Kargil. The Ladakh region is spread over 86 904 km^2 area.

Climate

Ladakh lies in the rain shadow side of the Himalaya and experiences both arctic and desert climates, as a result of which it is often called the 'Cold Desert'. The main features of this cold desert are wide diurnal and seasonal fluctuations in temperature with -40 °C during winters and +35 °C during summers. Annual precipitation is just 10 cm, mainly in the form of snow. Here, air is very dry and relative humidity ranges from 6%–24%. Thus, due to high altitude and low humidity, the radiation level is very high, soil is thin, sandy, and porous, and the entire area is devoid of any natural vegetation. Irrigation is mainly through channels from the glacier-melted snow. Rainfall in the area is almost negligible and the average snowfall is between 2–5 m in the villages. The variation in altitude variation affects the local climate. The region has more than 300 sunny days in a year and because of a thin atmosphere, solar radiation is as high as 6–7 kWh/m^2.

Leh district

Leh is one of the two districts located in Ladakh, the other being the Kargil district to the west, in the state of Jammu and Kashmir. India is bound on the north by the Ghanche district, a small border with Xinjiang, China, via the Karakoram pass, which is part of the district. Aksai Chin and Tibet is to the east; Kargil district to the west, and Lahul and Spiti to the south. Leh, with an area of 45 110 km^2, is the largest district in India in terms of area and lies between 32 ° to 36 °N and 75 ° to 80 °E longitude. Leh is divided into six blocks, namely Leh, Khaltse, Nyoma, Durbuk, Nobra, and Kharu.

Leh's climate

Leh has a cold, arid climate with long, harsh winters from October to early March, with minimum temperatures well below the freezing point for most part of the winter. The town gets occasional snowfall during winters. The humidity level is high with a year-round availability of good solar radiation.

Table 1 Climatic parameters over the Ladakh region

Months	District-Leh			District-Kargil		
	Ambient temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Ambient temperature (°C)	Relative humidity (%)	Wind speed (m/s)
January	-21.1	73.8	6.3	-17.6	76.0	5.5
February	-19.3	73.3	6.3	-15.9	76.6	5.5
March	-15.7	74.8	6.2	-12.2	78.0	5.4
April	-11.3	76.1	5.4	-7.6	77.9	4.9
May	-6.0	71.2	5.3	-2.5	70.6	5.0
June	0.3	62.0	5.4	3.9	60.1	5.2
July	5.0	58.2	5.2	8.1	57.7	5.2
August	5.0	60.3	5.1	7.8	61.7	5.2
September	0.7	56.8	5.5	3.8	57.8	5.3
October	-6.9	55.1	5.7	-2.8	54.8	5.2
November	-14.0	61.4	5.9	-9.8	61.6	5.3
December	-18.7	70.2	6.5	-15.3	71.5	5.7

Source RETScreen Database

Kargil district

Kargil district is situated between 30° to 35 °N latitudes and 75 ° to 77 °E longitudes. It is surrounded by Baramulla, Srinagar, and Doda districts in the south-west, Leh district in the east, Himachal Pradesh in the south, and Pakistan in the north-west. The district is divided into four, high-level natural valleys, namely the Suru Valley, the Drass Valley, the Indus Valley, and the Upper Sindh Valley of the Kanji Nallah Valley. The Zojila and the Fotulla passes situated at heights of 3567 and 4192 m above sea level, respectively, are called gateways to the Kashmir Valley, Leh district, and Kargil district. The whole district has high rocky mountains, and arid desert; is snow bound, and devoid of natural vegetation. It occupies a unique position because of its high altitude—8000 to 23 000 feet above the sea level. The topography

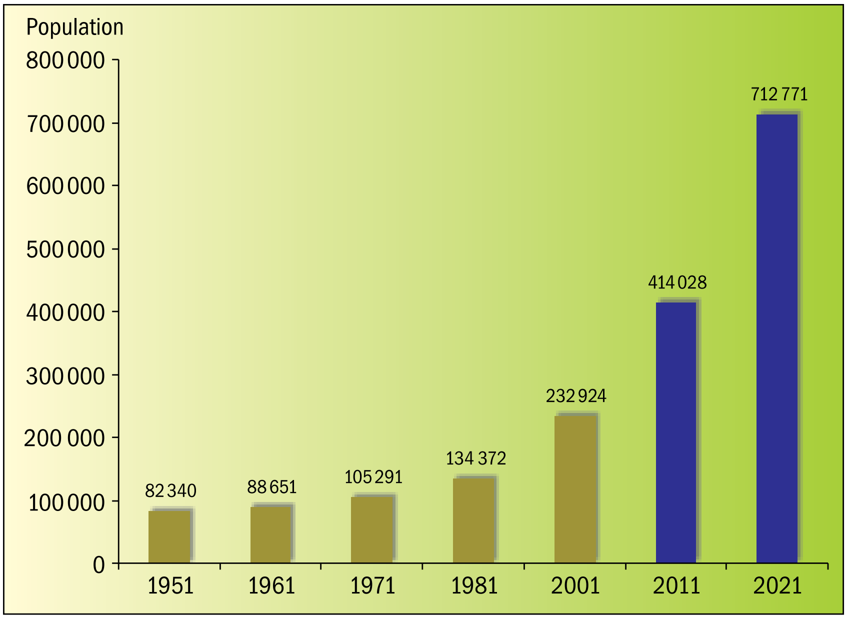

Figure 2 Projected increase in population

of the region is mountainous with little or no vegetation.

Kargil's climate

In Kargil, the summers are warm with cool nights, while winters are long and cold with temperatures often dropping to -40 °C. During winters temperatures drop to -60 °C in Drass, which is situated at about 56 km from the Kargil town. The Zanskar plateau is even colder, thus, making it a near-uninhabitable place for human habitation, except for the hardy Khampas. Table 1 gives a detailed account of the climatic condition of the Ladakh region.

Demography

The population of Ladakh region is 270 126, as per Census 2001. On the basis of the last 50 years data, it has been projected that the population of Ladakh region will increase up to 414 028 by 2011 and 712 771 by 2021, as given in Figure 2.

Population of Leh district

Leh district has a population of 1 17 232 (88 593 rural and 28 693 urban), as per Census 2001. There are 24 147 households (HHs) in Leh district, out of which 6580 are urban and 17 567 are rural, and the average family size is five. The population growth has been observed to be 30.42%, from 1991 to 2001, for this district. It has been estimated that the population of Leh will increase by 206 954 in 2011 and 352 305 by 2018, if the same trend continues.

Leh district has been sub-divided in to six blocks; out of which, the Leh block is the most populated and contains about 53% of the total population of the district. Further, 15% of the population lives in Khalsi, 15% in Nubra, 7% in Nyoma, 6% in Kharao, and 4% in the Durbuk blocks, respectively. There are 113 villages in the district, out of which 112 are inhabitated .

Population of Kargil district

The population of Kargil district is 119 307, as per Census 2001. The projection shows that the population of Kargil district will increase by 207 100 by 2011 and 360 515 by 2018. Kargil is sub-divided into two tehsils, namely Kargil and Zanskar; which are further sub divided into seven blocks. Kargil tehsil has a population of 107 138 (10 657 urban and 96 481 rural); while 12 169 people live in Zanskar. Kargil is the most populated area of the district, followed by Sankoo and Shargole. About 22% of the population of the district lives in Sankoo, 10% in Drass, 9% in Shargole, 8% in Shakar-Chiktan, and 7% in Taisuru blocks.

There are 17 146 HHs (2065 urban and 15081 rural) in the Kargil district. The Kargil region has 14 879 HHs, and the Zanskar region has 2267 HHs. There are 129 villages in the district, out of which two villages are un-inhabitated.

House use pattern of the Ladakh region

In the Leh district, 52 165 houses have been covered in the census. In the Kargil district, there are 38 043 houses covered in the Census. Table 2 shows trhe house use pattern in the Ladakh region.

Table 2 House use pattern of the Ladakh region

Category	Leh	Kargil
Total	52 165	38 043
Occupied	43 695	33 611
Residential	22 059	13 304
Residence-cum-other uses	777	3390
Shops/office	3333	2298
Schools	401	449
Hotel/lodges	209	137
Hospitals/dispensaries	167	151
Factory/sheds	502	300
Places of worship	544	934
Other non-residence uses	15 703	12 648

Energy scenario in the Ladakh region

The energy consumption scenario of the Ladakh region indicates that the per capita energy consumption of the region is about 8.17 kWh per day. The per capita energy consumption in the rural and urban areas is equal to 7.7 kWh and 12.85 kWh per day, respectively. However, the annual electricity consumption per capita in the Ladakh region is less than 150 kWh. The average per capita consumption of electricity in India was estimated to be 704 kWh during 2008/09. Obviously enough, this is fairly low when compared to similar trends in some of the developed nations such the US (~15 000 kWh) and fast emerging economies like China (~1800 kWh). The world average stands at about 2400 kWh. The Ladakh region has not yet been connected to the central power grid of the country and, thus, remains totally dependent on hydropower and diesel generators (DG). The installed power capacity of the Ladakh region is 20.89 MW, through diesel and hydro. The present unrestricted demand for power in Ladakh is 58.53 MW (which includes 20 MW for a defence establishment). At an annual rate of increase of 7%, this requirement is set to touch 94 MW by the year 2010 and 140.5 MW by 2025.

Energy use pattern

Energy consumption in the region is divided into the following five categories—domestic, industrial, agriculture, commercial, and transportation. The energy consumption in the domestic sector (HHs) accounts for more than 90% of the total energy consumption of the region. Remaining 10% energy is distributed to meet the energy needs within the industrial, commercial, and agricultural sectors. The power consumption in other sectors remains relatively small. It has been observed from data collected from secondary sources that the energy use pattern of the Ladakh region is predominantly oriented towards the utilization of thermal applications. This is mainly because of the climatic conditions of the region. In case of domestic energy supply; cooking and space heating constitute two major applications. These consume more than 95% of the total energy demand of the domestic sector. However, lighting is the most important energy requirement to connect the people with the modern channels of sustainable development.

Fuel use pattern

It has been noticed that fuel wood, dung cakes, kerosene, and LPG are amongst the major fuels used for cooking; within which, fuel wood and dung cakes constitute almost 85% share of the fuel used. Space heating in the rural areas is mainly done with the help of fuel wood, dung cake, coke, and kerosene; however, in the urban areas it is done with the help of LPG or diesel. In contrast, the hotels in this region use firewood and FO for space heating. Domestic lighting is being met through electricity, kerosene, and solar energy. There are almost 93% HHs, which own LPG connections within the city of Leh. As against this, the number of LPG connections in the Kargil district is more than 20 000. The consumption pattern of LPG in the remote areas mainly varies in accordance with the season.

There are a total of 474 hotels and restaurants besides 382 commercial establishments in the Leh district, while 204 hotels and restaurants and 46 commercial establishments are located in the Kargil district. Most of the commercial enterprises subscribe to the power generated by the Power Development Corporation (PDC). The energy consumption for the commercial sector of Leh is higher than that recorded for Kargil, mainly because the Leh district has a comparatively well developed tourism sector.

The Leh district does not have any heavy industrial users of electricity, barring two clinkering units and two flour mills; while the other industries are all minor consumers. Kargil has a sizable industrial sector. In 2004, it had 424 small-scale industries. Out of which, 256 industries are located in Kargil alone. However, just about 50 industries receive electricity from the Power Development Department (PDD). The other industrial units have their captive generation capacity varying between 5–25 kW. The average kerosene consumption for the industries is estimated at about 250 kilolitres.

Energy requirement in the defence establishments

Being the border region, there is deployment of large platoons of Indian Armed Forces and Indo Tibetan Border Police (ITBP) in the region. Defence establishments scattered all over the Ladakh region require continuous and reliable supply of energy. The major power supply to this sector is with the help of DG sets. The present connected load to meet the power needs of the army is approximately 10 MW; which is likely to increase to 20 MW by 2020.

Table 3 Category of HHs by the fuel available for cooking in the Leh district

Type of fuel used	Total HH	Rural HH	% of total HH	Urban HH	% of total HH
Total	23 362	17 298	74.04 %	6064	25.96 %
Firewood	4416	4342	98.3 %	74	1.7 %
Crop residue	321	290	90.3 %	31	9.7 %
Cowdung	1195	4481	99.7 %	14	0.3 %
Kerosene	2081	1178	56.6 %	903	43.4 %
LPG	11 903	3895	57.9 %	5008	42.1 %
Others (coal/electricity/ biogas)	146	112	76.7 %	34	23.3 %

Table 4 Category of HHs by the fuel available for cooking in the Kargil district

Type of fuel used	Total HH	Rural HH	% of total HH	Urban HH	% of total HH
Total	10 706	14 616	87.49%	2090	22.51%
Firewood	9069	8642	95.3%	427	4.7%
Crop residue	210	188	89.5%	22	10.5%
Cowdung	3734	3733	100.0%	1	0.0%
Kerosene	1401	815	58.2%	586	41.8%
LPG	2183	1140	52.2%	1043	47.8%
Others (coal/electricity/ biogas)	109	98	89.9%	11	10.1%

Electricity generation

Presently, the total installed power generating capacity in the Leh district is 13.19 MW; out of which 5.5 MW is through (16 Nos.) diesel gensets and 7.7 MW (5 Nos.) through hydropower plants. Igo Marchellong (3 MW), Stakna (4 MW), Hunder (0.4 MW), and Bazgo (0.3 MW) are the main operational SHP projects in the Leh district. The total electricity demand, mostly for domestic lighting in the Leh district, has been reported as 59 MW.

