidy and with subsidy are Rs. 1006 crore and Rs. 704 crore respectively.

Table 5.15 gives the details about the fuel oil savings in the pulp & paper industry. The total fuel oil required for all the processes is about 329 ktoe. However, fuel can be saved through the solar component is 59 ktoe yielding in annual CO_2 reductions of about 200 ktonne. The net monetary savings due to the replacement by solar is Rs. 325 crore per annum. The payback periods of solar component without and with subsidy are 3.3 and 2.3 years respectively.

Table 5.15: Overall benefits in pulp & paper industry with FPC

Description	Value
Total oil required (ktoe)	329
Total oil saved by solar (ktoe)	59
Annual CO_2 reductions (ktonne)	200
Gross annual monetary benefits (Rs. crore)	325
Annual O&M cost (Rs. crore)	20
Net annual monetary benefits (Rs. crore)	305
Payback period without subsidy (years)	3.3
Payback period with subsidy (years)	2.3

5.3.3.3 Dairy Industry

Overview

The dairy industry in India produces 13% of the total milk production in the world (IUF, 2013). The annual growth rate in milk production is around 4% in 2002-12. In FY 2011, 121.8 million tonnes of milk was produced (INDIASTAT, 2013). This sector generates about 90 million jobs. Milk processing in India is about 35% of the total milk production. However, only 13% of the total production is processed by organized sector (GIZ, 2011).

Processes involved for the scope of solar energy

Most of the dairy industries use furnace oil for thermal energy requirements and electricity for refrigeration. Energy intensive processes involved in the dairy industry which have the potential for solar integration are milk chilling, cleaning, boiler feed water and chemical processes. The details about operating temperatures, share of water and energy consumption for various processes are given in Table 5.16 (GIZ, 2011).

Table 5.16: Processes requirements in dairy industry

Process	Water consumption (%)	Energy consumption (%)	Temperature range, °C
Cold storage - Chilling	2	20	5-7
Cleaning	18	5	40-60
Pasteurisation, sterilisation and evaporation	18	36	70-120
Pre-heating for chemical processes	12	3	35-45
Incorporated into products	40	36	-
Other purposes	10		-

Potential for solar integration and expected savings

In India, the milk production in 2010-11 was about 122 million tonnes. The national norms for processing one litre of milk requires 0.034 kWh electricity, 5 ml of furnace oil and 2 litres of water (Mahananddairy, 2006; GIZ, 2011). Therefore, in the organized dairy industry, the annual total consumption of electricity, furnace oil and water are about 538 GWh, 77 ktoe and 31 billion litres respectively.

The total thermal energy requirements and equivalent furnace oil for various process operations in the dairy industry are given in Table 5.17.

Table 5.17: Thermal energy demand in dairy industry

Process	Water (Billion litre)	Thermal Energy required $\times 10^6$ (GJ)	Furnace Oil equivalent (ktoe)
Cleaning purposes	5.54	0.58	13.84
Boiler Feed Water	5.54	1.62	38.7
Chemical processes	3.69	0.23	5.53

Table 5.18 gives the thermal energy generated from solar component, its corresponding collector area and the capital costs with subsidy and without subsidy.

Table 5.18: Solar energy potential in dairy industry

Process	Thermal energy from	Suitable solar	Collector Area	Capital cost without	Capital cost with

	solar $\times 10^6$ (GJ)	collector	(million m^2)	subsidy (Rs. crore)	subsidy (Rs. crore)
Cleaning purposes	0.12	FPC	0.035	39	27.3
Boiler Feed Water	0.32	ETC	0.116	116	81.2
Chemical processes	0.047	FPC	0.013	14.3	10

From Table 5.18, it can be seen that the total thermal energy from solar component is 0.49×10^6 GJ. It can also be seen that the total collector area is 0.16 million m^2 and the capital cost without subsidy and with subsidy are Rs. 169 crore and Rs. 118 crore respectively.

Table 5.19 gives the details about the fuel oil savings in the dairy industry. The total fuel oil required for all the three processes is about 58.1 ktoe. However, the amount of fuel that can be saved through the solar component is 11.6 ktoe resulting in annual CO_2 reductions of about 40 ktonne. The net monetary savings due to the replacement by solar is Rs. 60.5 crore per annum. The payback periods of solar component without and with subsidy are 2.8 and 2.0 years respectively.

