

Rural electrification in India and feasibility of Photovoltaic Solar Home Systems

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ABSTRACT

Rural electrification is an integral component of poverty alleviation and rural growth of a nation. In India, electricity has not played effective role in the socio-economic growth of village. Gross Domestic Product (GDP) is increasing with 8% where as contribution of agriculture sector is 1.9%. Government of India has ambitious target of providing electricity to all villages by 2008 and all rural households by 2012. Steps are already initiated with Rural Electric Corporation, Rural Electricity Supply Technology mission, State Electricity Boards, Reforms in Power sector. An attempt has been made in this paper to assess the features of rural electrification in India and the feasibility of Photovoltaic Solar Home Systems (PV SHS).

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1. Introduction

India has one of the fastest growing economies in the world and ranked 6th place in the worldwide consumer of energy. Being the seventh largest country in the world, 6000 villages inhabit 72.2% of its human resource (census 2001). About, 40% of the total energy is in rural areas. Domestic sector constitutes major energy demand and its consumption accounts for 60% of energy used. The main energy sources are coal and oil, whilst hydro, wind, nuclear and biomass provide additional sources. Although hydropower has good potential, it has yet been utilized to its full potential. India holds 7% of the worlds coal reserves, whereas for oil 0.5%. Following are some of the salient aspects having direct and indirect bearings on energy supply, to rural –

- Both the traditional energy and commercial energy are in short supply and the demand supply gap is in increase.
- Pressure on traditional energy resources such as wood is continuously increasing due to growing population.
- Heavy dependence on commercial fuels such as coal and oil as a short term measure for meeting increasing demand is alarming in view of depleting fossil fuels and pollution.
- Energy supply to far-off rural areas is associated with high transportation and transmission losses of about 22.4%.

Thus emphasis should be laid on the auditing of the energy in such a way that ensures affordable, environment friendly and clean energy.

2. Impact of rural electrification

Importance of electricity as a crucial infrastructure input for economic development of the country has been well established. Recent studies of rural electrification indicate the following broad consensus concerning the impact of electrification in the rural areas [1].

A. Quantifiable benefits: cost saving and increased productivity

1. Industrial and commercial uses of electricity

- (a) motive power – replacing liquid fuel
- (b) lighting – replacing liquid fuel or gas
- (c) processing food – replacing liquid fuel, gas, biomass, animal waste
- (d) transport – replacing liquid fuel

2. Household uses of electricity

- (a) lighting – replacing liquid fuel, gas, biomass
- (b) cooking – replacing biomass, animal waste, wood, liquid fuel, coal, gas
- (c) drinking water – replacing liquid fuel for pumping
- (d) home appliances (fan, TV, radio) – replacing batteries, biomass, coal

3. Agricultural uses of electricity

- (a) water pumping – replacing liquid fuel, coal, muscle power
- (b) heating and drying – replacing biomass, coal, liquid

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- (c) milling, chaff cutting, threshing, etc. – replacing liquid fuel, hydro or muscle power

B. Benefits those are difficult to quantify

1. Modernisation, dynamism and attitude changes – catalytic effects
2. Quality of life, community services and participation
3. Income distribution and social equity
4. Employment creations

In recent years attention has risen regarding the issue of rural access to electricity supply and regarding the relation between energy (electricity) and poverty. Cecelski (2000) reviews several “success factors” in widening rural access to electricity, including subsidies, credit and leasing options for PV systems

2.1. Features of rural electrification

Rural electrification is an important component of Integrated Rural Development. In India, it has been given less importance because of the following reasons.

- Villages are located from 3 to 80 km away from existing grid or even more.
- They are located in difficult areas like forests, hill areas and deserts.
- The number of households may range between 2 and 200 with dispersed distribution of loads.
- Power demand in villages is quite low and rural domestic consumers are mainly peak time consumers and contribute for poor load factors of 0.2–0.3.
- The income level and hence the paying capacity is low.
- Previous definition of village was (source: Ministry of Power) – A village will be deemed to be electrified if electricity is used in the inhabited locality, within the revenue boundary of the village, for any purpose whatsoever.