The total installed power generation capacity in the Kargil district is 7.7 MW; out of which 4.45 MW is through diesel and 3.25 MW through hydro power. Iqbal (1.5 MW), Haftal (1 MW), and Marpachoo (0.75 MW), are the main operating SHP projects in the Kargil district. There are two ongoing SHP power projects in each district—Dumkhar (0.50 MW) in Leh and Sanjak (1.26 MW) in Kargil. Hydel power has the major share (>64%) in the total installed capacity, whereas 34% electricity is generated through DG sets in the Kargil district. The share of solar power is limited to just about 2%. During 2003/04, the total electricity consumption in Kargil was 127 17 thousand units. It has been observed that the domestic sector of Kargil is the major energy consumer and consumes about 66% of the electricity, followed closely by the commercial sector and the defence establishment.

Electrification

Out of 112 villages in the Leh district, 98 villages have been electrified. However, out of 98 electrified villages, 65 villages have been electrified by hydro/diesel and 33 villages by solar energy. Likewise, out of 127 villages in the Kargil district, 106 villages and 76 hamlets were electrified till 2004. Maximum number of villages of this district has been electrified by hydro/diesel. Out of the electrified areas of the Kargil district, it has been observed that Kargil is, thus, electrified—64% by hydel power, 34% by diesel, and rest 2% by solar energy

Electricity distribution

The generation and distribution of power continues to be one of the potential dimensions of development in Ladakh. These two vital functions are controlled by two organizations—PDC and PDD. PDC handles power generation; while the PDD oversees transmission, distribution, and maintenance of power units. The electricity supply across the district is not metered. A flat charge of about ₹50 per month is levied for the lowest slab of supply, with a connected load of 250 W per HH. Commercial establishments have a different tariff structure with a minimum connected load of 120 W, for which they pay about ₹70.

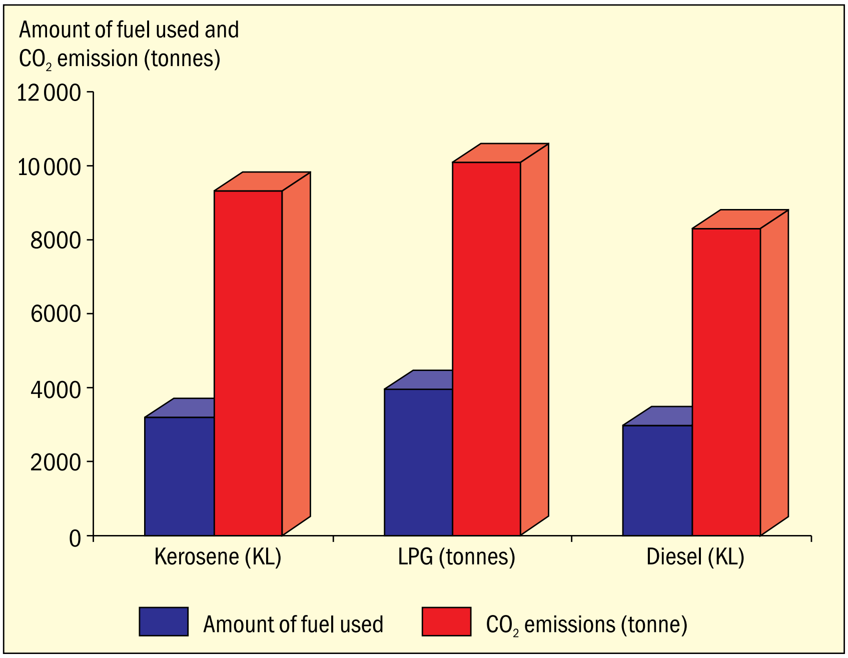

Figure 3 Amount of fuel used and CO_2 emitted

Overall energy consumption and distribution

The energy dependence of the Ladakh region is mainly on diesel, kerosene, biomass, LPG, and hydro power sources. A small amount is met through solar energy as well. It is observed that the annual cumulative energy use is about 174 503 thousand units; which is mainly within the residential sector for varied applications like cooking, space heating, lighting, and so on. Table 4 shows the fuel supply pattern of the Ladakh region.

From the hydro (7.8 MW)-and diesel (13.34 MW)-based power plants, the annual electricity generation is 23 310 000 kWh. Out of which, 16 695 thousand units were generated by hydro and 6615 thousand units by using diesel during the year 2007/08. The diesel used for power generation costs more than 100 million per annum with its annual consumption being reported as 3 million litres . This is given in Figure 3.

GHG emission

In all, the energy dependence of the Ladakh region is mainly on kerosene oil, LPG, and diesel. In order to estimate the associated GHG emission in the region, hydro, and biomass have been considered as being the key renewable energy sources. Based on the data received from secondary sources, presently the GHG emissions of the region are equivalent to 27 729.66 tonnes; out of which 9323.2 tonnes is contributed by kerosene oil, 10 087 tonnes by LPG, and 8616.2 by diesel. On the basis of these findings, the per capita GHG emission has been estimated as 78.7 kg/year; which is very small as compared to the national average (that is 1.9 tonnes of CO_2 emission reported for the year 2000).

Table 4 Fuel supply pattern of the Ladakh region

Type of fuel	Kerosene oil (KL)	LPG (Cylinders)	Biomass (Units)
Annual consumption	3951.79	229 371	126 202 000
Energy consumption (kWh)	19 419 840	28 881 600	
Source LAREDA, Leh			

2020 scenario

Taking the present rate of population growth of the Ladakh region (7.77% annual), it has been estimated that the population of the region will increase by 811 915. Assuming the business as usual (BAU) scenario of energy use, it has been estimated that the kerosene consumption will increase by 20 749 kilolitres, LPG by 16861 tonnes, and diesel by 15 752 kilolitres by 2020 , as shown in Figure 4. However, it has been estimated that the associated per capita GHG emissions will increase by 173.3 kg/year by 2020. As observed, based on the present growth rate, the annual GHG emissions will increase to 145 599 tonnes, annually.

Solar energy over the Ladakh region

Being a tropical country, most of the region in India receive good sunshine, and the number of clear sunny days in a year is also quite high. The country receives solar energy equivalent to more than 5,000 trillion kWh per year. The daily average global radiation is about 5.0 kWh/m^2 in the north-eastern and hilly areas, about 7.0 kWh/m^2 in the western regions and cold desert areas, with the sunshine hours ranging between 2300

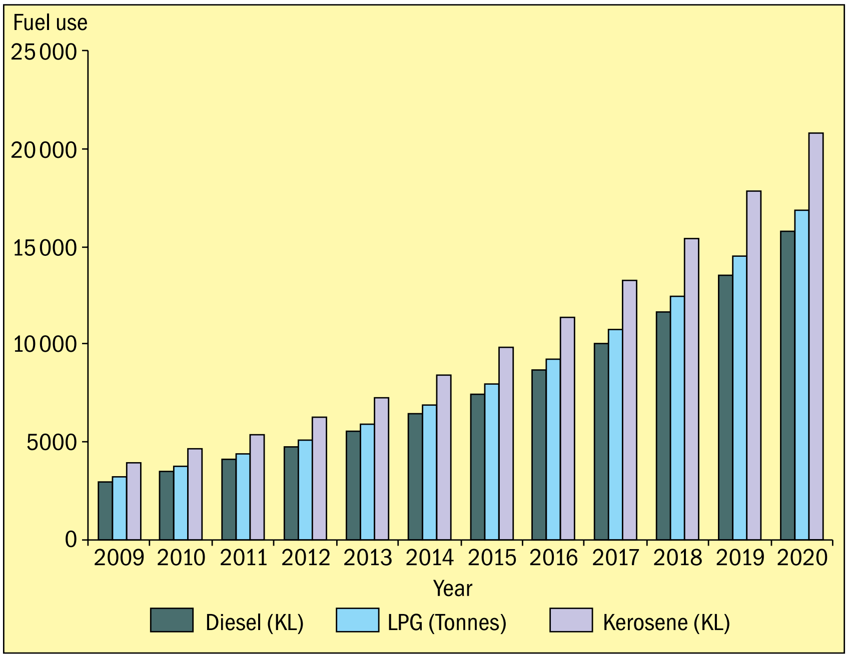

Figure 4 Estimated rise in fuel consumption

and 3200 per year. The Ladakh region is located in the 'cold and sunny' climatic zone of India and receives more than 300 clear sunny days, annually. The frontier locations receive global solar radiation as high as 6–7 kWh/m^2, annually, which also contains a small amount of diffuse solar radiation. The energy use pattern/habits, resource availability, and increasing energy demand are deemed as good indicators for the Ladakh region in its increasing shift towards solar energy use. Table 5 and 6 indicate daily and monthly solar radiation over Leh and Kargil—the two major regions of Ladakh, respectively.

Solar radiation over Leh

Leh is located at 34.17 °N 77.58 °E. Its average elevation is 3500 metres and average annual rainfall is 90 mm. As the location has a high visibility and low dust cover, the intensity of incident solar radiation is very high. The operating conditions (high solar irradiance and low ambient temperature) of Leh are the best recommended ones for solar photovoltaic systems. The location receives very less rain and experiences low cloud cover. The diffuse fraction of the solar radiation is low and, hence, the direct component is very high. The annual average global solar radiation over the region is about 5.90 kWh/m^2. It has been estimated that the annual global solar radiation availability over Leh is 2149 kWh/m^2—direct 1453 kWh/m^2 and diffuse 695 kWh/m^2 on a horizontal surface. Table 5 depicts solar radiation over Leh.

Table 5 Solar radiation over Leh

Months	Daily solar radiation (kWh/m^2)			Monthly solar radiation (kWh/m^2)		
	Global	Diffuse	Direct	Global	Diffuse	Direct
January	3.33	1.41	1.92	103.2	43.6	59.6
February	4.29	1.77	2.52	120.1	49.6	70.5
March	5.35	2.26	3.09	165.8	70.0	95.8
April	6.71	2.48	4.23	201.2	74.4	126.8
May	7.61	2.61	5.00	235.8	80.9	154.9
June	8.39	2.27	6.11	251.6	68.2	183.4
July	7.99	2.45	5.54	247.7	76.0	171.7
August	7.17	2.46	4.71	222.4	76.3	146.1
September	6.79	1.60	5.19	203.7	47.9	155.8
October	5.44	1.33	4.12	168.8	41.2	127.6
November	4.26	1.00	3.26	127.8	30.0	97.8
December	3.25	1.20	2.05	100.8	37.2	63.6

Source RETScreen and METEONORM

Solar radiation over Kargil

Kargil is located at 34° 30′ N, 76° 13′ E and lies in the 'cold and sunny' climatic zone of India. As the location has high visibility and low dust cover, the intensity of incident solar radiation is very high. Besides, rainfall is very less; hence, the area receives good solar radiation over the year. According to National Aeronautics Space Administration surface meteorology and solar energy data source, the pattern of solar radiation is consistent over the year and the fraction of diffuse solar radiation is low. It has been observed that the annual global solar radiation availability over Kargil is 1725 kWh/m^2—direct 1150 kWh/m^2 and diffuse 575 kWh/m^2 on horizontal surface (Table 6).

Quite clearly, the entire Ladakh region receives good amount of solar radiation. Worldwide, the locations that receive annual direct normal insolation (DNI) of more than 1800 kWk/m^2 are generally recommended for housing the large-scale solar power plants. Thus, Ladakh is also suited for large-scale concentrating solar power (CSP) projects; and for decentralized parabolic dishes to obtain process heat.

Solar technologies used in the Ladakh region

Solar energy technologies are very important for the Ladakh region as

Table 6 Solar radiation over Kargil

Months	Daily solar radiation (kWh/m^2)			Monthly solar radiation (kWh/m^2)		
	Global	Diffuse	Beam	Global	Diffuse	Beam
January	2.67	0.94	1.73	82.8	29.1	53.6
February	3.33	1.25	2.08	93.2	35.0	58.2
March	4.17	1.67	2.50	129.3	51.8	77.5
April	5.05	2.06	2.99	151.5	61.8	89.7
May	5.95	2.29	3.66	184.5	71.0	113.5
June	6.81	2.24	4.57	204.3	67.2	137.1
July	6.55	2.21	4.34	203.1	68.5	134.5
August	6.04	1.97	4.07	187.2	61.1	126.2
September	5.53	1.50	4.03	165.9	45.0	120.9
October	4.59	1.06	3.53	142.3	32.9	109.4
November	3.42	0.84	2.58	102.6	25.2	77.4
December	2.52	0.84	1.68	78.1	26.0	52.1

electricity demand is distributed and decentralized. At present, solar passive houses and solar PV-based home-lighting systems, SK-14 type solar cookers, and evacuated tube collector (ETC) based solar water heaters are amongst the most adapted solar energy technologies in the Ladakh region. Following applications for commercial and domestic use, where solar energy can play an important role, have been recognized.

