# Decentralized Solar Power for Rural Electrification in India: A Review

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***Abstract*- There is manifold challenges of providing electricity to rural areas. The ever rising demand–supply gaps, the transmission and distribution losses, the high cost of electricity for the end user are a few of these. Use of renewable energy technologies for meeting basic energy needs of rural communities has been promoted by the Governments world over for many decades. In the recent past, India took a major step in its pursuit of sustainable development by revisiting and elevating Solar Energy sector. The off-grid solar energy has proved to be a win-win technology for the remote areas without grid connection for electricity.**

**This paper attempts at reviewing and analyzing literature pertaining to decentralized rural electrification by solar energy. In this article, the present scenario of electricity and solar energy in India is discussed as well as the main applications of decentralized solar energy for rural electrification are highlighted. The literature on cost analysis including socio-economic benefits of the population and diffused policies for promoting solar power is also reviewed in this article. The paper discusses the strategies and future prospects in its concluding remarks.**

***Keywords*- Decentralized solar energy, rural electrification, and Socio-economic benefits**

## I. INTRODUCTION

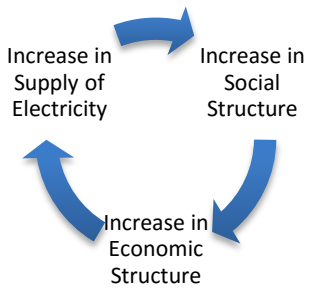
Energy is an essential requirement for all facets of our life and has been recognized as a basic human need. It is a prime mover of economic growth and is a critical infrastructure on which socio-economic development of the country depends. It has complex linkages with the environment. In other words, energy is directly related to development, as development means, growth and growth require energy. Further, it is the most effective tool for sustainable development. Energy impinges on poverty, jobs and incomes, access to social services, gender disparities, population, agricultural production and food security, health, land degradation, climate change and environmental quality, economic and social issues. Therefore, it must be viewed, as a means of contributing to the solution of a major global problem. In fact, the goal for energy can be stated very simple: sustainable development.

Being a versatile form of energy, electric power is one of the most important infrastructure sectors of the economy. Electricity, for instance, is an indispensable input for productive and economic activities, as well as for overall health and well-being of communities. The sources for electricity production can be classified into two broad areas: conventional or non-renewable sources and non-conventional or renewable sources. The most utilized sources since past decades are that of conventional resources like fossil fuels. At the global level, the primary source of electricity production is coal. All over the globe and especially in developing countries, the power sector is experiencing high tides of the energy crisis and environmental degradation. India is the world's sixth largest energy consumer relying on coal for more than half of its total energy needs. Therefore, India, growing with the world at a very fast pace needs to switch to renewable sources of energy mainly due to following two reasons:

1) India needs to increase energy consumption substantially because of strong positive correlation between energy consumption and human development.

2) Due to fast depleting fossil fuels creating energy crisis and severe environmental degradation, the rapid shift to less-polluting renewable energy will be needed to avoid catastrophic global warming.

The increase in population, accompanied by rapid urbanization and industrialization led to increase in the use of fossil fuels. Present fossil fuel is unable to meet the growing energy needs of the society. Thus, there is a need to look for viable alternative energy sources to meet the energy requirements.




The above diagram makes it very clear that economic and social development forms a cyclical process with electricity consumption. Therefore, for economic growth

increase in energy supply and consumption becomes mandatory.

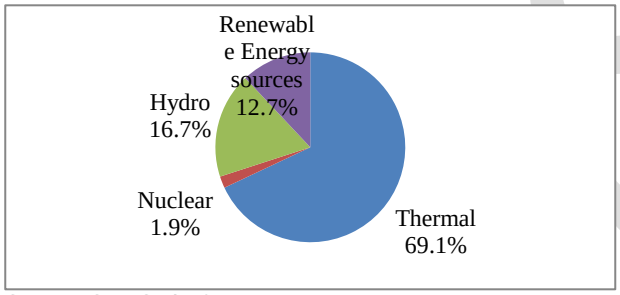
## II. POWER SCENARIO IN INDIA

Electricity is the prime driver of the development of India, which is witnessing a robust economic growth rate of near 8%. India possesses huge coal reserves of about 7.1% of the world's total [1] thus; coal-fired power plants contribute to about 70% of the total power generation [2]. India faces a significant gap between electricity demand and supply as reported by the Central Electricity Authority for the year 2009–2010 as almost 84 TWh, which is 10% of the total requirement. The peak demand deficit is more than 15 GW, corresponding to a shortage of 12.7% [3].