Table 5.19: Overall benefits in dairy industry

Parameter	Value
Total oil required (ktoe)	58.1
Total oil saved by solar (ktoe)	11.6
Annual CO_2 reductions (ktonne)	38
Gross annual monetary benefits (Rs. crore)	63.9
Annual O&M cost (Rs. crore)	3.4
Net annual monetary benefits (Rs. crore)	60.5
Payback period without subsidy (years)	2.8
Payback period with subsidy (years)	2.0

5.3.3.4 Leather Industry

Overview

The Indian leather industry occupies a prominent position on account of considerable export earnings, employment opportunities and production of various consumer products. The industry has diversified products such as footwear, garments, belts, wallets and other leather goods. The organized sector account for 56.4% and un-organized sector accounts for 43.6% in the total production (DIPP, 2012). Most of the leather production units are located in Tamil Nadu (52%), West Bengal (23%) and Uttar Pradesh (12%) (GIZ, 2011). Indian tanning units produce around 2 billion sq. ft of semi-finished/finished leather.

Process involved for the scope of solar integration

Leather industry processes can be broadly classified into two major categories. They are:

(i) Tanneries (Raw hides/skin processed into semi-finished/finished)

(ii) Consumer goods production (semi-finished/finished leather into variety of consumer goods) -The major processes in consumer good products are marking, cutting, dressing, sewing and stitching.

The major processes in tanning are pre-tanning, tanning and post tanning/finishing operations. All these processes, operating temperatures and fuel being used for heat generation are shown in Table 5.20.

Table 5.20: Processes involved in leather tanning operations

Processes	Pre-tanning	Tanning	Post-tanning
Operations	- Soaking/desalting - Liming/unhairing - Deliming - Pickling	- Chrome tanning - Vegetable tanning	- Splitting, Shaving, Trimming - Dyeing - Drying
Working fluid	Hot water	Hot water	Hot air
Temperature, °C	40-60	60-80	70-100
Fuel being used	Electricity and boiler fuels like furnace oil, rice husk, firewood, coal, etc		

Potential for solar integration and expected savings

Tanning operations require most of the thermal energy in terms of hot water between 40-80°C and hot air between 70-100°C (GIZ, 2011). It accounts 40% of the total thermal energy consumption in the leather industry (Chattopadhya, 2010). Table 5.21 gives basic information on production and energy consumption of the Indian leather tanning industry. It can be seen that the total capacity of Indian tanning units is 2 billion sq. ft. of hide/skin. The water consumption in all the tanning processes is approximately 30 liters per kg of hide/skin; whereas the energy consumption is 1400-1800 kcal per kg of hide/skin. Therefore, it is considered that, 1600 kcal of energy is required to process one kg of hide/skin.

Table 5.21: Indian leather tanning production and energy consumption

Parameter	Value	Source
Indian Tanneries production per annum (billion sq. ft.)	2	(CLE, 2013)
Total production of hides/skins in India (tonnes/annum)	700000	(GIZ, 2011)
Total number of tanneries in India	3000	(GIZ, 2011)

Water requirement for leather tanneries (litre/kg of hide)	30	(Chattopadhya, 2010)
Percentage of hot water required (%)	40	
specific energy consumption in tanning (kcal/kg)	1600	(Chattopadhya, 2010)
The specific heat consumption during drying of leather (kcal/kg)	1000	(GIZ, 2011)

Based on the data and assumptions highlighted in Table 5.21, the annual total energy and water consumption are estimated and given in Table 5.22. It can be seen that the consumption of total water is about 21 billion liters per annum and hot water required is 8.4 billion liters. The total energy consumption in the tanning operations is 4.7×10^6 GJ per annum. Out of that, the energy consumption for hot water and drying processes are 1.46×10^6 GJ (31%) and 2.93×10^6 GJ (62.5%) respectively.

Table 5.22: Total energy consumption in tanning operations

Parameter	Value
Total Water Consumption (Billion litres/Annum)	21
Total Hot Water requirement in leather tanneries (Billion litres/Annum)	8.4
Total Energy Consumption in Tanning Processes $\times10^6$ (GJ/Annum)	4.68
Total Energy Consumption due to Hot water requirements $\times10^6$ (GJ/Annum)	1.46
Total Heat consumption during drying processes $\times10^6$ (GJ/Annum)	2.93

Table 5.23 gives solar potential in leather tanning processes. It includes the estimation of hot water requirements, solar component, oil savings, and reduction in CO_2 emissions, capital costs and payback periods. It can be seen that the total water consumption in leather tanning industries are 21 billion liters per annum. It is assumed that 40% of the hot water temperature ranges from 40-80 °C. Therefore, the total hot water requirement in tanning processes is 8.4 billion liters per annum. The thermal energy from solar for water heating and air drying are 0.29×10^6 and 0.58×10^6 GJ/annum respectively. It is suggested that Evacuated Tube Collectors (ETC) collectors are more suitable since the temperatures requirements are in the range of 40-100 °C. It can be installed on factory rooftops with low annual O&M costs. The collector area is about 0.27 million m^2 and its capital cost without subsidy and with subsidy are Rs. 272 crore and Rs. 190 crore respectively.