Solar home lighting systems (HLS)

Solar HLS is powered by solar energy using solar cells that convert solar radiation directly to electricity; which is stored in batteries and used for the purpose of lighting whenever required. These systems are useful in non-electrified rural areas and as reliable emergency lighting system for important domestic and commercial applications. The system comprises of the solar PV module, charge controller, battery, and lighting system. The solar module is installed in the open on roof/terrace, exposed to sunlight and the charge controller and battery are kept inside a protected place.

Large-scale grid-connected solar power plant

SPV systems have several advantages that make it suitable for rural electrification and decentralized energy supply. Solar PV modules usually do not have moving parts and operate silently without hazardous emissions, and are expected to have a long life with little maintenance. Solar PV-based electricity generation is one of the most promising renewable energy technologies, which could be useful for lighting, water pumping, refrigeration, battery charging, and so on.

Solar water pumps

It has been observed that groundwater is available at a depth of 150 feet, below the ground. The solar powered water pumps can be of a great boon for the people of Ladakh, for pumping water, both for drinking as well as for irrigation purposes. The solar water pumping system is a stand-alone system operating on power generated by using the solar PV system. The power generated is used for operating DC surface centrifugal mono-block pump set for lifting water from bore/open well or water reservoir for minor irrigation and drinking water purposes.

Solar water heaters (SWH)

The most widespread application of solar thermal energy so far, has been to heat water. The SWH technology, as currently available, is based on the use of flat plate solar collectors, which are produced indigenously. Traditionally, the simple flat plate solar collector is used for the application, but nowadays evacuated tubular collectors (ETC)-based SWH systems have been commercialized worldwide. ETC-based solar collectors comprising of copper heat pipes are best suited SWH technology for the Ladakh region; which can tolerate the extreme weather of the region (-40 °C). A 100-litres capacity SWH can replace an electric geyser for residential use and save 1500 units of electricity, annually. The use of 1000 SWHs of 100-litres capacity each can contribute to a peak load saving of 1 MW.

- A SWH of 100-litres capacity can prevent emission of 1.5 tonnes of CO_2 per year
- Operating life is 15–20 years
- Approximate cost is ₹15 000–20 000 for a 100-litres capacity system
- Payback period 3–4 years when electricity is replaced.

Solar cookers

Solar cookers are commercial solar products, used in many parts of the world. India has large solar cooking units for community cooking. There are various types of solar cookers; but in line with the cooking habits of Ladakh region the best recommended solar cooker is SK-14; which is essentially a parabolic solar cooker used for frying (>250 °C). Also, the concept of community cooking is very feasible for defence establishments; which can directly replace a large amount of diesel and LPG. The community solar cooker can cook all types of food for about 40–50 people and can save upto 30 LPG cylinders in a year with optimum use.Cookers with higher capacity may be used, depending on the requirement.

Solar passive buildings

Passive solar buildings aim to maintain interior thermal comfort throughout the sun's daily and annual cycles, whilst reducing the requirement for active heating and cooling systems. Passive solar building design is one part of green building design, and does not include active systems such as mechanical ventilation or PV. The scientific basis for passive solar building design has been developed from a combination of climatology, thermodynamics, and human thermal comfort. There are numerous technologies based on solar passive architecture. Three most important solar passive technologies for the Ladakh region are 1) direct gain 2) trombe wall 3) attached greenhouse; which have already been adopted by maximum HHs in urban areas.

Direct gain attempts to control the amount of direct solar radiation reaching the living space. Trombe wall is a sun-facing wall essentially built from material that can act as thermal mass (such as stone, metal, concrete, adobe or water tanks), combined with an air space, insulated glazing, and vents to form a large solar thermal collector. With the help of these features, heat is collected during the day, and it migrates by conduction through the wall and is released during night.

Solar greenhouses

All greenhouses collect solar energy. Solar greenhouses are designed not only to collect solar energy during sunny days, but also to store heat for use at night or during periods when it is cloudy. They can either stand alone or be attached to houses or barns. A solar greenhouse may be an underground pit, a shed-type structure, or a hoop house. Large-scale producers use free-standing solar greenhouses, while attached structures are primarily used by home-scale growers. Passive solar greenhouses are often good choices for small growers because they are a cost-efficient way for farmers to extend the growing season.

Solar dryers

Solar dryers are used in agriculture for food and crop drying for industrial drying process. From the energy conservation point of view, dryers can prove to be the most useful device. Dryers not only save energy, but also save lot of time, occupy less area, improve quality of the product, make the process more efficient, and protect the environment. Solar dryers circumvent some of the major disadvantages of classical drying. Solar drying can be used for the entire drying process or for supplementing artificial drying systems, thus, reducing the total amount of fuel energy required.

Potential of solar technologies in the Ladakh region

On the basis of the secondary data, literature review, and interaction with NGOs active in this region, it has been observed that for cooking, space heating, and electrification, solar energy technologies can be used. Hence, sizable potential of solar thermal and solar PV technologies exist in this region.

Solar PV technologies

The potential assessment of the following solar PV technologies has been carried out, keeping in mind the electricity requirement of the people of the Ladakh region.

Solar home lighting (HLS) systems

Ideally, each household in the Ladakh region is a potential user of solar HLS. In the present scenario, the electricity availability is only for four hours per day, mainly for lighting. The electricity supply condition in urban areas is more reliable as compared to the rural areas. Thus, in the Ladakh region, 50% of the rural HHs has been taken as a potential case for use of solar HLS. A total number of 20 000 HLS has been identified for the Ladakh region.

Solar lantern

A total of 9000 solar lanterns have been distributed by the state nodal agencies (SNAs), through various schemes of MNRE. A survey may be conducted for analysing the problems and barriers of this particular technology adaptation. Battery replacement after every 3–4 years is deemed as a major issue with unobstructed use of SPV technologies. Hence, a suitable mechanism might be identified for replacing the batteries by offering some incentives.

Solar water pumps

For harnessing groundwater for domestic and agricultural purposes, solar water pumps have proven their worth in the region. So far, 22 solar pumps have been installed in various parts of the region (mainly in the Leh district). Based on the secondary data, about 500 solar water pumps are still required to satisfy the water pumping requirements of the region.

Off-grid PV power plant

Solar energy-based power generation is proposed only in those villages, where there are no hydro reservoirs. Further, there are topographical difficulties to connect with the existing/proposed

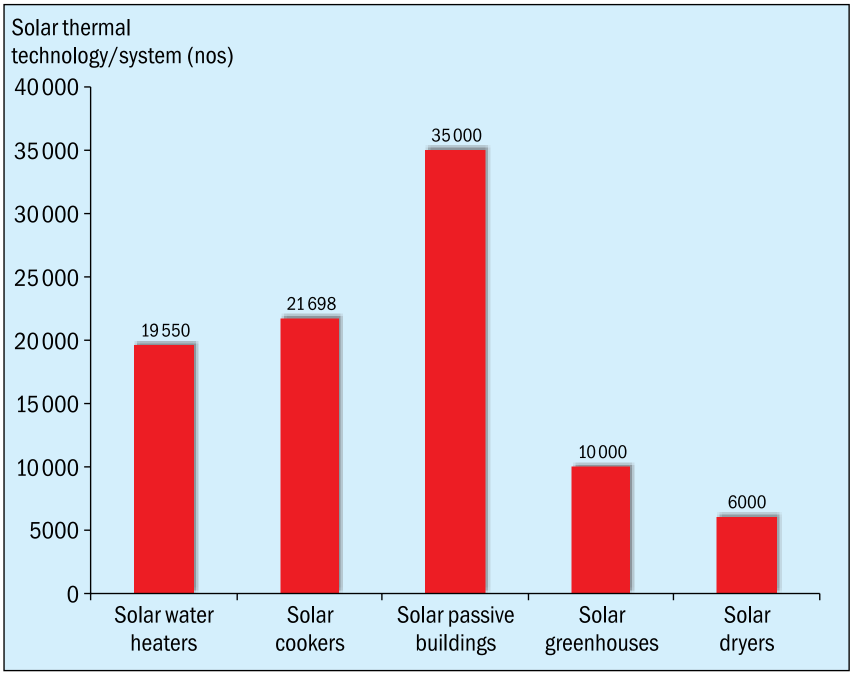

Figure 5 Number of solar thermal systems installed

power grid. The cumulative potential for off-grid projects has been observed to exceed 5 MW (40–50 kW single units).

Large-scale grid-connected solar PV power plant

In terms of resources and climate, the Ladakh region is best suited for large-scale solar PV system use. Grid connected solar power generation could be an optimum solution for the region. It can effectively replace diesel as an existing fuel for power generation. The Leh valley comprises of enough land and already has a transmission and distribution (T&D) network. To begin with, a 20-MW capacity solar PV project could be implemented to satisfy the electricity requirement of the district. Further, similar kind of projects could be implemented in various parts of this region. The MNRE expects that Jammu and Kashmir will generate about 20 000 MW from solar energy by 2020, mostly concentrated in Ladakh region of the state.

Solar thermal technologies

The potential of solar thermal technologies in the region has been identified on the basis of the secondary pro-data and e-information.

Solar water heating systems

Four types of buildings have the potential for applying solar water heating systems in the region, namely residential, hotels/lodges, hospitals/dispensaries, and places of worship. Such systems require water supply from an overhead cold water tank and sunlit space for the installation of solar collectors. Keeping these requirements in view and irregular bathing habits of the people of this region, 50% of the total HHs are considered for the use of SWHs. The per HH capacity of these systems could be 100-LPD. On an average, 1000 LPD systems have been considered for hotels and lodges, to meet the hot water requirements. The hot water demand for hospitals is assumed to be 50 LPD per bed. There appears to be a large variation in the occupancy of places of worship and, therefore, average capacity of systems is taken to be 200 LPD. Taking into account these considerations, a cumulative capacity of about 4 million LPD has been calculated for the Ladakh region excluding the defence establishments.

Solar cooking

Based on the census 2001 data, about 51% HHs in Leh and 13% HHs in Kargil have been provided with LPG connections. Leaving aside these HHs, solar cooking can well be adopted almost in all other HHs. There are two design configurations, which are commercially available, namely SK-14 and steam cooking systems for community cooking application. Keeping in view the family size of about 4–5 members per HH, SK-14 can be used in the rural areas. A cumulative number of about 20 000 SK-14 solar cookers have been estimated for possible use in this region. In addition, about 50 steam cooking systems could be set up in the urban areas and places of worship besides defence establishments.

Solar passive buildings

Noticeably, the practices of applying principles of solar passive heating are quite prevalent in the region. However, these practices have to percolate to the lowest level as well. Theoretically, all the HHs have the potential for adopting these features. A cumulative number of 35 000 houses (22 000 houses in Leh and 13 000 house in Kargil) have been identified as having the potential. This is based on the study of the housing pattern of the region. In addition, retrofitting of the existing houses might be a potential area.

Solar greenhouses

There could be some requirement of commercial green houses for growing vegetables in winter and of solar dryers for drying of fruits and vegetables. Based on the relevant inputs, some NGOs have worked out the available potential. A cumulative number of 8000 solar greenhouses (size of 16 feet x 32 feet) has been identified as potential for the domestic sector. For community purposes, the total potential have been assessed as 2000 (size 18 feet x 100 feet). Presently, few NGOs are installing such kinds of greenhouses in the region.

Solar dryers

In order to improve the quality of locally grown cash crops, dry fruits, medicinal plants/produces, and preservation of the agro produces for long periods of time, solar drying is the best suited approach. Based on the study of ongoing practices and information taken from NGOs and SNA, the potential number has been worked out as 6000 solar dryers in the Ladakh region. The best suited drying technology might be simple cabinet type and convective cabinet type solar dryers.

Solarification of the Ladakh region: the scenario

The region has been accorded sufficient importance by the Government of India vis-a-vis rural electrification and decentralized energy supply. However, because of the increasing energy demand, typical topography, extreme climatic conditions, and technological limitation, the success stories have been limited so far. Hence, a lot more needs to be done for rural electrification and decentralized energy supply. The following are some of the initiatives taken by the Government of India.