### *A. Power Generation*

India's net cumulative installed power generation capacity from various sectors is 207006.04 MW (Aug 2012) [4]. Literature shows that there exists a remarkable energy demand-supply gap in India. Currently, this DD-SS gap is estimated to be 6.7%. The primary reason for electricity shortage is an over-reliance on thermal energy from coal and gas, as shown in figure 1. Currently, only 12.7 % of India's energy is supplied by renewable energy (fig. 1).

Fig. 1. Total Installed Capacity.




*Source: GoI, CEA 2014*

Renewable energy sources (RES) contributing significantly in total installed capacity, presently, 12.7% power is produced from different renewable energy sources such as small hydropower project, biomass gasifier, industrial and urban waste, biomass power, the wind and solar power etc.

### *B. Power Consumption*

There has been an increasing trend in power consumption in India. The increase in per capita consumption of power in India was not much in 1989 and has gradually increased thereafter. It was just 176 KWh in 1980-81 and bounced to 1000 KWh in 2011-12. Table 1 shows the per capita consumption of power in past few years.

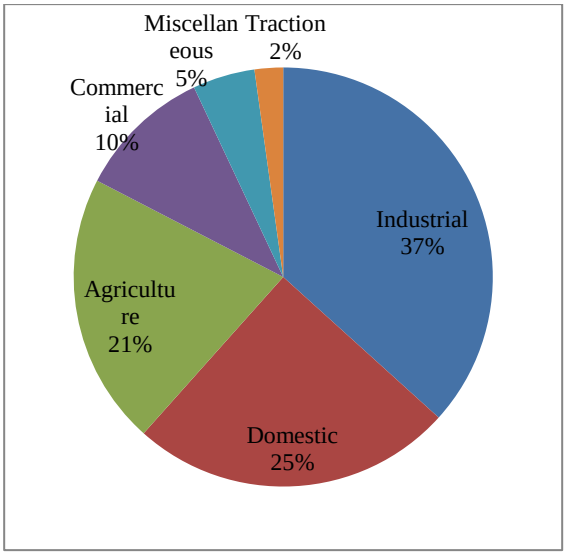
TABLE 1. GROWTH OF PER CAPITA CONSUMPTION OF ELECTRICITY IN INDIA

| Year | Per capita consumption of power (KWh) |
|---|---|
| 1980-81 | 176 |
| 1990-91 | 348 |
| 2000-01 | 559 |
| 2001-02 | 563.2 |
| 2002-03 | 577 |
| 2003-04 | 592 |
| 2004-05 | 612.5 |
| 2005-06 | 631.5 |
| 2006-07 | 671.1 |
| 2007-08 | 717.1 |
| 2008-09 | 734.5 |
| 2009-10 | 778.6 |
| 2010-11 | 813.3 |
| 2011-12 | 1000 |

*Source: GoI, Central Electricity Authority Report 2013*

The power consumption pattern in India is differentiated in various sectors like agriculture, industry, commercial, domestic, traction, etc. but the quite relevant and large fraction amongst all only after industry sector is occupied by domestic and agriculture (fig. 2). Agricultural sector thus presses on higher energy needs which it is deprived of in many of the Indian rural areas.

Fig. 2. India's Electricity Consumption Sector-wise




*Source: GoI, CEA 2012-13*

On the quality side, the electricity grid shows high voltage fluctuations and power outages in almost all parts of the country on many days for several hours. The transmission and distribution losses are high and the production of electricity from conventional sources does not meet the demand generating sufficient demand-supply gap and thus resulting in power deficit, which is required to be met by the high potential renewable energy sector in India.

### *C. Power Demand-Supply Gap*

India is going through churning power crisis issues. The power generation is inadequate. Due to country's growth trends, the demand for electricity is rising continuously. We are the 4th largest energy consumer in the world with a per capita consumption around 7.5 KWh per year. The demand for energy has grown closer to 3.5% per annum over the last three decades. The peak demand for electricity in India at the end of IX plan was 78,441 MW and the supply was 69,189 MW, resulting in a deficit of 9,252 MW (11.8 percent). Further, in the year 2009-10 [march] the peak demand for electricity has increased to 1,18,472 MW and supply was only 1,02,725 MW, contributing to a deficit of 13.3 percent to the economy. During X plan, only 23,000MW was added to the original target of 41,000 MW. The CEA report clearly reveals that the deficit in the demand and supply of electricity has been continuously rising in the past two decades and this has been depicted in table 2.