Total furnace oil required in leather tanning industries is 116 ktoe. The amount saved by solar is estimated at 23.3 ktoe per annum. Therefore, the CO_2 emission reductions would be 75.4 ktonne per annum. The gross annual monetary savings due to oil saved are Rs. 128.3 crore per annum.

The net savings are Rs. 124.5 crore. Hence the investment payback periods without subsidy and with subsidy are 2.2 and 1.53 years respectively.

Table 5.23: Solar energy potential in leather tanning processes and overall benefits

Parameter	Value
Total water consumption (Billion Litres/Annum)	21
Total Hot Water requirement in leather tanneries (Billion Litres/Annum)	8.4
Solar Integration (%)	0.20
Energy for hot water generation from solar $\times 10^6$ (GJ/Annum)	0.29
Energy for drying from solar $\times 10^6$ (GJ/Annum)	0.58
Total energy from solar $\times 10^6$ (GJ/Annum)	0.88
ETC collector area required (Million m^2)	0.27
Capital cost without subsidy (Rs. crores)	272.75
Capital cost subsidy (Rs. crores)	190.92
Total oil required (ktoe)	116.61
Total oil savings due to solar (ktoe)	23.32
Annual CO_2 reductions (ktonne)	75.4
Gross annual monetary benefits (Rs. crores)	128.3
Annual O&M costs (Rs. crores)	3.82
Net annual monetary benefits (Rs. crores)	124.5
Payback period without subsidy (years)	2.2
Payback period with subsidy (years)	1.53

5.3.3.5 Automobiles

Overview

The Indian automobile industry manufactures about 11 million two-wheeler and four-wheeler vehicles every year. India ranks high in terms of the production of 2-wheeled vehicles; its manufacturing capacity is around 8.5 Million.

The production of vehicles and its Compound Annual Growth Rate (CAGR) is given in Table 5.24 (ACMA, 2013; GIZ, 2011). It can be seen that the total production of all these vehicles in FY 2012-13 is about 21 million. The CAGR is high for passenger and construction vehicles and low for tractors. However, Automotive Component Manufacturers Association of India (ACMA) estimates that the production will double by FY 2020-21. The equivalent passenger vehicle is considered as a car in this analysis.

Table 5.24: Indian automobile industry production capacity

Vehicle Type	Production in FY 2012-13	CAGR for 2012-21 (%)	Equivalent to Passenger Vehicle
Passenger vehicle	32,34,000	13	1
Commercial vehicle	8,32,000	11	2
Tractors	6,41,000	5	4
Two & three wheelers	1,65,61,000	7	0.5
Construction vehicles	54,000	14	3.7

Process involved for the scope of solar integration

Most of the processes in the automobile industry are mechanical and they are driven by electricity. However, few processes require considerable amount of thermal energy for drying and cleaning. Generally, drying is usually provided by air heating and cleaning by hot water. This thermal energy requirement for air heating and water heating is about 0.001 Mkcal/Eq.vehicle (about 200°C) and 1000 litre/Eq.vehicle (85-95°C) respectively.

Potential for solar integration and expected savings

Specific energy & water consumption

Table 5.25 gives the specific energy and water consumption to produce an equivalent passenger vehicle from 2009 to 2012 (NAEC, 2011; NAEC, 2012). It may be noted that the specific electrical and thermal energy consumption reduced to approximately 50% from FY 2009-10 to FY 2011-12. Similarly, water consumption reduced by nearly 40%.

Table 5.25: Specific energy consumption in automobile industry

Year	Electrical Energy Consumption (kWh/Eq. Vehicle)	Thermal Energy Consumption (Mkcal/Eq. Vehicle)	Water Consumption (kL/Eq. Vehicle)
2009-10	188.34	0.8673	2.85
2010-11	127.46	0.5187	1.95
2011-12	95.72	0.4142	1.70

Total primary energy consumption

Table 5.26 gives the estimated electrical energy, thermal energy and water consumption in the automobile industry per annum for India.

Table 5.26: Total primary energy consumption in automobile industry

Parameter	Value	Unit
Annual Production of Vehicles Equivalent to Passenger Vehicles	1,59,42,300	Passenger car
Total Electrical Energy Consumption per annum	1,526	GWh
Total Thermal Energy Consumption per annum	7,678	GWh
Total Water Consumption per annum	27.10	Million kL

Table 5.27 gives the potential for integration of solar technologies in automobile industry and expected savings in terms of fuel oil. It can be seen that the thermal energy required for air heating and water heating are 18.54 and 1204.87 GWh respectively. The thermal energy for air heating and hot water from solar are 3.71 GWh and 240.97 GWh, respectively.