Solar rural electrification programme

The MNRE, in coordination with the Planning Commission, had sanctioned a major project entitled, *"Solar Electrification of Villages and Hamlets in Ladakh"* in 2001. This programme got implemented through two nodal agencies, namely Ladakh Renewable Energy Development Agency (LREDA) for the Leh district and the District Development Commissioner (DDC), Kargil, for the Kargil district. Under this scheme, 10 000 solar home lighting systems and 6000 solar lanterns were installed/distributed in 39 un-electrified villages in the Leh district and in 18 un-electrified villages and 27 un-electrified hamlets within the Kargil district. As of now, 7000 HLS are installed in the Leh district along with 5000 SPV lanterns. During 2002/03, MNRE had targeted 4000 HLS and 2400 solar lanterns. Under this programme, 4000 SPV HLS (3600 single module, 400 double modules) have been distributed across 73 villages

of the Kargil district comprising 442 hamlets. In addition, so far, about 2400 solar lanterns have also been distributed in 2400 bunkers.

Off-grid solar PV

The first solar PV-based power plant of 40-kWp capacity came into being at Nyoma in 1999 through the Ladakh Autonomous Hill Development Council (LAHDC). This plant was supplying electricity to two villages having more than 450 HHs. However, the load requirement shot up beyond the capacity of the power plant, due to which, it is now supplying power only to a hospital and a residential school. In 2007, Ladakh Ecology Development Group (LEDeG); a prominent NGO based in Leh, commissioned a SPV power plant at Tangtse, with active support from the India Canada Environment Facility (ICEF), MNRE, and LAHDC. The power plant supplies electricity to 350 HHs and 29 commercial units, for five hours a day. Thus, it has completely replaced the existing 250-KVA diesel generator of the power development department. The diesel generator, besides polluting the otherwise pristine and highly fragile environment, consumed an average of 48 200 litres of fuel, annually.

SunTechnics has installed a PV and wind hybrid system of 50-kWp capacity at Tangtse, Leh. Out of which, 40 kWp comes from SPV and the rest of the 10 kW from wind resource. This plant supplies power to a population of 600 inhabitants living in about 400 barracks. In addition, few academic institutions and NGOs have installed solar PV-based power plants of smaller capacities for captive power consumption.

Solar cooking

The Ladakh region has enough potential for domestic and community cooking. Gadhia Solar Ltd has installed a solar steam cooking system with a capacity to make 1000 meals a day. This suffices the requirement of about 500 soldiers in a unit of the Indian Army in Leh. Prior to this, the army kitchen, at this base, was consuming nearly 50 kg of LPG and 70 litre of diesel daily for cooking. LEDeG distributed more than 300 SK-14 solar cookers in the Leh district alone during 2007/08.

Solar water pumping

Leh has the cumulative installed solar water heating capacity of more than 5000

LPD. ETC-based solar water heaters with heat pipes are the best recommended technology for this region. In order to lift/pump the water, presently 22 SPV pumps have been installed at various locations of the Leh district.

Solar greenhouses

Apart from the above solar technologies and applications, solar greenhouses for agro-production and solar dryers for fruit processing are finding enough acceptance in the Leh area. Two types of solar greenhouse models have been adopted by the residents and communities for the production of vegetable and other cash crops.

Solar passive buildings

As space heating forms a large part of energy use; solar passive technologies are widely accepted in the Ladakh region. Presently, in the urban areas, almost all new houses are being constructed with solar passive features. Three main solar passive technologies are in use in the region—direct gain, insulation (wall and roof), and Trombe Wall. This technology is being promoted by the MNRE and few international funding organizations like European Commission and implemented through various NGOs, mainly GERES, LEDeG, LEHO, and so on. A Group of NGOs led by GERES (a French NGO) is engaged in the Ladakh region to train local rural people (masons and carpenters) to built houses using solar passive concepts. These include a process of insulating the walls and roof besides constructing attached sun-spaces.

Recent initiatives

Based on the detailed studies undertaken in the Ladakh region and after consultations with all the stakeholders, the Ladakh councils in Leh and Kargil, district officials, and NGOs, the MNRE has prepared a plan for the large-scale use of renewable energy with a total financial requirement of ₹4730 million. The plan envisages the build-up of 30 small/micro hydel projects aggregating to 23.5-MW capacity, setting up of about 300 SPV power plants of 5–100-KW capacity, 2000 SPV home lighting systems, and about 40 000 solar thermal systems. The solar greenhouses proposed to be set up in



the region would help in increasing the production of green vegetables during the winters. The implementation was to begin from June 2010, to be completed in December 2013. The renewable energy projects are expected to result in the saving of about 2000 million litres of diesel per year. Ministry of Power, Government of India, is presently setting up two large capacity hydroelectricity projects in both the districts.

- The 44-MW Chutak Hydroelectric project of National Hydroelectric Power Corporation Ltd (NHPC) is a run-of-river hydro project located in the Kargil district.
- 45-MW hydro-electric project on the Indus at Alchi, (70 km from Leh)

In addition, MNRE is also funding small off-grid projects through various schemes with Ladakh Renewable Energy Development Agency (LREDA).

Major recommendations

The Ladakh region is totally isolated from the modern world. A prestine land, it is accustomed to following traditional methods and life is characterized by intense spirituality. Typical geography, income levels, and improvement of human development index are some of the issues, which may be considered towards fixing the subsidy or financial support for dissemination of solar systems in this region/subsidies on solar products/technologies, similar to the north-eastern region of the country.

- Solar home lighting systems are essential for the villages far away from the grid, with discontinuous electricity supply. The single module HLS can be given to the rural HHs and the double module HLS model might be given to the urban and defence establishments, depending upon the purchasing power of an end-user.
- Solar lanterns have the maximum possible potential in the bunkers/remote villages and in defence establishments. The cumulative estimated potential could be targeted by 2012; as the technology is well demonstrated and proven in the region.
- Solar water pumps are quite suitable for the urban areas of the region. Given that the demonstration projects have been successful here, the sectors/areas can be identified for installation of these systems.
- Large-scale solar PV technology based solar power projects of 20-MW capacity might be targeted under the first phase of the recently initiated Jawaharlal Nehru National Solar Mission.
- The issues and barriers facing the Nyoma and Tangste solar power projects could be studied and an exact sizing of the solar power plants, within the 40–50 villages, carried out.
- Keeping in view the low income levels in the rural areas of Ladakh, a special package could be developed to provide up to 90% support for various solar thermal systems, mainly solar water heaters, solar cookers, solar greenhouses, and solar dryers.

Acknowledgements

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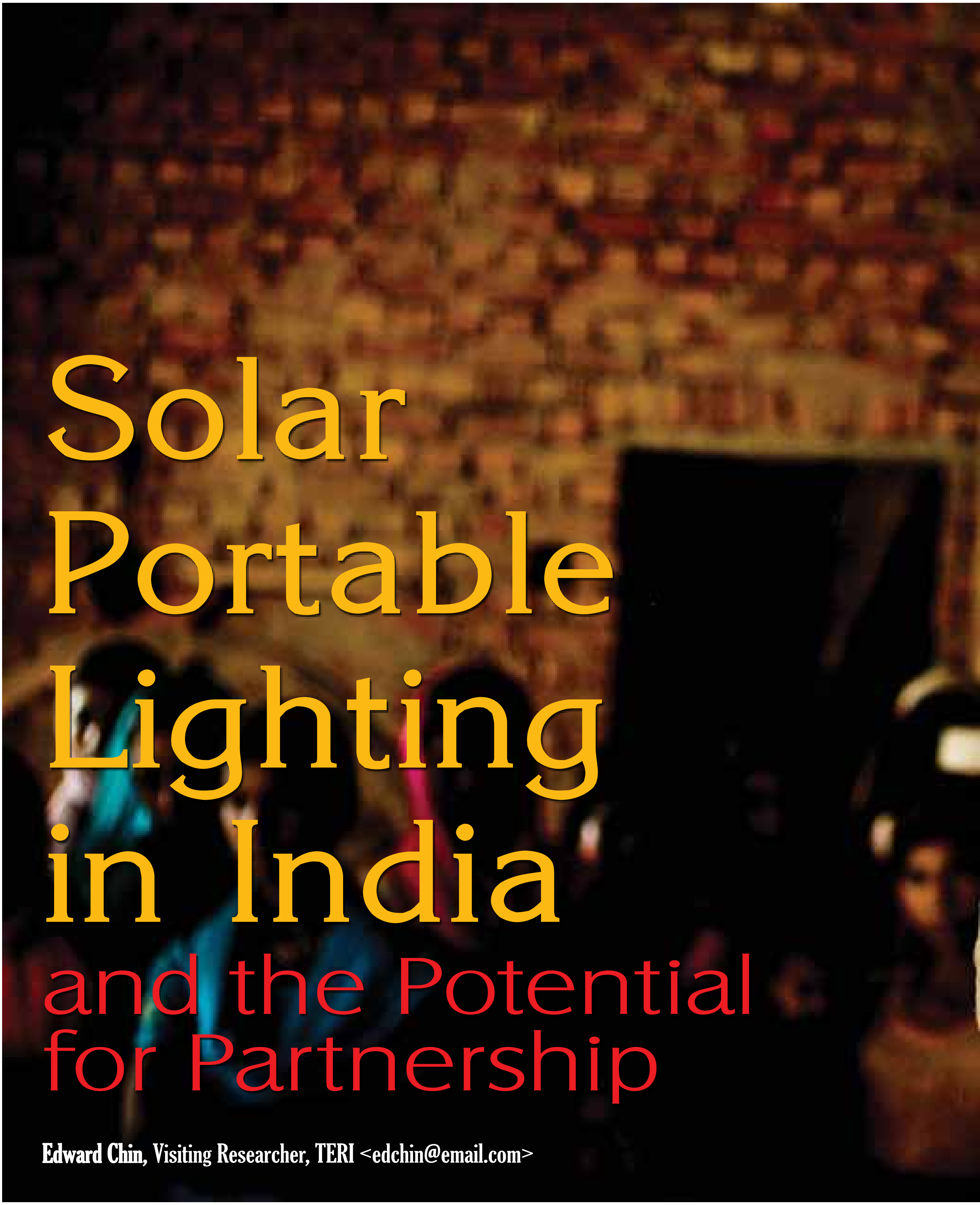

Solar Portable Lighting in India

and the Potential for Partnership

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Courtesy: LaBL, TERI

Background

The Energy and Resources Institute (TERI) launched a campaign—"Light a Billion Lives" (LaBL)—on 7 February 2008. Solar charging stations have since been built in villages across India to offer non-polluting, portable lighting units, commonly known as solar lanterns for night-time illumination. LaBL's goal is to transform the lives of those without any access to reliable electrical lighting. There are 1.6 billion people worldwide, who lack access to electricity, 25% of whom are located in India alone. Of the 76 million Indian rural households that have no access to electricity, 65 million presently rely on kerosene lighting.

LaBL has the twin objectives of taking solar lanterns to the poor rural households that lack the basic access to conventional electricity, and making this service self-sustainable. To achieve these two objectives, LaBL works with several partners to design, develop, and install solar lantern services in the rural areas. It conducts studies to identify suitable villages in which these lanterns should be distributed and collaborates with local implementation partners that carry out the groundwork. These partners essentially link TERI with the local entrepreneur in the village, who operates the charging station and leases the solar lanterns on a day-to-day basis.

LaBL has adopted a "fee-for-service" business model, where revenue from the lease of solar lanterns is used to sustain the service. Although LaBL takes responsibility for establishing the charging station and all other related activities, the on-going operations are expected to be self-sustaining and supported by the fees charged for renting a lantern. Furthermore, villagers or local NGOs are expected to contribute towards the upfront costs of setting up the charging station wherever possible, which ultimately helps to create a sense of ownership and value for the service. This is determined during TERI's scoping study with due diligence process.

Common goal of improving lives with solar lighting

Alongside TERI, other companies such as One Million Lights (non-profit), d.light, and SELCO (both for-profit) have been actively promoting solar lighting across rural and suburban India. It is clear that there is much common ground in the goal of replacing polluting and dangerous kerosene lamps with cleaner and more cost-efficient solar lanterns.

For example, d.light's mission statement is to "enable households without reliable electricity to attain the same quality of life as those with electricity. We will begin by replacing every kerosene lamp with clean, safe, and bright light". Similarly, One Million Lights has a mission to "improve the daily lives of children and adults by providing clean and healthy lighting… distributing solar lights… [to] replace environmentally toxic kerosene lamps."

Ultimately, LaBL is interested in finding the most efficient means of making solar lighting widespread and sustainable, whether directly through its own campaign or indirectly through other ventures.

A challenging business case for all players

Kerosene lighting is an undoubtedly unhealthy solution and a switch to solar would have clear benefits for both the environment and the consumers. A solar lantern with a lifespan of 10 years is able to displace about 500–600 litres of kerosene, thus mitigating about 1.5 tonnes of carbon dioxide. With solar lanterns, there are also no risks of burning and health problems afflicted from the burning of kerosene. In terms of light quality, even low-end-specification solar lanterns produce brighter light than a kerosene lamp. In the long-term, a solar lamp is also cheaper than a kerosene lamp.

However, despite clear long-term advantages to the consumers, the complete business case for adopting or switching over to solar lanterns remains economically unviable for a significant proportion of the market. Cash flow is the key issue here. The upfront costs required to set-up a lantern service or to purchase a lantern act as a significant barrier to a widespread adoption of solar lighting. Also, the cost of technology remains very high, as do the various cost components of getting the lantern from a factory to the consumer, such as marketing and distribution.