TABLE 2. POWER SUPPLY SCENARIO IN INDIA

| Year | Peak Demand MW | Peak Met MW | Deficit/Surplus MW | In % |
|---|---|---|---|---|
| 2002-03 | 81,492 | 71,547 | -9,945 | 12.8 |
| 2003-04 | 84,574 | 75,066 | -9,508 | 11.2 |
| 2004-05 | 87,906 | 77,652 | -10,254 | 11.7 |
| 2005-06 | 93,255 | 81,792 | -11,463 | 12.3 |
| 2006-07 | 1,00,715 | 86,818 | -13,897 | 13.8 |
| 2007-08 | 1,08,866 | 90,793 | -18,073 | 16.6 |
| 2008-09 | 1,09,809 | 96,685 | -13,124 | 12 |
| 2009-10 | 1,19,166 | 1,04,009 | -15,157 | 12.7 |
| 2010-11 | 1,22,287 | 1,10,256 | -12,031 | 9.8 |
| 2011-12 | 1,30,006 | 1,16,191 | -13,815 | 10.6 |
| 2012-13 | 1,35,453 | 1,23,294 | -12,159 | 9.0 |
| 2013-14 | 1,35,918 | 1,29,815 | -6,103 | 4.5 |

*Source: Compiled from various annual reports of Central Electricity Authority (CEA).*

## III. SOLAR ENERGY IN INDIA

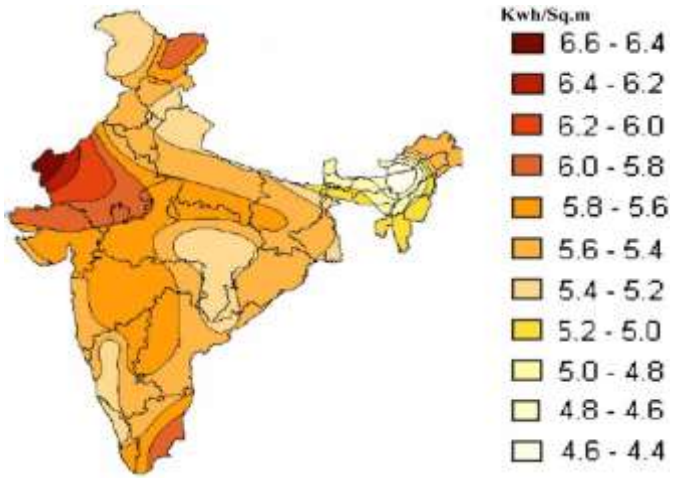
Contemporarily, India put forth sustainability as its approach towards growth and development [5] i.e. meeting the needs of the present without compromising the ability of future generations to meet their own needs [6]. In this regard, Solar Energy (SE) is one of the sectors that are identified to support this endeavor.

### *A. Solar Potential in India*

India is a hotspot for solar energy as it lies in the sunny belt of the world. The scope for generating power and thermal applications using solar energy is huge. Most parts of India get 300 days of sunshine a year, which makes the country a very favorable place for solar energy deployment [7]. The daily average solar energy incident over India varies from 4 to7 kWh/m$^2$ with the sunshine hours ranging between 2300 and 3200 per year, depending upon location [8].

The technical potential of solar energy in India is gigantic. The country receives enough solar energy to produce more than 500,000 TWh per year of electricity, assuming 10% conversion efficiency for PV modules. It is three orders of magnitude greater than the likely electricity demand for India by the year 2015 [9]. Figure 3 shows a map of India with solar radiation levels in different parts of the country. It can be observed that although the highest annual global radiation is received in Rajasthan, northern Gujarat and parts of Ladakh region, the parts of Andhra Pradesh, Maharashtra, Madhya Pradesh also receive fairly large amount of radiation as compared to many parts of the world especially Japan, Europe and the US where development and deployment of solar technologies is maximum [10].

Fig. 3. Solar Radiation on India




*Source: taken from NREL and http://www.mnre.gov.in*

*B. Decentralized Applications of Solar Power*

Literature depicts that even though a lot have been done by the government for rural electrification, there is a high need for amendments and formulation of policies for decentralized use of energy. Decentralization also needs the proper participation of the local population for making them energy self-sufficient. It remarks that there are a variety of social-cultural as well as economic and access-related factors contributing to low or zero electrification in rural areas.