Table 5.27: Potential for solar integration in automobile industry

Parameter	Value	Unit
Total thermal energy for air heating/drying per annum	18.54	GWh
Total hot water requirement	15.94	Billion Litres
Thermal energy required for hot water	1204.87	GWh
Solar Integration	20	%
Total thermal energy for air heating/drying from solar	3.71	GWh
Total thermal energy for hot water from solar	240.97	GWh

The overall benefits with the installation of 0.30 million m^2 of solar collector area in the automobile industry are given in Table 5.28. It is suggested that ARUN dish is suitable for air heating since the required temperature is about 200 °C and ETC is suitable for water heating since the hot water temperature ranges between 85-95 °C. Capital cost with and without subsidies are Rs. 300 crore and Rs. 210 crore respectively. It can also be seen that the gross annual monetary savings due to furnace oil is Rs. 128.6 crore per annum and the O&M cost for solar systems is Rs. 6 crore. Therefore, the net monetary benefits are Rs. 122 crore per annum. The total annual CO_2 reduction from automobile industry with solar component is about 75 ktonnes.

Table 5.28: Solar energy potential and overall benefits in automobile industry

Parameter	Value	
	Arun dish	**ETC**
Process	Air heating	Water heating
Total thermal energy requirement per annum $\times 10^6$(GJ/annum)	0.067	4.34
Solar Integration	0.20	0.20
Thermal energy from solar $\times 10^6$(GJ/annum)	0.013	0.87
Collector area (million m^2)	0.0047	0.29
Capital cost without subsidy (Rs. Crores)	10.6	290.6
Capital cost after subsidy (Rs. Crores)	7.7	203.4
Total oil required if no solar (ktoe)	1.77	115.2
Total oil savings due to solar (ktoe)	0.35	23.04
Annual CO_2 reductions (ktonne)	1.1	74.5
Gross annual monetary benefits (Rs. crore)	1.95	126.7
Annual O&M (Rs. Crores)	0.37	5.8
Net annual monetary benefits (Rs. Crores)	1.58	120.9
Annual CO_2 reduction (ktonne)	1.1	74.5
Payback period without subsidy (years)	6.7	2.4
Payback period with subsidy (years)	4.9	1.7

5.3.3.6 Food Industry

Overview

Food industry is a wide area and it comprises many segments such as fruits, vegetables, milk, milk products, beverages, meat, marine products, grain processing, packaged food, packaged drinks etc. The food processing sector in India contributes about 9 to 10% of GDP in agriculture and manufacturing sector (MOFPI, 2013). The sector has invested a capital of about Rs. 2.5 Lakh crore in producing an output of around Rs. 5.8 lakhs in FY 2010-11 in various food sectors such as grain mills, edible oils, beverages, dairy products, fruits & vegetables products, animal feeds, meat processing etc.

The energy demand in all these sectors is mainly for storage, processing, transport and preservation. Further the processing units such as bottles, cans, kegs and other process equipment require cleaning. Most of the thermal energy demand in these processes requires energy in the form of hot water/steam and hot air at temperatures below 200°C.

The processes which have the potential for solar energy in the food industry are sterilization, pasteurization, cooking, bleaching, washing and drying (SolarPaces, 2013). The various processes with its operating temperature range and suitable solar component to replace the existing fuels are given in Table 5.29 (Comsolar, 2013).

Table 5.29: Various processes and operating temperatures in food industry

Process	Temp (ºC)	Fuel being used	Suitable solar component
Washing	60-90	electricity, furnace oil and rice husk	FPC
Chilling/cold storage	<5	electricity and diesel	ETC driving chillers
Sterilization	60-120	furnace oil and diesel	ETC
Pasteurization	60-80		FPC
Cooking	90-100	furnace oil and rice husk	ETC
Bleaching	60-90	furnace oil and rice husk	FPC
Drying	60-90	electricity, furnace oil and rice husk	ETC (Air based)

Since food industry is very varied and the information is limited, we have not made an assessment in detail to estimate the solar potential. The integration of solar in food industry has a scope for energy replacement of 80 ktoe (GIZ, 2011) and annual CO_2 reductions of about 260 ktonne CO_2. This is equivalent to the solar collector area of 1.1 million m^2 and leads to net monetary savings of Rs. 222 crore per annum.

5.3.4 Summary of Solar Potential for Process Heating in Various Industries

The summary of solar potential for process heating in textiles, pulp & paper, dairy, leather, automobile and food industries are given in Table 5.30. The observations and policy recommendations are given below.

- Total solar collector area potential of about 8.8 million m^2.
- The fuel oil saved with solar component is about 590 ktoe per annum. The total CO_2 emission reductions are about 1,900 ktonne per annum.
- The net monetary savings due to solar component is about Rs. 2,750 crores per annum.
- The capital cost without subsidy is about Rs. 10,600 crores.

- The capital cost with subsidy is about Rs. 7500 crores. Therefore, the capital subsidy sought is about Rs. 3000 crores.
- The payback periods for FPC and ETC collectors without subsidy ranges from 2 to 3.5 years. The payback period is reduced to 1.5 – 2.5 years with subsidy.