LaBL financially supports the adoption of solar lanterns by subsidizing the upfront costs required to establish a solar lantern service, which would otherwise be economically unviable for many villages. To ascertain whether the service would be valued and sustained, due diligences are carried out at villages before the charging stations are built, which involves considerable time and expense. As and where the villagers can afford, they contribute a proportion of the upfront fees, primarily to ensure that there is a sense of value for the service being rendered to them.

The strong potential for partnership

A partnership between LaBL and other ventures, particularly an increasing number of for-profit companies focusing on India, could benefit all parties. Where agreed, LaBL's expertise and assets could be used to extend the outreach and efficiency of for-profit companies. LaBL has developed a detailed understanding of regions in India, where studies have been conducted and solar recharging stations have been installed. In these regions, it has also worked to inform villagers of the various benefits of using solar lanterns, which is a vital and expensive process in increasing their widespread adoption. It also has a valuable distribution network in place through local NGO partners and already-developed solar recharging stations across India.

Moving forward, for-profit companies will most likely have a strong influence on the pace and extent to which LaBL will be able to achieve its goal of widespread and sustainable solar lighting. In particular, they are well positioned to address the commercial issues, which currently act as major barriers to the adoption of solar lanterns. For example, they have been encouraging innovation in product development and consumer financing, which is resulting in better lanterns and more options for villagers to buy them. They also provide strong after-sales service, increasing the sustainability of their products and encouraging satisfied customers to recommend their products, which results in future growth in sales.

The market for solar lighting in India is vast and many regions still remain unreached; competition for customers is currently a minor issue compared with the challenges from distribution costs and overall economic viability. Therefore, a partnership between LaBL and other solar lighting distributors could allow

Courtesy: LaBL, TERI

combined expertise and strategic focus to help improve upon product quality, while also continuing to bring down the technology related costs. Furthermore, it could help to increase marketing, widen distribution networks, and enhance after sales services, all in a more cost-efficient manner.

LaBL has commissioned 28 997 solar lanterns across 281 villages spread over 15 Indian state. However, to increase the momentum towards its ultimate goal of lighting a billion lives, a further catalyst is required. This catalyst could come from partnerships with for-profit companies who are also working to increase the adoption of solar lighting in India, albeit with a different business model. Through collaboration, one can reach more number of people in lesser time and with greater efficiency. Such a partnership would also have clear benefits for the for-profit companies, which otherwise continue to face considerable challenges in this difficult market.

Social ventures: successes till date and challenges ahead

Exciting social ventures have been launched to sell solar lanterns to populations without reliable electrical

power supply. They have achieved some notable successes so far. For example, d.light has attracted awards and headlines across the globe for its work, which focuses on the Indian market. Founded in 2008, it reached 100 000 people in eight countries in its first year of operations itself. In 2009, its reach quintupled to 500 000 people in 28 countries. It estimates that nearly a million people now uses d.light solar lanterns and claims to be profitable within the next two years. It has ambitions to sell 10 million lanterns by 2010 and 100 million within the next decade. Another player, the Solar Electric Light Company (SELCO), was founded in 1995 to provide sustainable energy solutions and has since sold, serviced, and financed 100 000 solar systems.

However, despite these initial successes, for-profit companies face significant challenges ahead. Three barriers to their future growth have been identified.

Affordability: providing upfront investment for energy schemes (currently most schemes funded by angel investors, foundations, social VC funds, and donations)

Distribution: developing and maintaining necessary distribution systems and infrastructure to enable them to reach sufficient scale

Solar awareness: educating rural populations about the improvements made in solar technology and accompanying benefits from switching to solar lighting

The majority of target consumers for solar lanterns have a very low income and limited savings, which makes the financing of new lanterns a major barrier to its widespread adoption. Most for-profit companies sell (rather than rent) solar lanterns and they are increasingly collaborating with the microfinance institutions to support those who are unable to self-finance the purchase.

However, the cost of replacing kerosene lamps with solar lanterns still remains prohibitively high for most of the market, despite admirable innovations in the microfinance support. Microfinance institutions are overcoming initial obstacles, such as high cost per transaction, lack of assets for collateral amongst the debtors, and fear of high rates of loan defaults. Nevertheless, in most of the cases, the cost of deposit for micro-financing loans is still too high; restricted cash-flow and lack of savings prohibit the purchase of solar lanterns.

Although there are successful microfinance case studies (for example, the "telephone lady" pioneered in Bangladesh), the microfinance case for solar lanterns present some new practical challenges. In Bangladesh, women used microfinance loans to buy mobile phones, selling access (call-time) to the fellow villagers. This immediate source of income is then used to repay the loan. However, an investment made in a solar lantern takes more time to pay-off, even while considering the savings made from not having to purchase kerosene. Furthermore, there is often no actual income from the lamp.

While analysing the suitability of the microfinance model for solar lanterns, two types of use should be considered: first, household use that generates no additional income from lantern use and second, commercial use that enhances productivity and generates additional income. For the former, the high price of lanterns still prohibits majority of the market to purchase a lantern. The primary problem of cash flow is well summarized in an interview with SELCO CEO Harish Hande, "some people could promise to put away ₹10 a day… but not ₹300 a month." Required upfront deposits of 15%–25%, required by the regulations of the Reserve Bank of India (RBI), are unaffordable to most. On few occasions, for-profit companies have received grants or charitable donations to pay for the deposits. However, for those who do not benefit from this, the percentage of the total household expenditure on light would increase, even if, only in the short-term. This would be unfeasible or at least unattractive for the consumers.

For the households that are able to generate additional income from the purchase of a solar lantern, microfinance could be a possible solution. This additional income could be used to pay an on-going cost of the loan (interest and loan repayment). Also, depending on the size of the additional income, the increased productivity could pay for the entire on-going microfinance payment. For-profit companies using the microfinance model have often targeted this specific segment of the market. For example, SELCO states, "we begin with the precept that the solution must not be paid for from the existing income of the person. It must extend it." Even so, the lamps required to sufficiently extend the productivity and income of its users are of higher-specifications and are more expensive. Solar lanterns can replace kerosene lamps as a source of light that enables shops to stay open after sunset. However, even the top-end commercial lanterns are not yet luminous enough to allow detailed production activity such as weaving to continue.

The high distribution cost is also a major hindrance for the for-profit companies that are working to extend their outreach. The highest demand for solar lighting comes from the dispersed rural populations living in small villages across an entire sub-continent. In this market, distribution channels for any consumer product are scarce and expensive to develop. Furthermore, these costs of distribution are necessarily passed on to the consumers in a for-profit business model. This effectively limits the size of the market that for-profit companies can viably address. Therefore, the reduction of distribution costs is a major concern for the for-profit companies looking to extend their reach and achieve greater growth.

Finally, the awareness of the new solar lighting products needs to be raised amongst the rural population. Solar technology products have been present in India for the last several decades. However, in the beginning, these products suffered a poor reputation of having high cost and low quality. The reality today has changed dramatically and robust lighting products are now available at lower prices. Potentially skeptical rural populations need to be made aware of this progress, but for-profit companies often lack the resources and, in many cases, the established reputation required to carry out this task. To encourage a higher growth rate in the solar lighting market, it will be important to increase awareness regarding the product quality and provide clear explanations of the benefits (financial and others) of switching to solar lighting.

The specific benefits of partnership

LaBL's mission to light a billion lives is unconstrained by restrictions on product vendor types and specific business models. Every lantern sold by for-profit ventures works towards the ultimate target of a billion lives. It is, therefore, in LaBL's interest to develop partnerships that support other solar lighting ventures in extending their reach and expanding the market. Benefits gained from these partnerships, for example, through improved efficiencies, would be passed-on to the consumers.

LaBL continues to have a highly important role to play, in its own right, alongside for-profit companies. At least the short-to-medium term, for-profit companies will focus entirely on commercially viable populations with an ability to pay; owing to which, this target market will be limited in size. The International Finance Corporation (IFC) suggests that prices must fall below $5 before lanterns become universally affordable, but the cheapest solar lamps currently in the market are from $10 onwards. Furthermore, populations in the remote villages may simply be beyond the economically viable range of the for-profit companies. Outside the commercially viable market, there still lie numerous poorer villages with high kerosene consumption, thereby indicating considerable demand for the solar lantern. There are benefits in supporting such populations to make the much needed transition from kerosene lamps to solar lanterns. LaBL's current programme works to provide this support and should continue to do so.

In the meantime, LaBL can also support for-profit companies in overcoming major challenges. The following steps can be taken.

Lower distribution costs: leading to lower costs of operations for for-profit companies, which would be able to pass on savings to consumers through inexpensive solar lanterns. In a partnership, LaBL could make its distribution channels (currently in 281 villages) available to the for-profit companies for selling their solar lanterns. For-profit companies would gain access to an existing charging station and a population that would already be well-informed of the benefits of solar lighting. Consumers would then have a choice between renting or purchasing a lamp.

Courtesy: LaBL, TERI

Improve awareness amongst the rural populations: enhancing the reputation of solar lighting products and, thereby helping to increase the demand. TERI, and by association LaBL, has a strong reputation, particularly given its established relationship with the Indian government. Rural populations can be relatively confident that LaBL will have a long-term presence with quality assurances for its products. TERI could help to educate the villagers across India about the benefits of solar lighting. Furthermore, for-profit partners who sell their solar lanterns through the LaBL stations could potentially gain the endorsement of TERI.

Improve economies of scale: lowering the unit costs of lanterns. This could be supported through LaBL's continued work in the field, subsidizing the costs of setting up the solar lantern services through grants and charitable donations, even where populations lack the ability to pay for the up-front costs. The LaBL campaign would, therefore, continue to increase solar lantern demand from manufacturers and, thus, improve the economies of scale.

Improve research and development efficiency: leading to better products at lower prices. Although LaBL does not manufacture lanterns directly, it performs valuable tests in-field and gathers data, which often supports manufacturers to design product specifications. A partnership could support for-profit companies to focus on their research and development and efficiently develop new products at lower prices. Furthermore, LaBL could potentially lead the way in developing and reviewing government-approved standards for solar lanterns, which ensure that products meet a certain level of quality while remaining affordable for the rural population.

The sharing of LaBL's distribution channels should benefit all the concerned parties. It would, thus, increase the total number of solar lanterns actually deployed in the field and help LaBL towards realizing its long-term goal of lighting a billion lives. Although there is a theoretical possibility that for-profit companies will cannibalize the LaBL solar lantern market, this should be unlikely in most the cases as demand continues to outstrip supply in areas where LaBL initiative is present. The LaBL solar charging stations are currently limited to servicing of approximately 50 lanterns, each.

Introducing the option to purchase lanterns, alongside TERI's rental model, is likely to be appealing for some consumers. The strong aspiration to ownership suggests that as and when villagers can afford to, they would replace their rented lantern with a purchased one. This aspiration is likely to exist not just for the success-status reasons, but also for convenience. By purchasing a lantern and solar panel, consumers could avoid making time-consuming visits to the solar charging station. If, LaBL lantern users increasingly purchase lanterns, more rental lanterns could be freed-up for the use of those, who do not have adequate financial provision to acquire a lantern. The sale of lanterns on the LaBL sites (primarily solar recharging stations) should, therefore, increase the usage of solar lighting.

Managing a partnership

Details of partnership arrangements need to be carefully conceived and managed. LaBL's local entrepreneurs need to be thoroughly trained and must understand both the short-term and long-term strategies in renting and selling solar lanterns. There could be a temptation to focus on selling high-priced lanterns, which achieve larger profits per lantern sold, but the number of people who can afford this will be limited. It is, thus, essential to grow the market for solar lighting for a long-term success. This growth will most likely be achieved primarily through a rental service, which seems to be more affordable to the rural populations. Therefore, partnerships will have to be carefully managed to ensure that LaBL's goals are achieved alongside those of the potential for-profit partners.

To further support the growth of the solar lighting market, for-profit companies could be asked to pay a commission on lanterns as sold through the LaBL distribution channels. This would be contributed towards the fund used for expanding the LaBL campaign in economically less viable villages. Details would have to be negotiated with the partners, but the commission charged should be below the level of distribution costs that for-profit companies would otherwise have to pay. Therefore, both sides would still gain from a partnership; LaBL from the greater reach of solar lighting and a new regular revenue source to further develop its campaign, and for-profit companies from an extended market reach and lower distribution costs. LaBL could use the fund to subsidize more villages where the demand is high but ability to pay is currently low. With possible economic development in these villages, these subsidized charging stations will in time provide new distribution points for the for-profit companies, when purchasing the lanterns becomes feasible.

Improving business, quality of life and the environment

Partnership between LaBL and for-profit companies could, therefore, act as a catalyst to accelerate the adoption of solar lanterns in more number of villages across India. By improving efficiencies and lowering costs for for-profit companies, the addressable market for solar lantern purchases will grow. In the meantime, LaBL will continue to extend its campaign to more villages, with the help of the financial support from for-profit partners through commission based payments. In this vast market with considerable growth opportunities alongside significant challenges present, collaboration through partnerships will benefit all players, the consumers, and ultimately the environment.