Modified definition of village from 2004 to 2005 is – A village would be declared as electrified if –

- (a) Basic infrastructure such as Distribution Transformer and Distribution lines are provided in the inhabited locality as well as the Dalit Basti/ hamlet where it exists. (For electrification through Non Conventional Energy Sources a Distribution transformer may not be necessary.)
- (b) Electricity is provided to public places like Schools, Panchayat Office, Health Centers, Dispensaries, and Community centers.
- (c) The number of households electrified should be at least 10% of the total number of households in the village.

Electrical power sector was recognized as one of the Millennium Development Goals in 2000, for the upliftment of the masses and poverty alleviation. The Five Year Plans of Government of India, World Bank, International Monetary Fund, etc. have identified this socially relevant sector and initiated several measures like

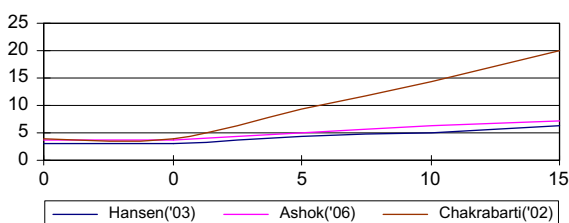


Fig. 1. Cost of grid electricity (Rs/kW h) with distance (km).

Electricity Act 2003, Deregulation, Unbundling, Independent Power Producers (IPP), and Electricity Regulatory Commission.

3. Key features of grid connection

Rural electrification in India is carried out mainly by grid connection. The method of 'connecting a village to be electrified to the nearest village that has been electrified' has led to an inefficient, unmanageable distribution network. This has resulted in the following problems:

- (1) Average Cost of grid connection increases with distance (Fig. 1) (Chakrabarti et al., 2002). The effect of T&D losses may further increase the delivered cost.
- (2) Aggregate and technical losses in India amounts to 50% (source: Central Electrical Authority) (Tables 1 and 2).
- (3) Number of average 100 h Customer Hour Lost (CHL) per month due to both scheduled and unscheduled load shedding by grid (Fig. 2) (source: Central Electrical Authority).
- (4) Still 157 million households are not having access to electricity (Fig. 3) (source: Rural Electric Corporation).
- (5) In India, per capita energy consumption is increasing and is 559 kW h in 2007 (Fig. 4) (source: Central Electrical Authority).

It is estimated that 125,000 villages (21% of all villages) currently lack electrification in India (Sharma, 2007), with about

Table 1

Percentage aggregate technical and commercial losses in rural side. (Source: Central Electrical Authority.)

Aggregate technical and commercial loss	Percentage
South grid	4
State grid	4
33 kV	5
11 kV	5
LT dist	20
Collection	12

Table 2

Percentage aggregate technical and commercial losses.

AT and commercial loss	Percentage
South grid	4
State grid	4
33 kV	5
11 kV	5
LT dist	20
Collection	12

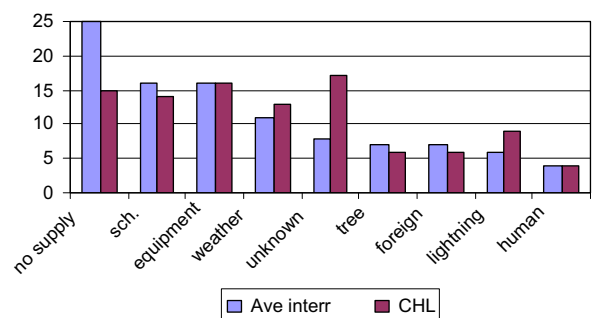


Fig. 2. Customer Hour Lost and average interruptions.