  The payback period for ARUN dish collector without subsidy is about 6 years. With subsidy, the payback period is reduced to 5 years. These collectors are able to supply temperatures greater than 200°C. Therefore, with the government subsidy, the payback period is decreased by 1-1.5 years.
- Process heating by solar energy can be sustained even without subsidy if one considers the alarming increase of oil price and volatility of supply.
- Government should create more awareness across the industries in utilizing solar energy for process heating.

Table 5.30: Summary of solar energy potential for process heating in various industries

Industry type	Process	Temp range °C	Eq. furnace oil (ktoe)	Oil savings by solar (ktoe)	Solar field area (million m^2)	Capital cost without subsidy (Rs. crore)	Capital cost with subsidy (Rs. crore)	Payback period without subsidy (years)	Payback period with subsidy (years)	CO_2 emissions reduction (kt CO_2 /year)
Textile	Sizing, scoring, bleaching, mercerizing, dyeing and finishing	40-100	2197	395	6.1(FPC & ETC)	6537	4577	3.2	2.2	1277
Pulp & paper	Preheating of boiler feed water	60-80	329	59	0.9 (FPC)	1006	704	3.3	2.3	191
Dairy	Chemical processing, cleaning and boiler feed water	35-150	58	11.6	0.16 (FPC & ETC)	169	118	2.8	2.0	38
Leather	Cleaning and Drying	40-100	117	23.32	0.27 (ETC)	272.7	191	2.2	1.5	76
Automobile	Drying	~200	1.77	0.35	0.0047 (ARUN 160)	10.6	7.7	6.7	4.9	75
	Cleaning	85-95	115.2	23.04	0.29 (ETC)	290.6	203.4	2.4	1.7	
Food	Washing, cleaning, sterilization, pasteurization, cooking, bleaching and drying	60-120	400	80	1.1 (ARUN 160)	2353	1721	6.6	4.8	259

5.4 Conclusions and Recommendations

In order to obtain a policy perspective on the different applications of solar energy analysed in this chapter, a comparison has been made on a normalized scale. The starting point has been taken as one unit of incident energy i.e. 1 kWh. The end point has been taken as the energy available to the end user. For grid-connected PV and decentralized PV, conversion efficiencies of best available technologies in the market have been taken into account. T&D losses have been considered for grid-connected PV. In the case of solar process heating, efficiency of conversion has been used for calculating the energy available to the end user.

The metrics that have been used for comparison are:

- Fossil fuel and CO_2 avoided
- Levelized cost of energy (LCOE)
- Subsidy availed by user
- Internal Rate of Return (IRR)
- Societal benefit

In the cases of grid-connected PV and decentralized PV, the fossil fuel that is avoided is coal and to calculate the CO_2 avoided, the emission factor of coal based grid electricity has been taken as the baseline. For solar process heating, the substituted fossil fuel has been considered to be furnace oil and the emission factor for this has been used as the baseline. LCOE calculations have been performed over the lifetime of the technologies with the discount rate being equal to the weighted average cost of capital (WACC). This analysis is presented in Figure 5.9. Societal benefits have been qualitatively analyzed for the comparison (Table 5.31).

Table 5.31: Societal benefits of solar energy applications in India

Application of solar energy	Societal benefits
Grid-connected PV	• Employment generation in manufacturing industry and on ground solar systems • Growth in domestic industry availing the benefits of solar power generation • Provisions to supply peak power shortages using solar capacity addition
Decentralized PV	• High direct impact in areas where systems are installed (education, health, access to energy) • Reduction of local air pollution by avoiding fossil fuel based electricity generation
Solar Process Heating	• Reduction of diesel/furnace oil import and use thereby leading to less pollution • Reduction of diesel subsidy for government (Rs. 1.36/kWh_{th}) • Less dependency on fossil fuel for industries