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A rural family in Chikanpada uses an average of five litres of kerosene per month, or $1 worth at $0.20/litre after government subsidy in India (**Source** *Wall Street Journal*);

d.light's Kiran lamp costs $10 for over 200 months of use (assuming 50 000 hours life of LED, eight hours use per day, 30 days per month), which is just $0.05 per month or 5% cost of a kerosene lamp.

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MAPPING SOLAR FOR TECHNO-ECONOMIC FEASIBILITY

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Background

Imagine generation next taking advantage of scientific revolution such as Google Maps, also reaping rich dividends from an enhanced use of renewable energy technologies. Society has strong expectations from scientific institutions to evolve energy maps similar to the Ministry of New and Renewable Energy (MNRE) solar map as well as the The Energy and Resources Institute (TERI) solar map. Renewable energy will be accessible to a wide range of end-users as never before. There are federal tax credits, cheaper photovoltaic (PV) systems in the market, and hefty rebates that make the return on investment more attractive, for exploring different applications of renewable energy. The solar map of an Indian city can be similar to San Francisco and Boston, but it will be larger and play another role. Figure 1 shows the solar map of India. "The key difference in this map versus others is that India is looking to partner with NGOs like TERI or a private company in a Public Private Partnership (PPP) mode on the backend of the map". The uniqueness of this method lies in the fact that the city planners and government can utilize it to plan where best to integrate solar on the grid. It may be helpful in planning new substations in an ever-growing city. But, shifting through this stack of information can often be daunting, so officials entrusted with city sustainability issues are simplifying the process by rolling out solar maps online. This is a way to make it much more tangible for the public. The more we can streamline the process, the greater is the likelihood of expanded solar utilization.

Routing the renewables

Renewable energy sources are the key to a sustainable energy supply infrastructure, since these are both inexhaustible and non-polluting. Renewable energy technologies, relevant to the Indian continent, are now commercially available, the most notable being wind power, PV, solar thermal systems, biomass, and various forms of hydraulic power. These technologies provide cost-effective solutions as efficient sources are integrated within the plant schematics. So far, various models have been proposed for optimally allocating different types of renewable distributed generation (DG) units in the distribution system. The underlying rationale is to minimize the annual energy loss. The methodology is based on generating a probabilistic generation-load model that combines all possible operating conditions of the renewable DG units with their probabilities, hence, accommodating this model in a deterministic planning problem. The planning problem is formulated as mixed integer non-linear programming (MINLP), with an objective function for minimizing the system's annual energy losses. However, these models have constraints, which mainly include the following.

- Availability of the hourly sources
- Voltage limits
- Feeders' capacity
- Maximum penetration limit
- Discrete size of the available DG units (within a legal framework)

Methodology

The mapping is addressed to the energy demand and the potential energy resources. Data were collected based on sampling field-based work and survey conducted in 2007 and 2010. The activity not only covers renewable energy for specified area, but also its inhabitant distribution pattern. There are three typical regions, based on their potential energy sources. Each region has a specific source of the energy to be focused on. At the foot of the mountain, the work is focused on potential

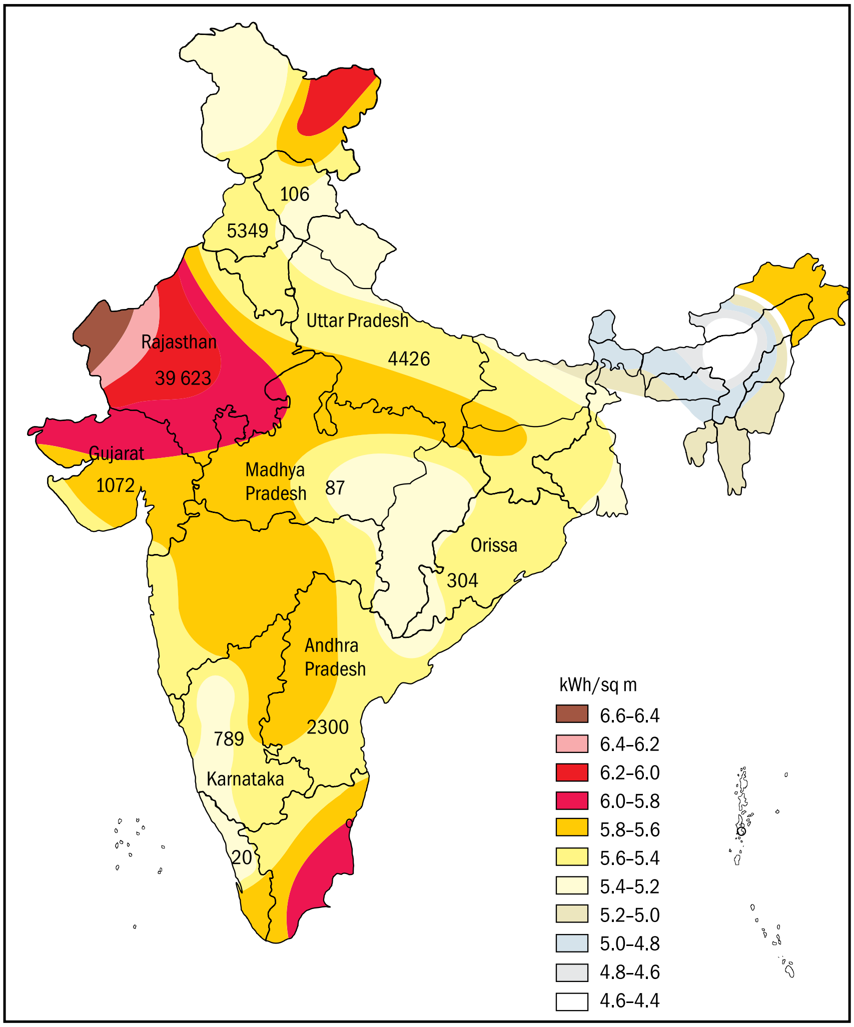

Figure 1 Indian solar map
Source MNRE, India

hydropower and geothermal sources. In the plains, it focuses on estimating biomass production from plantations and agricultural waste. In the coastal region, the potential of wind and solar are the main energy sources to be explored. This mapping is, supposedly, capable of furnishing accurate data about renewable energy diversification distribution all over the province.

Solar energy maps that indicate the wide-ranging spatial distribution of solar irradiation are required by the researchers of solar power systems. However, the irradiation measurement networks at the ground level are often not enough to obtain reliable information of solar energy distribution in the world. On the other hand, Geostationary Meteorological Satellites (GMS) may provide the images of cloud fields over the whole surface of the earth. The main cause of an irregular change in the irradiation at the ground level is due to the clouds; therefore, the methods for estimating the irradiation by using the GMS images may be very useful.

The ionosphere plays an important role in the earth's environment, because it controls, limits, and often threatens the performance of terrestrial and space-based radio systems. Adequate understanding of the variability of ionospheric electron density has witnessed long-standing efforts of the ionospheric scientific community. The ionosphere displays variations on a wide range of temporal and spatial scales. The global data sets and analytical tools at the National Renewable Energy Laboratory (NREL) and, specifically for India, at the Centre for Wind Energy Technology (C-WET) permit modelling and wind resource predictions that do not need to rely on country-supplied data. In many regions of the world, reliable surface wind data is sparse and, thus, often not available for pursuing the desired areas of interest. However, the use of upper-air (weather balloon) and satellite-derived wind data in an advanced computer mapping system enables the NREL to produce wind resource maps with valuable information, even if high-quality surface wind data may not be available. The reliable surface wind data is useful in providing ground validation of the model predictions.

Model distributive generation system (DGS)

To solve the two impending energy investment-related planning problems—transmission and fluctuation—of renewable energy development, we propose a long-term investment planning model. It can help analysts, investors, and policy-makers to find out how to make full use of both the existing and emerging technologies to support the development of renewable energy. This is to reform the energy infrastructure and make it cleaner and greener in the long run. The model, based on parallel planning method for power systems, requires a large region to be partitioned into multiple sub-regions. Each sub-region is modelled as two optimization models.

- One is an hour-level model with the objective to minimize the power price volatility caused by imbalance in the demand and supply of power and CO_2 emission at an hourly basis.
- Second is a year-level model with the objective to minimize the investment cost of transmission, operation, and fossil/clean power capacity expansion at an annual level.

Specific model-based understanding

The year-level model also needs to satisfy the RPS (Renewable Portfolio Standard) requirements, because it is a yearly policy. We use an energy storage system to store any surplus clean power, for example, wind power, and this helps solve the fluctuation problem of wind energy. The stored energy is allowed to be traded amongst the neighbouring sub regions. All models are linear or mixed linear programming models and, thus, need to satisfy conditions of fossil/clean power capacity expansion and available clean energy.

The goal is to foster rational thinking in complex decision-making situations related to environmental problems, by studying the physical laws underlying environmental phenomena. This work provides a background for an engineering researcher to learn and achieve a scientific understanding of important environmental issues concerning pollution and mitigation. There is an urgent need to comprehend not only the physical and chemical principles underlying a process, but also to translate this understanding into a mathematical formula, solve the resulting equations, and interpret/apply the results towards process improvement with requisite engineering interventions. The field of mathematical modelling has made significant progress, both in terms of techniques of modelling and the ability to handle complex models. Thus, today, it is possible to reduce the actual experimentation to minimum and obtain the required information through numerical experimentation on the mathematical model. Figure 2 shows an integrated energy model.

In tune with virtually all fields of engineering design today, the trend is towards more digital prototyping and computer-based evaluation-cum-testing, before a commitment is made to time-consuming and expensive production of either scale models or full-size physical prototypes of components or systems. Nevertheless, a point comes when physical tests -become necessary, so the emphasis today is on using digital technologies to streamline the testing, in order to minimize the time required for testing and subsequent data analysis.

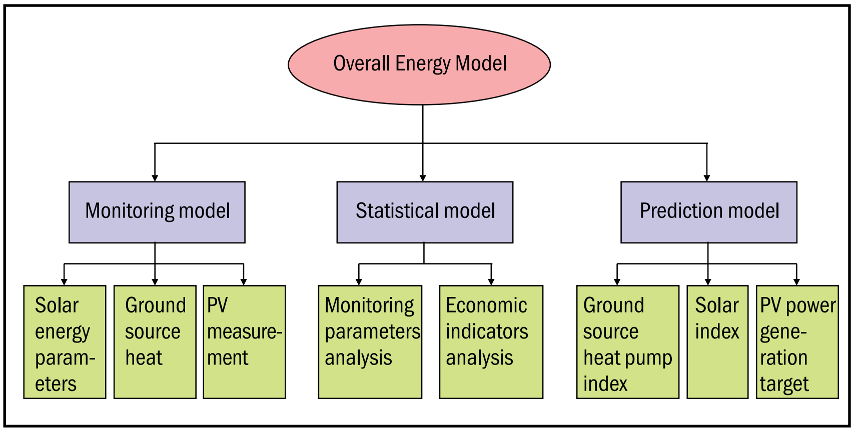

Figure 2 Intergrated energy model

The end-use realization

The available models have been designed to target the following requirements of the DGS.

- Analyse the situation, decide the data collection strategy, and enunciate methodology on new and renewable energy sources.
- Collect and collate the relevant data required for modelling.
- Apply conceptual modelling for the design of integrated systems like input on energy sources for the design of hybrid power plant to exploit maximum renewable energy sources at a reasonable price.
- Either apply proposed models or develop mathematical models for simulating environmental impact.
- Generate different scenarios so as to arrive at an effective-environment management plan with a view to support the decision-makers.

The company outlook

One of the companies at the forefront of digital modelling and testing is National Instruments. Having progressed from its roots in virtual instrumentation, this company now has a powerful software for modelling, simulation, and control functions. For example, National Instruments Labview and the Labview Control Design and Simulation Module can be used to simulate a full wind turbine system, including the turbine, mechanical drive train, generator, power grid, and controller. The Control Design and Simulation Module provides a numerical simulation environment that enables the users to test the model.The Control Design and Simulation Module can be used to analyse the interactions between hybrid mechanical-electrical systems. The quality of existing models can be improved and other control strategies investigated by simulating deep-bar induction generators and more complex models of drive trains.

Mapping the potential

The maps, many of which are partially financed by the MNRE programme, have simplified the process of mapping the solar potential. After entering an address, users are presented with a bird's-eye view of the location and a box with tailored information, including roof size and solar potential of the home or business. Cost and energy savings also pop up, with a list of installers and incentives.

San Francisco, USA, developed the first solar map with Citizen's SAFE methodology, which uses a combination of aerial imagery and 3D modelling with an emphasis on sun and shade and obstructions to determine a building's solar potential. The other information is pulled up from various cities, state and federal websites, and databases. It is essentially an aggregated form of incentive-based information that is uploaded into the technology. The mapping makes it easier for people to understand the technologies, costs, and available incentives by providing this one-stop resource.