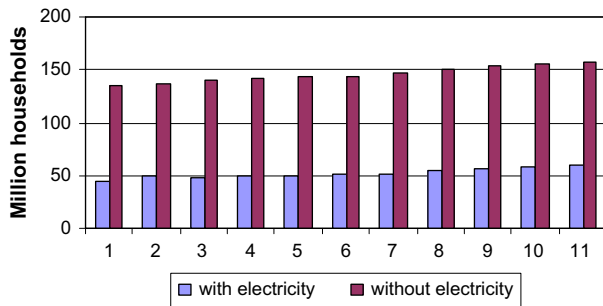


Fig. 3. Electricity supply to rural households in millions.

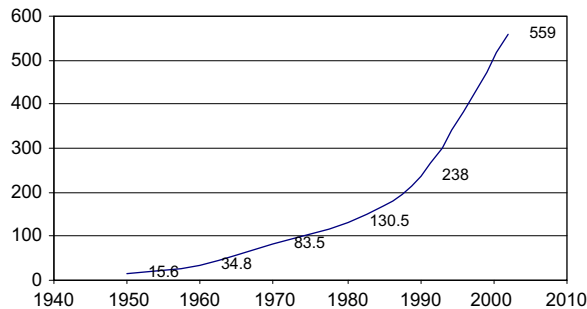


Fig. 4. Increase of Per Capita consumption of Electrical Energy (kW h).

18,000–24,500 villages classified as too remote or inaccessible, for which electricity supply from the grid may not be possible in the near future (Ghosh et al., 2004; Nouni et al., 2007, 2008). Therefore, decentralized electricity production, defined as electricity-based production within the village that is not linked to a grid or to transmission or distribution networks, provides a plausible medium-term solution to the electricity accessibility issue (Sharma, 2007). The government of India has identified the goal of electrifying every village in India by 2012, giving priority to decentralized power generating plants for villages too remote for extension of the conventional grid lines (Ghosh et al., 2004). Furthermore, where villages are presently connected to the grid, the current supply of electricity is sporadic and in many regions not up to acceptable standards.

The advantages of decentralized electricity generation are numerous, including avoiding reliance on state utilities, which are not able to provide reliable supply or access. Other advantages include decreased reliance on fossil fuel-based electricity generation, decreased loss in transmission, which is currently estimated to be 40% in India, and direct employment opportunities within the villages, the sites of equipment and operation (Sharma, 2007). Hence electricity planners are compelled to think of supplementary or alternative electrical energy supplies to these areas. Several options are- solar, wind, biofuels, and fuel cells. Indian conditions are best suited for solar energy because of –

- generation at site and hence proximity to utilities
- very less transmission and distribution losses
- customer is the owner of his or her own power-generating system
- on an average 250–300 clear sunny days in a year (Purohit et al., 2002a)
- reduction in the cost of PV cell to Rs 180–200 per Watt in 2008 from Rs. 1000 in 1998
- the production of power is environmentally friendly
- suited for roof top generation and Building Integrated PV (BIPV)

- the systems are suitable for any part of the India (e.g., under serviced areas)
- Proven technology of panel, battery and controller
- solar PV systems are durable and maintenance is easy
- no fuel cost is involved and electricity is generated for more than 20 years without any traditional fuels.

Sunlight is the world's largest energy source (170,000 TWth) and it can be readily accessed with existing technology [4]. India being a tropical country is blessed with plenty of sunshine. The average daily solar radiation varies between 4 kW h and 7 kW h per square meter for different parts of the country (Mani and Rangarajan, 1982). Thus, it receives about 5000 trillion kW h of solar energy in a year (MNES, 2005).