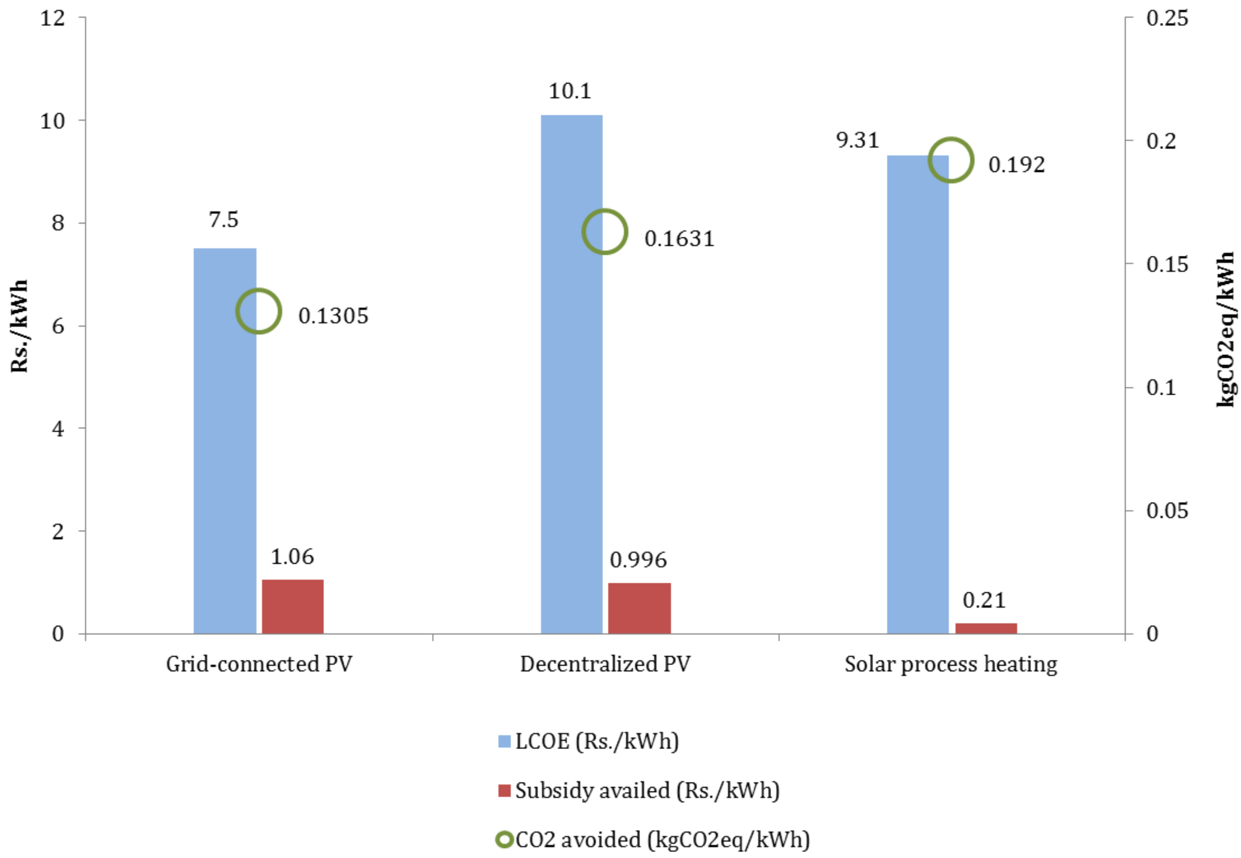


Figure 5.9: Comparison of different applications of solar energy in India

This research shows that solar process heating applications lead to higher environmental benefits than grid-connected PV and decentralized PV. However, the amount of subsidy received from the government is the least in this case. A mechanism can be formulated which enables REC and RPO participation for organizations engaged in decentralized and process heating technologies. The thermal energy units can be normalized to electrical units which can then be used to create RECs. These RECs can be traded within industries, CPPs and OACs and also allow DISCOMs to fulfil their RPO obligation. The subsidy provided by MNRE to these two technologies is not sufficient for developers to recover their investments. If the RPO and REC mechanism can be plugged into these contexts, the financial aspects of the technologies will allow them to be feasibly implemented in the country. Later stages of this project will include similar analysis of other solar energy applications such as solar process cooling and desalination. Policy recommendations will be made after comparing such applications in an Indian context.

From chapter 2 it can be concluded that to meet the 100 GW target by 2030, India needs to rapidly ramp up its indigenous manufacturing industry of solar PV and CSP. Although imported modules are cheaper at the moment, policies should be formulated which continue to protect the fledgling domestic PV manufacturing industry and carve out a niche for CSP manufacturers as well. Research suggests that in the short term (2016-17), it is wiser to continue to import cells and modules and concentrate on manufacturing the BoS components such as backsheet, glass and encapsulant. However, beyond this point the DCR clause should remain in place and in fact be increased to a point where Indian manufacturers not only operate their chains at full capacity but also have the incentive to expand. Since ingot manufacturing for PV is an energy intensive process, policies have to be introduced which allow local manufacturers to access cheaper and more stable energy sources. Also, import duties and taxes need to be lowered in the short term to make Indian manufacturers more competitive.

GIS based potential assessment in chapter 3 shows that if only 5-10% of suitable wastelands in Karnataka are used for solar power installations, the installed capacity would exceed 10 GW. Although research carried out in this analysis does not extend to other states, it is safe to assume that there is enough suitable land in India to easily reach the 100 GW target and in fact exceed it by 2030. Thorough potential assessment studies need to be undertaken for the rest of the country to determine where solar power projects can be installed with minimal negative social and environmental impacts and targets for the country need to be aligned with such potential estimates. Enabling policy mechanisms like the RPO need to be revised in a timely manner so that the potential can be achieved within the desired timeframes.