Summary

The 14.5% hike in rate is the projected hike resulting from the report's "high distributed generation" scenario. It relies mainly on smaller solar projects so as to meet the 33% mandate instead of larger projects and other technologies, such as wind and geothermal power. These happen to be cheaper than solar.

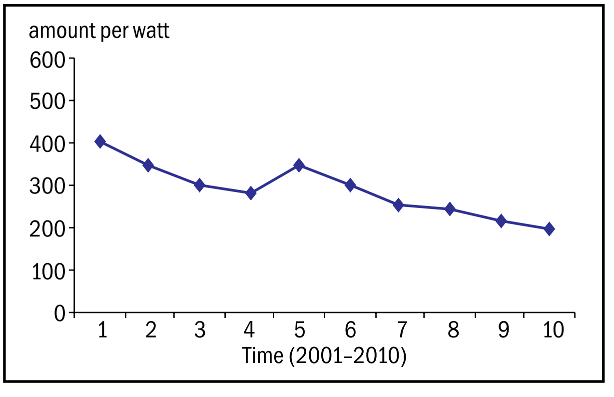

Figure 3 Cost variation of SPV over time

The 33% "reference case" infers that a 7.2% hike in rate would result from this scenario.

More importantly, the report assumes no reduction in renewable energy costs by 2020. This has already been proven wrong because costs for wind turbines and solar panels have dropped in the last couple of years. Solar panel costs, in particular, have plummeted and are projected to fall even further in the coming years. This is mainly because this industry has finally reached a point where global production has increased and the market has become saturated. This is a good outcome for the consumers, but not so good for solar producers competing to achieve the lowest possible prices. The planet may ultimately win in this price battle. Figure 3 depicts the solar buzz analysis of falling module prices, since 2001.

The impact of different instruments to support the market diffusion of renewable energy sources in the electricity sector, in the backdrop of some key policy objectives, has been analysed. Based on the historical evolution of renewable energy sources in the electricity sector (RES-E) in India and Europe, the effectiveness and efficiency of RES-E support have been assessed. The effectiveness of various RES-E support schemes largely depends on the maturity and the credibility of the system. Stable planning is important to create a sound investment climate and to lower social costs, as a result of a lower risk premium. Administrative barriers can have a significant impact on the success of an instrument and, thus, hamper the effectiveness of, in principle, very powerful policy schemes. It has to be mentioned that the different instruments are characterized by a different level of maturity, and policy schemes in some countries. For instance, quota obligation systems, in particular, are still in a transitional phase.

The big policy impacts

For the two main policy instruments currently applied in Europe and India, which are feed-in systems and quota obligations, the main conclusions read as follows.

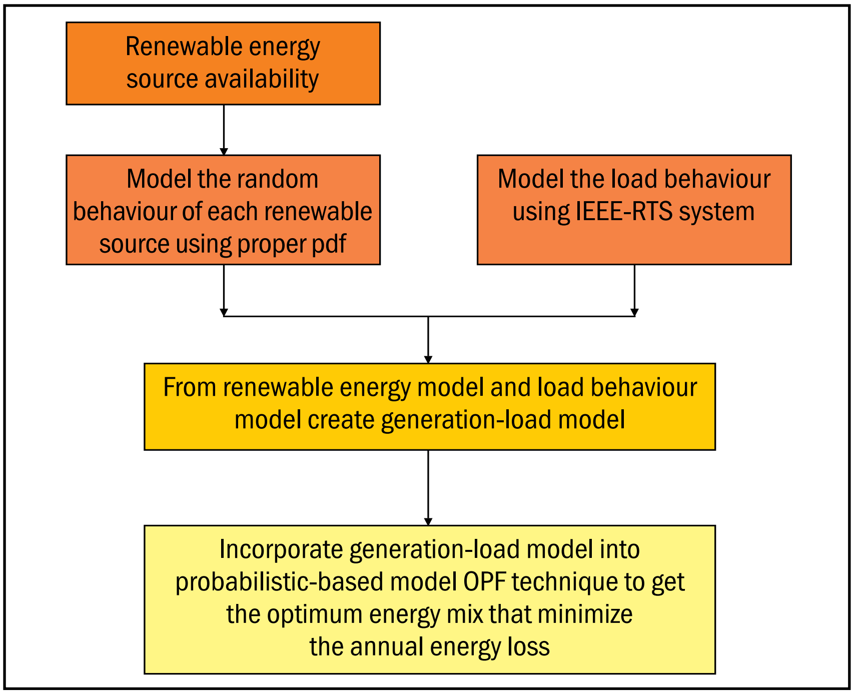

Figure 4 Renewable energy model with load behaviour

Feed-in tariff

Feed-in tariffs have been successful for triggering substantial capacity expansion in most of the countries where they have been introduced. A guaranteed tariff is effective, flexible, fast, and easy to install, besides having low administration costs.

Quota obligation based on TGCs (TGC system)

The ability of quota systems to lead to significant extensions in RES-E generation capacity remains to be proven. Today, the low level of investor security is the main problem with respect to quota systems, with its impact on the effectiveness as well as on the efficiency of support. One important advantage of a quota obligation is that the target can be exactly reached by putting in place enough incentives. Thus, in contrast to a feed-in tariff scheme or a tender procedure, no adjustment is necessary to fulfil the targets.

Summing up the possible outreach

To conclude, it can be said that even if we achieve 33% renewable energy-based deployment by 2020, the renewable energy mandate, mostly in-state solar PV generation, may cost ratepayers a relatively lesser amount by 2020. Simultaneously though, the state will see a significant job growth in the renewable energy industry, reduced greenhouse gas emissions, more efficient homes and vehicles, and probably the largest benefit of ensuring that we continue to take advantage of the boom in renewable energy around the globe. More and more investors and leaders are recognizing that renewable energy is the next big thing to roll in.

The application related to the commercial methodology for acquisition of energy, stemming from the distributed generation mode, enables us to undertake studies and analysis of the sites mapped out. It allows the definition of each site surveyed, the potential for generation and co-generation, with fuels obtained in-house or acquired from external sources, such as waste products and/or hot process gases, calculate the current existing surplus on the site, highlighting any data provided by clients and the result of calculations based on this information for calculating the potential surplus. These would be enabled through an active implementation of cogeneration or generation units driven by waste products or hot process gases.

MAXIMIZING THE OPERATIONAL LIFE OF A GRID-CONNECTED PV SYSTEM

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Background

Most of the grid connected photovoltaic systems (GCPVS) have not been able to achieve the required plant load factor (PLF). This is mainly due to the fact that these are not appropriately designed to realize their optimal operating capacities. In most of the cases under consideration, it has been observed that some salient technical details have not been put in place. And, wherever they have been incorporated, the principles were not monitored as required for an optimal efficiency realization.

However, maximizing the total net economic benefit achieved during the operational lifetime period of a GCPVS can be achieved by the following.

1 The optimal number
2 Type of system devices
3 The optimal values of the photovoltaic (PV) module installation details

Introduction

The decision variables to be included in an optimization process should mainly include, but not be limited, to the following.

1 The optimal number
2 Type of the PV modules
3 The DC/AC inverters
4 The PV modules optimal tilt angle
5 The optimal arrangement of the PV modules within the available installation area
6 The optimal distribution of the PV modules among the DC/AC inverters

The economic viability of the resulting GCPVS configuration must be evaluated by considering the following.

1 Net present value
2 The discounted payback period
3 The internal rate of return method

The main target of any GCPVS design will be to maximize the total economic benefit achieved by selling the PV generated energy to the locally available electric grid.

Decision factor

An important factor that needs to be considered for optimizing the GCPVS is the optimal value of its sizing ratio, which is the ratio of the nominal power capability to the DC/AC inverter nominal power rating.

Important components

The maximum power point tracking (MPPT) operation is used in order to extract the maximum available power from the PV power source.

The optimal GCPVS sizing ratio value minimizing the total system cost will be affected by the following.

1 Site specific solar irradiation
2 The DC/AC inverter efficiency

Methodology for the GCPVS optimal sizing

The best way to merge the technical and the economic goals is to employ a strategic technical approach relating to the voltage stability and ruggedness of the grid, into which the PV generated power will be fed. This is because of an unpredicted and unstable nature of the energy production, which largely depends on the availability of the solar energy.

Also, in the existing scheme of things, the revenues accrued from the sale of the produced energy to the system network, along with the maintenance and cost of the feeder power, is of importance.

Operational cost of the GCPVS design method

The operational and economical differences amongst the various PV module and DC/AC inverter types are related to the following few parameters.

1 The PV module tilt angle
2 The cost of the land required to install the GCPVS
3 The cost of the mounting structures for modules
4 The maintenance cost

The proposed methodology

The following are the methods to evaluate whether the total number of the GCPVS modules and the PV module installation details are satisfactory or not.

1 The available installation area dimension limitations guarantees the feasible allocation of the available PV modules among the DC/AC inverters, according to the technical constraints imposed by the PV modules and the DC/AC inverters specifications
2 To evaluate whether the optimization procedure maximizes the GCPVS total net profits, as achieved during the active life of a PV system .

The GCPVS modelling

Assumptions

1 Energy produced by the GCPVS modules is supplied to the electric grid and it is calculated on an hourly basis, for a year.
2 The calculated annual GCPVS energy production is constant during the full life span of a PV system.

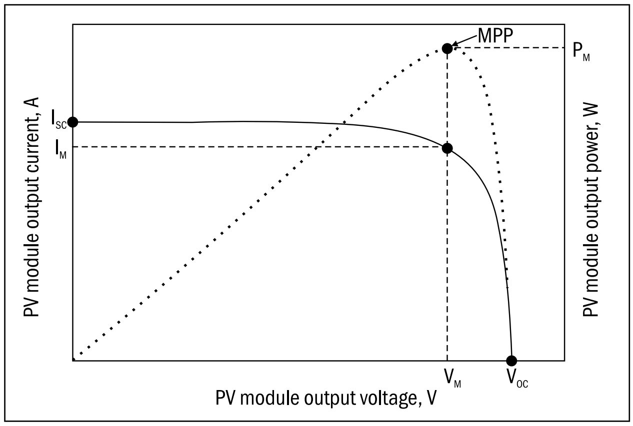

Figure 1 PV module current-voltage and power-voltage characteristics

Arrangement of modules

The arrangement of the module is very important to effectively utilize the available solar energy radiation available at a given site. The maximum power and fill factor of the modules are equally critical to understand the variations that exist within the panels, when subjected to the same environmental conditions.

The fill factor is also very important to consider, as it happens to be different for crystalline silicon, amorphous silicon, and few other cell production technologies. In order words, these values are practical values, which can be determined easily and verified with the PV manufacturers.

The following are the other important parameters.

1 Open circuit voltage characteristics
2 Short circuit current characteristics
3 Maximum voltage
4 Maximum current
5 Maximum power
6 Air mass spectrum
7 Efficiency of the DC/AC inverter

The above conditions are summarized in the following equations.

$$FF = \frac{P_M}{V_{oc} \times I_{sc}} \quad \text{...(1)}$$

$$I_{sc(t,\beta)} = [I_{sc,STC} + \alpha_t [T_c - 25°C]] \frac{G(t,\beta)}{1000W/m^2} \quad \text{...(2)}$$

$$V_{oc} = V_{oc,STC} + K_v [T_c(t) - 25°C] \quad \text{... (3)}$$

$$T_c(t) = T_A(t) + \frac{NCOT - 20°C}{800 W/m^2} G(t,\beta) \quad \text{... (4)}$$

I_{SC} (t,) = PV module short current (A)
V_{oc} (t) = Open circuit voltage (V)
I_{sc} (t) = PV module short-circuit current under STC (A)
G(t,β) = Global irradiance (W/m²) incident on the PV module placed at tilt angle β
K_I = Short-circuit current temperature coefficient (A/°C)
V_{OC}, STC = Open-circuit voltage under STC (V),
K_V = Open-circuit voltage temperature coefficient (V/°C)
T_A(t) = Ambient temperature (°C)
NCOT = Nominal cell operating temperature (°C) as provided by the PV module manufacturer
FF(t,β) = Fill factor

$$N_{series,min} = \frac{V_{imin}}{V_{M,min}} \quad \text{... (5)}$$

$$N_{series,max} = \frac{V_{imax}}{V_{ocmax}} \quad \text{... (6)}$$

Where

1 V_{imin} and V_{imax} are the minimum and the maximum permissible DC/AC inverter input voltage levels (V) specified by the DC/AC inverter manufacturer
2 V_{ocmax} and $V_{M,min}$ are the maximum open-circuit voltage (V) and the minimum voltage (V) at the maximum power point (MPP), respectively.

Cable specification

$$N_{s,min} \leq N_s \leq \frac{P_{max}}{P_{M,max}} \quad \text{... (7)}$$

The value of N_s should be set equal to N_{smax} in order to reduce the power loss in the cables that connects the PV module to the DC/AC inverter.