4. PV cells

In 1839 Edmund Becquerel observed that 'electric currents arise from certain light-induced chemical reactions'. The first notable application was in 1958 when PV solar cells were used to power the satellite Vanguard 1. The first application started in US space ship during 1950s. The development of the technology has continued since that time, driven very much by the needs of the various world-wide space programmes. In India, Bharat Heavy Electricals Limited started PV cell production in 1983 and followed by others. Photovoltaic cells refers to the creation of voltage from light. SPV systems directly convert sunlight into useful electricity. This process is called photo electric effect. The energy generator in a PV system is the solar cell. Solar cells are essentially thin wafers of silicon. These cells are connected in series and parallel constitute a solar panel. The types of solar panels in use are crystalline silicon and thin films. Currently all the PV panels available in India are composed of crystalline silicon cells. Depending upon the output load, one or more solar panels may be required. The direct current generated from these solar cells is stored in a battery. Between the battery and the loads, charge controller is provided. These prevent the overcharging and discharging of batteries by regulating the flow of electricity. Compact fluorescent lamps (CFL) are normally used as lighting loads. Other loads are electrical devices that operate on DC or AC. In case of AC loads inverters are used. Following are applications of PV–

- (a) Stand alone systems for home lights, TV, radio
- (b) Portable lighting systems for home, agriculture fields, educational institutions, health centers
- (c) water pumping for irrigation and drinking water
- (d) Refrigeration
- (e) rural telecommunication
- (f) PV integrated buildings
- (g) Road and railway signaling

The electricity generated by PV panel can be used directly and/or stored in batteries and used even after sunset. Recent technologies of PV cells are –

- a. Electrochemical solar cells:
 - (i) Electrochemical solar cells have their active component in liquid phase
 - (ii) Dye sensitizers are used to absorb light and create electron–hole pairs in Nano-crystalline titanium dioxide semiconductor layer
 - (iii) Cell efficiency ~7%
- b. Ultra Thin Wafer Solar Cells:
 - (i) Thickness ~45 μm
 - (ii) Cell Efficiency as high as 20.3%

Advantages of PV System

PV technology is identified as most environment friendly technologies. It requires only sunlight and no other energy fuel [2,3]. Being modular in design, the capacity can be increased to meet additional demand. It is easy to dismantle and reconfigure these systems for other applications. PV systems require little maintenance. These components can be manufactured and assembled locally.

- (1) Environment friendly as they do not emit gaseous and liquid pollutants
- (2) Can be easily transported, assembled and installed in remote areas
- (3) Produce DC electricity that can be stored in batteries
- (4) Zero fuel usage
- (5) Noise free
- (6) Robust and reliable and weather proof and having long life of 20 years
- (7) Low maintenance cost
- (8) Every kW h of generated solar power prevents the release of around 0.7 kg of carbon dioxide

Despite these advantages PV system has several disadvantages.

- High capital cost, makes the system cost-prohibitive.
- Few types of devices can be operating using PV.
- PV systems being less competitive compared to other sources and are not suitable source for meeting large loads.
- Higher potential of these systems is mainly in remote rural areas where grid connection is not cost effective.

5. Feasibility of PV panel for a rural house

The average energy consumption of a household is influenced by many factors like construction and size of house, climate, season, size of house, and size of family (census 2001, average 5.3 persons per house with three rooms). Electricity consumption has been estimated for electrified areas, with use varying from 0.33 kW h per household per day for landless households to 0.84 kW h per household per day in larger landholdings for lighting purposes (Ramachandra et al., 2000b). Rural house comprises of mainly lighting load, TV, Tape recorder, radio for average five persons.

Utility	Watt	Hour	Total
Lamps (three)	40	2.5	300
Tape/radio	20	3	60
TV	80	3	240

Total daily consumption = 600 W h

The size of PV array system-

Number of 75 W panel required $(600/75) = 8$ numbers

PV panels can work for 6 h per day and 300 days in a year, the electricity produced per day = 8 panels $\times$ 75 W $\times$ 6 h = 3.6 kW h = 3.6 unit

Initial investment:

PV cost = Rs. 200/W

MNES subsidy = Rs. 125/W

The investor has to pay Rs. 75/W

Cost of PV panel for consumer = 75 W $\times$ Rs. 75 $\times$ 8 = Rs. 45,000

Battery cost = 5 battery $\times$ Rs. 5000 = Rs. 25,000

Inverter cost = Rs. 6500

Installation cost = Rs. 3500

Maintenance cost = 5 $\times$ 2500 $\times$ 5 = Rs. 62,500

Total cost = Rs. 107,500

Payback period = 14.9 years

Arid regions in India receive plentiful solar radiation (average solar insolation available is 5 kW h per square meter per day) with the potential availability of 20 MW per square kilometer (source: Indian Renewable Energy Development Agency). IREDA is planning to electrify 18,000 villages by year 2012 mainly through solar PV systems. Targets have been set for the large scale utilization of PV technology by different sectors within the next 5 years.

The average daily solar radiation varies between 4 kW h and 7 kW h per square meter for different parts of the country (Mani and Rangarajan, 1982). Twenty two year averaged insolation on incident on latitude 15.467° and longitude 75.067° rural indicates that there is ample scope for using PV in rural areas (Fig. 5) and additional 2.71 kW h energy can be saved in tubular batteries with one panel of 35 W Dharwad (Karnataka state) (Figs. 6 and 7).

Life of solar panel is 25 years with panel and other accessories are maintained properly.

Electric lighting (up to 200 times brighter than kerosene lamp) directly improves the quality of life. It allows children to study in the evening and women to gain some precious time for them or to extend income generating work into the evening hours (Domdom et al., 2000).

Government of India provides central financial assistance (CFA) for solar panel and Rs. 200 service charge as an encouragement for the utilities.

Model	Solar home lighting system	Central Service Subsidy in Rupees
Model I	18 W, one-light	3000
Model II	37 W, two-light	5500
Model III	74 W, four-light	10,000

(Source: Annual Report, 2002–2003, Ministry of New and Renewable Energy remote village electrification programs as per No15/6/2006-07-RVE).

The initial cost of a four-light 37 W PV SHS in 1999 was Rs. 18,500 for which financing from a bank could be obtained at 12% interest over a 5-year period. This corresponded, after a down payment of 15% to a household expenditure of Rs. 4362 per year or Rs. 364 per month. On average, energy accounts for about 7.5% of the expenditure of a household. If, to be liberal, this is doubled, it means that 15% of its monthly expenditure is the upper limit to what a household can spend on energy. The income distribution pattern in India is such that only about 7% of the households have this income required to afford PV SHS. Assuming that only half of those households that can afford PV SHS are prepared to switch to PV SHS, it appears that much less than 5% of the richest rural households constitute the market for such systems.

The potential penetration is greater with the smaller systems. The two-light 20 W SHS costs about Rs. 11,500 and can be obtained

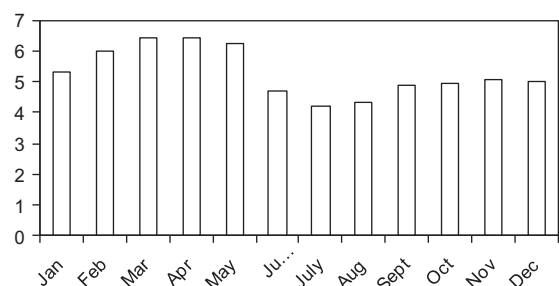


Fig. 5. Solar insolation (kilo-Watt hour per square meter per day). (Source: NASA surface meteorology.)

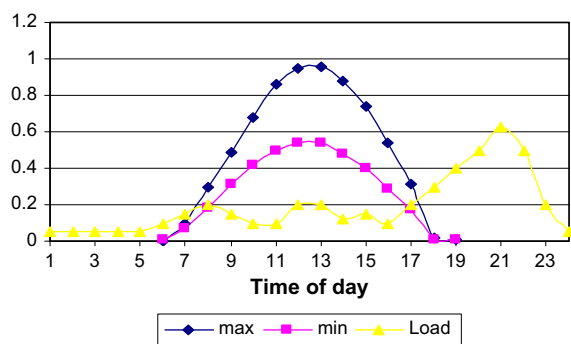


Fig. 6. Solar radiation max and min (kW h)/square meter and rural load (kw).