According to IEA[1], in 2008, over 400 million people in India, including 47.5% of those living in India's rural areas, still had no access to electricity. Because of the remoteness of much of India's un-electrified population, off-grid renewable energy can offer an economically viable means of providing connections to these groups.

With the rising demand of energy and implementation of policies to support renewable energy, these sources have started to be utilized for generation of electricity in India. Solar thermal energy is used in solar cooking, solar water heater, solar drying, solar heat treatment of grain/seeds, solar powered water pumps, solar refrigeration and air conditioning, etc. Solar photovoltaic systems are used in water pumping, telecommunications, refrigeration, photovoltaic power generation, etc.

Chaurey and Kandpal, 2010[2] states that PV technology is one of the best among several RE technologies that was adopted globally as well as in India for meeting basic electricity needs of rural areas that are not connected to the grid. The PV system thus is a good choice for power generation. Another significant study carried by Choragudi, 2013[3] analyzes the off-grid solar lighting systems for India's sustainable and inclusive development goals by using a Multinomial Logit Model. This study discusses the trends and patterns of SOLS (Solar off-grid Lighting Systems) diffusion. For this, a household level analysis was done in rural areas.

The two most widely used SOLS in India are SLs and SHs. While SL is a portable lighting system with only one lighting point, SH is a fixed system with at least two lighting points, fans, and even television (the nature and number of appliances that can be operated depend on the capacity of the system).

*C. Techno-Economic Feasibility*

According to a very relevant research by Purohit and Purohit, 2010[4] using the cost-benefit analysis the techno-economic evaluation of concentrating solar power generation in India have been explained. According to them, resource assessment is the primary and essential exercise for solar energy project evaluation. The approach adopted by them for estimation of electricity generation from the projects is through comparison of direct and direct normal radiations at locations of the new site and the projects. Hence, electricity generation figures are estimated on the basis of an actual site related data, whereas project cost could be presumed similar in the new site. They analyzed the CDM (Clean Development Mechanism) benefits by using Life Cycle Analysis (LCA).

Ramachandra et al, 2011[5] identifies that India has a huge Solar potential in order to meet the rising energy demand which would lead to socio-economic progress of the country. The techno-economic feasibility criteria of the solar systems for choosing the best system for the identified area for implantation have also been studied. The research explains the future prospects of solar power in India along with the organizational and social aspects related to solar power generation in the country.

Sharma, 2011[6] analyses the global scenario of solar power generation throwing light on the potential, technology and policy framework to support the solar growth in countries. It has been observed that solar technology has grown at a very fast pace in recent times resulting in cost reductions. Yet India has not adopted the solar system power generation techniques despite being one of the nations with highest solar potential. The leading countries with developed solar technique adoption are U.S, Germany, Spain, Italy and even China has become a competitor. There exist an immense scope and availability of solar energy in India with the reduced technical cost to fill the energy demand-supply gap and move towards economic and sustainable development.

The research questions like the barriers that prevent solar deployment? What policies have been introduced to boost solar market? Have they produced desired results, etc and the techno-economic analysis of competitive solar energy with fossil energy counterparts including the analysis of cost reduction and environmental benefits have been discussed in detail by Timilsina et al, 2011[7] by using "Levelized cost" method, taking into account all the associated variables. The study also discusses the policy instruments and their impacts on the solar energy power generation and the policy challenges. Solar energy development under the climate change regime has also been analyzed.

According to the research conducting by Sahoo and Shrimali, 2013[8] the effectiveness of domestic content criteria had been extensively analyzed for India's Solar Mission which helps to explain the competitiveness of the India Solar Market.

Purohit et al, 2013[9] explained the extensive potential of CSP (Concentrated Solar Power) technologies in Northern India, especially in Rajasthan taking into account the resource assessment and availability and central/state policy framework for promoting CSP in India. According to them, mechanisms like feed-in-tariff can provide long-term and assured security to investors. The study has used life cycle assessment for identifying the cost of energy produced by renewable technologies. To estimate the energy yield over the locations

in NW parts of India they have used the System Advisor Model (SAM). SAM includes energy performance models for all CSP technologies along with grid connected Solar PV.

Shrimali and Sahoo, 2014[10] throws light on the potential of solar energy in India, various types of solar power generation and the resource requirements and performance feasibility of solar power systems in India. The deployment of the domestic content requirement is also discussed in detail with special reference to JNNSM (Jawaharlal Nehru National Solar Mission).