Chapter 4 provides an overview of the existing policy mechanisms in place for solar power in various states of the country. It is clear that the targets set are ambitious and that the RPO mechanism needs to be stringently enforced on obligated entities to reach these targets. Although most distribution utilities in the country are financially unstable, they need to meet their targets. In their attempts to do so, the cost of electricity borne by the end consumer will increase by a certain amount but looking at the projections of coal based electricity price hikes in the electricity domain are inevitable. Policy measures need to be undertaken to ensure that the price rise for the consumers happen gradually over time while at the same time ensuring that high end consumers (industry and commercial establishments) bear the initial burdens or resort to investing in solar power themselves. Companies like Infosys Technologies Ltd. and Volvo have already announced plans to diversify their businesses into solar energy for self-consumption purposes. Rooftop PV systems need to be further incentivized in the form of higher capital subsidies or net-metering or FiTs in order for small scale consumers to be part of an inclusive growth of solar power in the country. Rural and decentralized applications (with micro-grids) also need to be encouraged with more community level participation and increasing the number of micro-finance institutions thereby enabling energy access for all.

Later stages of this research will explore the efficacy of more detailed policy measures such as using public financing for solar projects in India and monetizing direct solar thermal energy applications for industry.

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Annexure 1: Definitions of Land Use/Land Cover Classes

Built-up land

It is an area of human habitation developed due to non-agricultural use and that has a cover of buildings, transport and communication, utilities in association with water, vegetation and vacant lands. It consists of 3 classes under built-up viz., urban, rural and mining.

Urban: Urban areas are non-linear built up areas covered by impervious structures adjacent to or connected by streets. This class usually occurs in combination with, vegetated areas that are connected to buildings that show a regular pattern, such as vegetated areas, gardens etc. and industrial and/or other areas. It includes residential areas, mixed built-up, recreational places, public / semi-public utilities, communications, public utilizes/facility, commercial areas, reclaimed areas, vegetated areas, transportation, industrial areas and their dumps, and ash/cooling ponds.

Rural: These are the lands used for human settlement of size comparatively less than the urban settlements of which the majority of population is involved in the primary activity of agriculture. These are the built-up areas, smaller in size, mainly associated with agriculture and allied sectors and non-commercial activities. They can be seen in clusters non- contiguous or scattered.

Mining: Mining areas encompass area under surface mining operations. The recognizable impacts of these activities on the landscape are unmistakable giant pit mines covering vast areas. The presence of water bodies does not necessarily imply inactive or unused extractive areas; ponds or lakes are often an integral part of an extractive operation. (USGS, 1999) It includes surface rocks and stone quarries, sand and gravel pits, brick kilns, etc. These are areas of stockpile of storage dump of industrial raw material or slag/effluents or waste material or quarried/mixed debris from earth's surface.

Agricultural land

These are the lands primarily used for farming and for production of food, fibre, and other commercial and horticultural crops. It consists of:

Cropland: These are the areas with standing crop as on the date of Satellite overpass. Cropped areas appear in bright red to red in colour with varying shape and size in a contiguous to non-contiguous pattern. They are widely distributed indifferent terrains; prominently appear in the irrigated are as irrespective of the source of irrigation. It includes kharif, rabi and zaid crop lands along with areas under double or triple crops.

Plantations: These are the areas under agricultural tree crops planted adopting agricultural management techniques. Depending on the location, they exhibit a dispersed or contiguous pattern. Use of multi-season data will enable their separation in a better way. It includes agricultural plantation (like tea, coffee, rubber etc.) horticultural plantation (like coconut, areca nut, citrus fruits, orchards, fruits, ornamental shrubs and trees, vegetable gardens etc.) and agro-horticultural plantation.

Fallow: An agricultural system with an alternation between a cropping period of several years and a fallow period (Ruthenberg, 1980).In another terms these are the lands, which are taken up for cultivation but are temporarily allowed to rest, un-cropped for one or more season, but not less than one year.

Forest

The term forest is used to refer to land with a tree canopy cover of more than 10 percent and area of more than 0.5 ha. Forests are determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 m. It consists of:

Evergreen/Semi-Evergreen: This term as such describes the phenology of perennial plants that are never entirely without green foliage (Ford-Roberston, 1971). This category comprises of tall trees, which predominantly remain green throughout the year. It includes both coniferous and tropical broadleaved evergreen species. Semi- evergreen is a forest type that includes a combination of evergreen and deciduous species with the former dominating the canopy cover.

Deciduous: This applies to the phenology of perennial plants that are leafless for a certain period of the year (Ford-Roberston, 1971). These are the forest types that are predominantly composed of species, which shed their leaves once a year, especially during summer. It also includes tree clad area with tree cover lying outside the notified forest boundary areas that are herbaceous with a woody appearance (e.g. bamboos, palms, tree ferns etc.).