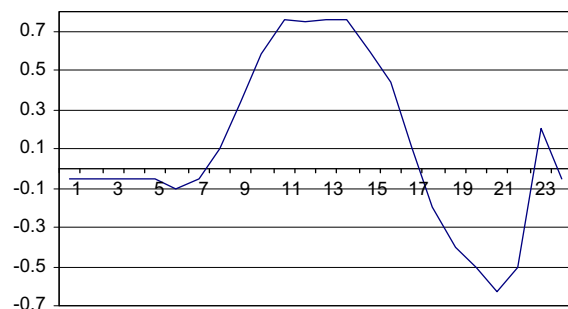


Fig. 7. additional solar energy (kW h) stored in a day.

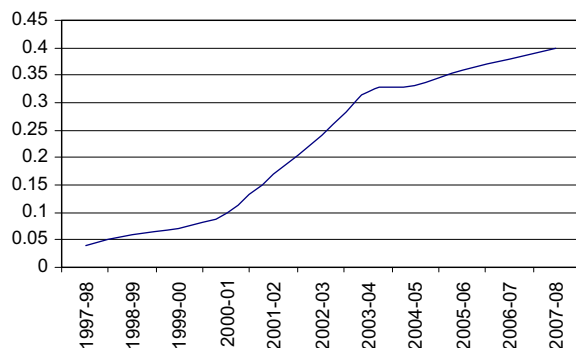


Fig. 8. Growth of solar home systems in millions. (Source: MNES Annual Report, 2008.)

with the same financing terms as the four-light system. This cheaper system implies Rs. 1725 down payment and Rs. 226 per month requiring an income of about Rs. 1506 per month available to about 17% of the households. The one-light 10 W SHS costs about Rs. 5500 and implies (with the same financing terms) about Rs. 825 down payment and about Rs. 108 per month requiring an income of about Rs. 720 per month available to about 75% of the households.

It follows that the two- and four-light systems can only be afforded by the richest rural sections constituting 17% and 7% (respectively) of the population. Even the cheapest one-light PV SHS is beyond the means of the poorest 25% of the rural population.

The purpose of PV SHS is, not merely to improve the quality of life of the household, but to illuminate activities that augment income. suppose that a one-light PV SHS permits a tribal household to weave two extra baskets per evening to earn Rs. 5 per basket and therefore (after paying for materials) about Rs. 250 per month.

Then the income generated by the PV SHS more than pays for the investment on the light. A similar case is that of a mobile vegetable vendor who can have two extra hours of sales. Thus, there are non-elitist niche markets for PV SHS.

An analysis shows that, given the 2006 costs of four-light 37 W PV SHS and the income distribution pattern in rural India, only about 10% of the households have the income required for PV SHS even with financing from a bank at 12% interest over a 5-year period. Assuming that only half of those households that can afford PV SHS are prepared to switch to PV SHS, it appears that the market for such systems is restricted to much less than 5% of the richest rural households. The potential penetration is greater with the smaller systems. About 23% of the households have the income to afford the two-light 20 W SHS, and about 75% of the households can afford the one-light 10 W SHS.

In calculating the panel and the battery sizes considering the solar panel capacity is designed 10% higher than the average requirement. The depth of discharge for the battery is taken to be 75%.

Load description	Load [W]	Minimum panel size	Minimum battery size AH
2 × 6 W lamp	12	25	26
2 × 8 W lamps	16	32.5	33.5
3 × 6 W lamps	18	36	37

In case of most of the manufacturers, there is a viable minimum size of the deep discharge batteries, which usually ranges above 40AH. Considering the cost of the larger battery, it is more economic to go for systems with panel capacities above 30 W peak.

The day and night cycle, high cost of solar technology due to availability factor and low efficiencies are the two major key factors for non-acceptability of this technology on a larger scale.