Another study by Alafita and Pearce, 2014[11] analyzes the costs, risks and uncertainties of solar photovoltaic by cost flow analysis. Securitization of Solar PV has also been analyzed for its growth under this study. It also identifies the policy interventions to reduce risk and have explained the importance of Power Purchase agreements (PPAs) in penetration of solar energy.

### *D. Policies Promoting Solar Power*

A huge number of policy instruments have been instigated to support solar technology and several electricity policies in the last few years have talked about the need and priority to promote renewable energy. Foremost amongst them is the Electricity Act (2003) which de-licensed stand-alone generation and distribution systems in rural areas [11, 12]. The National Rural Electrification Policy, 2005 [13] and National Rural Electrification Policy, 2006 also stresses the need for urgent electrification [14]. The New Tariff Policy (2006) stated that a minimum percentage of energy, as specified by the Regulatory Commission, is to be purchased from such sources [15]. The details of directive released by the Indian government to promote renewable energy are discussed in later sections.

#### *1. Electricity Act 2003*

The act provides that cogeneration and generation of electricity from renewable sources would be promoted by the State Electricity Regulatory Commissions (SERCs) by providing suitable measures for connectivity with grid and sale of electricity to any person and also by specifying, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee. Such percentage for purchase of power from these sources should be made applicable for the promotional tariffs to be determined by the SERCs at the earliest. Progressively the share of electricity from renewable energy sources would need to be increased as prescribed by SERCs. Such purchase by distribution companies shall be through competitive bidding process. Considering the fact that it will take some time before renewable technologies compete, in terms of cost, with conventional sources, the Commission may determine an appropriate differential in prices to promote these technologies [11].

#### *2. National Electricity Policy 2005*

The National Electricity Policy 2005 stipulates that progressively the share of electricity from non-conventional sources would need to be increased; such purchase by distribution companies shall be through competitive bidding process; considering the fact that it will take some time before non-conventional technologies compete, in terms of cost, with conventional sources, the commission may determine an appropriate differential in prices to promote these technologies [12].

#### *3. National Rural Electrification Policies (NREP), 2006*

The goals of NREP-2006, include the provision of access to electricity to all households by the completion of the year 2009, quality and reliable power supply at reasonable rates, and minimum lifeline consumption of one unit/household/day as a merit good by the year 2012 [16]. For villages/habitations where grid connectivity would not be feasible or not cost effective, off-grid solutions based on stand-alone renewable based systems may be taken up for the supply of electricity. Where these also are not feasible and if the only alternative is to use isolated lighting technologies like solar photovoltaic, these may be adopted. However, such remote villages may not be designated as electrified. State governments have to be prepared and notify a rural electrification plan in their respective states, which should map and detail the electrification delivery mechanism. The plan may be linked to and integrated with district development plans. The plan should also be intimated to the appropriate Commission. Moreover, Gram Panchayat should be involved in it and issue the first certificate at the time of the village becoming eligible for declaration as electrified. Subsequently, the Gram Panchayat shall certify and confirm the electrified status of the village as on 31st March each year [17, 18].

#### *4. Jawaharlal Nehru Mission*

An ambitious programme, National Solar Mission, launched by Government of India aims at the ultimate capacity of 20,000 MW solar power generations by the year 2020. This capacity enhancement is targeted in three phases:

| Phase | Time period | Grid connected | Off-grid |
|---|---|---|---|
| 1 | 2007-12 | 11000 MW | 200 MW |
| 2 | 2012-17 | 10000 MW | 1000 MW |
| 3 | 2017-22 | 20000 MW | 2000 MW |

*Source: MNRE*

## IV. CONCLUSION

India has a severe electricity shortage, especially in remote rural areas. It needs massive additions in capacity to meet the demand of its rapidly growing rural economy.

Development of solar energy, which is indigenous and distributed and has the low marginal cost of generation, can increase energy security by diversifying supply, reducing import dependence, and mitigating fuel price volatility. Solar energy development in India can also be an important tool for spurring regional rural based economic development, particularly in many underdeveloped states, which have the greatest potential for developing solar power systems; which is an unlimited and clean source of energy. It can provide secure electricity supply to foster domestic industrial development. Thus, it can be concluded that photovoltaic power systems will have an important share in the electricity of the future not only in India but all over the world.

To conclude, the present paper is an attempt to review the progress made in solar energy research and adaptation as an effective measure of conserving fast depleting fossil fuel usage and the policy measures enacted and adopted by India to use its natural solar potential to its advantage in achieving sustainable development.

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