Forest Plantation: These are the areas of tree species of forestry importance, raised and managed especially in notified forest areas. The species mainly constitute teak, Sal, eucalyptus, casuarinas, bamboo etc.

Scrub Forest: These are the forest areas which are generally seen at the fringes of dense forest cover and settlements, where there is biotic and abiotic interference. Most times they are located closer to habitations. Forest blanks which are the openings amidst forest areas, devoid of tree cover, observed as openings of assorted size and shapes as manifested on the imagery are also included in this category.

Littoral/Swamp/Mangrove Forest: These are tropical and subtropical vegetation species that are densely colonized on coastal tidal flats, estuaries salt marshes etc. This category includes all the areas where the canopy cover/density is above10%.

Grass/grazing land

These are the areas of natural grass along with other vegetation, predominantly grass-like plants (Monocots) and non-grass-like herbs (except Lantana species which are to be classified as scrub). It includes natural/semi-natural grass/ grazing lands of Alpine/Sub-Alpine or temperate or sub-tropical or tropical zones, desertic areas and manmade grasslands.

Wastelands

Described as degraded lands which can be brought under vegetative cover with reasonable effort and which are currently underutilized and land which is deteriorating for lack of appropriate water and soil management or on account of natural causes. It consists of:

Salt-Affected Land: Generally characterized as land that has excess salt in the soils with patchy growth of grasses.

Gullied / Ravinous Land: They are the resultant of terrain deformation due to water erosion which occurs widely in all agro-climatic zones. Gullies are formed as a result of localized surface run-off affecting the unconsolidated material resulting in the formation of perceptible channels causing undulating terrain. They are mostly associated with stream courses, sloping grounds with good rainfall regions and foothill regions. These are the first stage of excessive land dissection followed by their networking which leads to the development of ravenous land. Ravines are basically extensive systems of gullies developed along river courses.

Scrub Land: These areas possess shallow and skeletal soils, at times chemically degraded extremes of slopes, severely eroded or subjected to excessive aridity with scrubs dominating the landscape.

Sandy Area: These can occur in coastal, riverine or inland areas. Desertic sands are characterized by accumulation of sand developed in situ or transported by Aeolian processes. Coastal sands are the sands that are accumulated as a strip along the sea-coast. Riverine sands are those that are seen as accumulations in the flood plain as sheets which are the resultant phenomena of river flooding.

Barren Rocky/Stony Waste: These are rock exposures of varying lithology often barren and devoid of soil and vegetation cover.

Rann Area: An extensive salt marsh of western India between the Gulf of Kutch and the Indus River delta.

Wetland / water bodies

All submerged or water-saturated lands, natural or man-made, inland or coastal, permanent or temporary, static or dynamic, vegetated or non-vegetated, which necessarily have a land-water interface, are defined as wetlands. It consists of:

Inland Wetlands: These are the areas that include ox-bow lakes, cut-off meanders, playas, marsh, etc. which are seasonal as well as permanent in nature. It also includes manmade wetlands like waterlogged areas (seasonal and perennial).

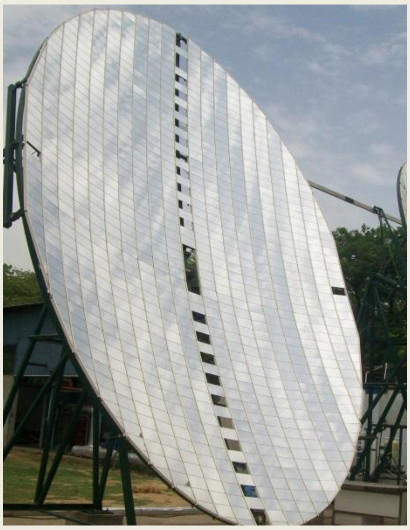
Coastal Wetland: These include estuaries, lagoons, creek, backwater, bay, tidal flat/mud flat, sand/beach, rocky coast, mangrove, salt marsh/marsh vegetation and other hydrophytic vegetation and saltpans.

River /Stream / Canals: Rivers/streams are natural course of water flowing on the land surface along a definite channel/slope regularly or intermittently towards a sea in most cases or in to a lake or an inland basin in desert areas or a marsh or another river. Canals are artificial water course constructed for irrigation, navigation or to drain out excess water from agricultural lands.

Water Bodies: This category comprises areas with surface water in the form of ponds, lakes, tanks and reservoirs. This category consists of permanent and temporary water bodies.

Snow and glaciers

These are the areas under snow cover confined to the Himalayan region. They are mostly located in mountain peaks and steep slopes/high relief areas. These are the areas which remain under snow either on temporary or permanent basis. These are the areas under perpetual snow cover throughout the year. They are the origins of most of Himalayan river systems.

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