Growth of solar home systems in India is encouraging (Fig. 8).

5.1 Factors to be considered for PV panel erection

- PV panels installed in India must have southern exposure. For maximum daily output, PV modules should be exposed to the sun for as much of the day as possible especially during the peak sun hours of 10 am to 3 pm.
- The southern exposure must be free from obstructions such as trees, mountains and buildings that might shade the modules.
- The unobstructed southern exposure must also have appropriate terrain and sufficient space to install the PV system.
- The solar panels are fixed with no sun tracking facility and the charge controller is simple ON/OFF type with no maximum tracking facility.
- Several environments have detrimental effects on the long term performance capability of solar cell arrays like high wind, snow, ice loading, and corrosion by moisture, high temperature and air born contaminants.
- In case of stand alone PV supply for households, each family will be responsible to manage and monitor its own loads within the available source rather than metering every house. This can lead to much better energy management and saving.
- Batteries and fluorescent lights are the two components with the most frequent failures in solar home systems. Protection of the battery can be enhanced by improved charge regulators, which are currently of simple design. To enhance product quality, improved designs of fluorescent light inverters and charge regulators need to be developed

Issues/suggestions/action plan

- (1) A detailed survey has to be made village wise and various alternatives have to be examined for techno-economic point of view so that more realistic view can be taken.
- (2) SPV can be marketed for intensification of household electrification.
- (3) The quality of goods of SPV technology to be improved to make the systems more reliable with minimum standards [4].
- (4) SPV is to be designed to suit the end user requirement and field tested for local use.
- (5) Cost have to be considerably reduced which alone can make it a competitive product in the market.
- (6) Countrywide network for serving the products and supply of spares have to be established.
- (7) Low cost funds and grants from International agencies should come forth to take up SPV to the rural areas.
- (8) Development of sufficient capacity building by way of institutional support, training of rural personnel, implementation models and technical and financial management is essential.
- (9) SPV based hybrid systems can be encouraged to ensure sustained power supply to the consumers.
- (10) Rural electric cooperatives should be restructured to administer and manage decentralized renewable energy systems.

Solar technology shows enormous potential for contributing to the alleviation of social problems. Hardly any other technology is as closely compatible with sustainable development criteria as photovoltaic. Photovoltaic can bring electricity into remote rural areas and raise local living standards.

6. Conclusion

Rural electrification is a 'selective catalyst' to improve agricultural productivity through mechanization and is essential for many rural activities. Electrification cannot by itself ensure economic development but it is a necessary but insufficient condition. It works best when it is complemented by social and economic infrastructure development.

- Short-term implementations in next 5 years for immediate improvement

- Medium term implementations in next 5–15 years-technologies that can potentially achieve improvements relative to current technology
- Long-term implementations in next 15–30 years – Proven technologies that could reduce net energy costs and reduce emissions, leading to sustainable development [5–7].

A combination of short, medium and long-term strategies helps the policy makers to plan and implement the programmes for sustainable rural electrification, with emphasis must shift from energy consumption to energy services. According to the Renewable-Global-Status Report 2006 Update, about 2.5 million households across the world, reportedly use SHS. In India, 5 lakh SHSs have been deployed till December 2007. Recent programs are showing good results but more promising new approaches need to be tested to determine if they can address poverty, equity, environmental and public health concerns in the context of on going global restructuring of energy industries. Time will tell, but the indicators are promising.

There is a vast scope for utilizing of solar photovoltaic energy in India. With continuing R&D and cost reduction it can become the most potent energy source. With a clear renewable energy policy in place, India is the forerunner in this sector. There is room for manufacturers, foreign investors, local financial and institutional agencies and others. Solar energy can be one of the thrust areas due to its accessibility through the country in sufficient quantity. For we owe it to ourselves and our children to provide for sustainable development with due regard to our ecology. Renewable energy is nature's resource and we must use it for human kind in consonance and harmony with nature.

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