Where,

P_{Mmax} (W) is the maximum possible PV module output power level at the MPP, according to the incident solar irradiation and ambient temperature conditions prevailing at the GCPVS installation site.

Modules and inverter arrangement

The maximum number of the PV module related parallel branches connected to each of the DC/AC inverter, N_{pmax}, depends on the PV modules and the DC/AC inverter nominal power ratings, and it is calculated using the following equation.

$$N_{pmax} = \left(\frac{P_{max}}{N_s P_{M,max}} \right) \quad \text{... (8)}$$

In order to fully exploit the power capability of each DC/AC inverter, thus reducing the total number DC/AC inverters required are minimized alongside the maximum possible number of PV modules.

Applied equations and conditions of optimized model of the mounting structure

The required distance between the adjacent rows of the GCPVS installation should be kept constant, according to the designed specification, under all conditions. The dimensions of the actual installation area, which is practically used to install the target GCPVS can be calculated, according to the total area requirements of each row and the spacing between the adjacent rows.

However, the dimensions of the total available installation area impose an upper limit on the values of each row and their spacing as described above.

Optimized model of the mounting structure

The PV modules mounting structure should be constructed using metallic rods or based on any strong structure that can withstand the strong wind effect, so that the tilt angle does not vary during such occasions. Further, the estimation of the corresponding cost is based on the calculation of the total length of the metallic rods, as required for the installation of the target GCPVS.

The mounting structures used to install the GCPVS PV modules are comprised of multiple, identical mounting structures.

Also, the intermediate vertical rods should be installed at all those points where the row vertical height has been increased by 2 m.

The PV modules metallic mounting frames, however, may be installed on concrete foundation bases. The total length of the metallic rods can be calculated and used to optimize an overall system gain.

The total manufacturing and installation cost of the GCPVS mounting structures

$$C_B = B\,c_S + B_B\,c_B \quad \text{... (9)}$$

Where

c_S (₹/m) = per unit length cost of the metallic rods

c_B (₹/m³) = per unit volume cost of the concrete foundation bases

B = total length of the metallic rods required for the installation of the entire GCPVS

B_B = total volume of the concrete foundation bases required to support the GCPVS module metallic mounting frames

The value of c_S depends on the following.

1 Required thickness
2 Type of the construction material of the metallic rods

It is usually specified by the system designer at the beginning of the GCPVS optimal sizing procedure according to the following.

1 The weight of the PV modules supported
2 The typical environmental conditions, for example, humidity, air moisture salinity, and so on, possibly cause corrosion on metallic substrates as prevailing at the GCPVS installation site.

GCPVS net profit maximization using GAS

The decision variables used during the GA optimal sizing procedure are the following.

1 The total number of GCPVS modules
2 The number of PV modules lines comprising each GCPVS row
3 The PV modules tilt angle
4 The optimal total number of the GCPVS DC/AC inverters
5 The optimal allocation of the available PV modules among the DC/AC inverters

The objective function that is maximized during the optimization procedure

The GCPVS total net profit function J(x), which is equal to the difference between the following.

1 The present value of the total profits achieved from selling the produced energy to the electric grid during the system operational lifetime period—PE(x)
2 The sum of the total capital—Cc(x)
3 Maintenance cost—Cm(x)

$$\max_x \{J(x)\} = \max_x \{P_E(x) - C_c(x) - C_m(x)\} \quad \text{... (10)}$$

Where,

x is the vector of the decision variables listed above.

The total net profit achieved during the GCPVS operational lifetime period

It depends on the following.

1 The amount of energy generated by the GCPVS modules
2 The price at which the energy produced by the GCPVS is sold to the electric grid

However, it does not depend on the following.

1 The price at which the electric grid customers purchase the electric energy
2 Grid operator in order to fulfil their energy requirements
3 The corresponding load profile

Total capital cost

The total capital cost Cc(x), is calculated as follows.

$$C_c(x) = (1-s)(N_t C_{PV} + N_{dc} C_{INV} + C_L + C_B) \quad \text{... (11)}$$

Where,

1 s(%) is the capital subsidization rate as provided by the MNRE
2 C_{PV} and C_{INV} are the capital costs of each PV module DC/AC inverter, respectively
3 C_L is the cost of purchasing the required installation land area
4 C_B is the manufacturing and installation cost of the PV modules mounting structures

The cost of the required installation area

The cost of the required installation area, C_L, is calculated as follows.

$$C_1 = SW_1 \quad \text{... (12)}$$

Where,

c_1 is the cost of the installation land per unit area (₹/m^2)
S is the southern dimension of the actual installation area
W is the western dimension of the actual installation area

The present value of the total cost of repairing the DC/AC inverters can be calculated by reducing the future value of each of the DC/AC inverter repair cost to the corresponding present value.

The number of repairs, which must be performed on the DC/AC inverters during the lifetime of the GCPVS will be given as N_r

Where

$$N_r = \frac{n24.365}{MTBF} \quad \text{... (13)}$$

Where,

1 MTBF is the mean time between failures of the DC/AC inverters as specified by the manufacturer.

The constraints for the optimization procedure require the following.

2 A potential solution of the optimization problem
3 Constraints (N_1, N_2, β)
4 N_1 = GCPVS total number of PV modules
5 N_2 = number of lines per row
6 β is the tilt angle
7 Optimal solution of the problem
8 Generation from the available solar radiations

The constraints of the optimization procedure are the following.
1 $0 \leq \beta \geq 90°$
2 Constraints (N_1, N_2, β) = Satisfied

Where,
Constraints (N_1, N_2, β) are the set of the GCPVS design constraints

Economic analysis

The following are the profitability evaluations of each optimally sized GCPVS.
1 NPV = net present value
2 The discounted payback period
3 The internal rate of return methods

The NPV of an investment is the sum of the present values of all cash inflows and outflows related to the investment.
1 NPV must be positive
2 NPV is equal to the total net profits function, J (x)

The discounted payback period is defined as the time period that sets the system NPV to zero
1 NPV =J (x) for 0 for n = n*

This contributes towards the fulfillment of the continuously increasing electric energy demands and reduction in the pollution caused by the thermal and electric energy generating units.

Optimal sizing and economic analysis results

1 The installation of GCPVSs by private investors is supported in India by subsidizing the corresponding investment capital cost.
2 In this case, the main target of the GCPVS design is the maximization of the total economic benefit achieved by selling the PV-generated energy to the electric grid.

Conclusion

The advantage of the design aspects of the GCPVS is that it can influence the total economic benefit as achieved by performing this type of investment analysis, such as the operational and economical differences between various PV modules and DC/AC inverter types, the PV modules tilt angle, the cost of the land required to install the GCPVS, and the cost of the PV modules mounting structures. Additionally, it also involves the ability to calculate the global optimal solution, in the case of complicated problems with non-linear programming methods. Utilizing full-scale procedures like these are bound to result in an optimal value of a GCPVS in more than one way.

Lighting up One Million Lights

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The need

Electricity is the fundamental necessity to further sustainable development for rural households, which are living at the base of the pyramid. Lack of clean and reliable illumination, once the sun sets, limits the productivity of millions of people worldwide. It is a huge impediment to initiating development opportunities in key sectors such as health, education, and infrastructure. International collaborations between the civil society, government, and private sector have been working to address the need for safe and clean solar lighting for a quarter of the world's population. One Million Lights, a non-profit organization, based in California, has a unique and innovative approach that is furthering solar lighting to rural communities with a personal touch.

Origin of the 'One Million Lights' programme

Founded in 2008 by Anna Sidana, the One Million Lights' mission is "to improve the medical, education, and economic well-being of the rural neighbourhoods by providing solar lighting as a safe and clean alternative to harmful kerosene, both for individuals and communities throughout the developing world." Anna's inspiration for founding the organization can be traced back to a rural school in Rajasthan, India. Anna's father had built this school 45 years ago as an elementary school with only five students on its roll. Today, the school has expanded to include grades up to the 12th standard. During a visit in 2003, Anna realized how simple technological advancements, such as solar lighting, could further rural education and, thus, began her illuminating journey towards One Million Lights.

The global impact

One Million Lights has benefited 77 communities in 18 countries around the world. The organization has distributed over 18 000 solar lights to communities in need, illuminating the lives of more then 125 000 people globally. Distribution of these solar lights to rural communities happens through several means, including partnerships with grassroot NGOs, the One Million Lights School Programme, and the Global Ambassador Programme. The domestic programmes in the US have touched the lives of more than 50 000 people, including many students.

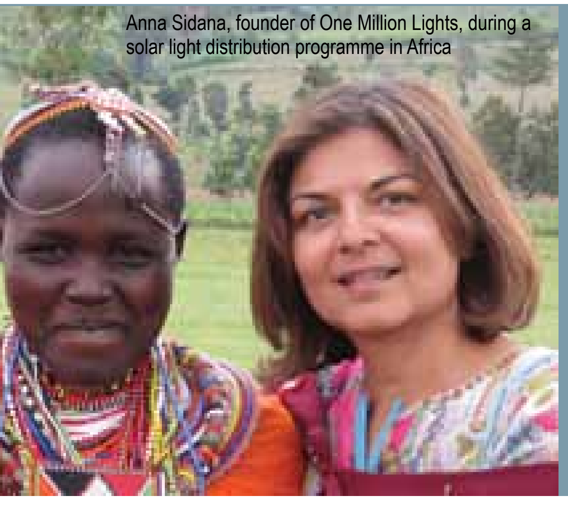
Highlighting a recent model

The One Million Lights Global Ambassador Programme, launched in January 2010, has a "donor-meets-recipient" model that allows individuals a hands-on approach in contributing to the cause of solar lighting for the rural poor. Ambassadors work with the One Million Lights team to identify a community in need of solar lighting, such as a rural health clinic, village school or households that are otherwise dependent on kerosene for lighting, due to the lack of access to the local grid or partial electrification. Ambassadors raise funds for the programme through novel means, such as grants, social networking sites, or familial donations, and then personally distribute the lights during their travel abroad.

Global ambassador—Karishma

"It was an incredible, life-changing experience visiting a village school to distribute the solar lamps. Not only did I become more socially aware of the problems in our society, and the little things I can do to help, but it was a self-learning process as well," said Karishma Popli, a fourth generation American of Indian descent, who distributed lights in August 2010 to a rural school with a strength of 350 students in Rajasthan, India. Her underlying story for the distribution of lights to this particular school was nearly similar to Anna's inspiration for One Million Lights. Karishma's great grandfather had converted their ancestral home into a school for the underprivileged students in grades 1-12 prior to immigrating permanently to the US. It was during a previous visit in 2006, Karishma realized the lack of energy access here and thought that, and "alternative energy sources, such as solar lamps would improve the quality of life of the students tremendously."

Karishma's grant proposal to her school, Thomas Jefferson High School for Science and Technology in Alexandria, Virginia, was to provide solar lamps to underprivileged students at a village school in Rajasthan. This was to enable them to effectively study at night. Equipped with the Grant award money along with a matching grant from the One Million Lights Global Ambassador Programme, Karishma was able to successfully distribute solar lights to the children at Haveli School. "This is a practical, low-cost, and efficient way to bring rural school children out of darkness and into a bright future with the help of solar light and technology!" Karishma is a classic example of the new type of donor base that is emerging. Simply donating money to an organization that is doing aid work is not sufficient for this active group. People want to personally see



Anna Sidana, founder of One Million Lights, during a solar light distribution programme in Africa

Solar lighting facilitating student education in rural areas

the end results. They want to know how the money is being utilized and how it is benefiting the recipients in their day-to-day lives. Programmes like Kiva have been successful because they connect with the people.

The emerging new donor base

Kiva is a non-profit organization headquartered in San Francisco, California that allows individuals to lend money via the Internet to microfinance institutes in developing countries around the world. Lenders have an opportunity to view profiles of different entrepreneurs in need of capital to start and sustain a small business through the help of Kiva's Field Partners. Each entrepreneur's profile includes a picture, information about the loan, its use, and how much fund has been raised. As loans are repaid over a period of time, Kiva lenders can withdraw their principal or re-loan their funds to another entrepreneur, thus, furthering economic growth in the developing regions of the world.

Almost a quarter million loans have been made through Kiva, most of which have been advanced to women entrepreneurs. As on December 2010, the total value of loans made through Kiva was $178 million dollars with a lender base in more than 200 countries. Kiva also has stories of how some of these lenders have travelled to other countries to meet entrepreneurs whom they have given funds.

The Global Ambassador Programme was essentially designed to take the relationship between donor (fundraiser) and recipients further by providing the means for personal contact and interaction. It is an opportunity for those passionate about a cause and get actively involved in the process of helping rural communities.

It also promotes environmental awareness and facilitates the growth of a generation of young adults socially conscious of the hardships faced by communities at the base of the pyramid. For Karishma, "seeing all 350 students, gathered in the school courtyard, eager to receive a solar lamp as well as learn about the benefits of solar technology is something I will never forget."

An innovative programme for schools

One Million Lights Schools Programme is working alongside the Ambassador Programme to encourage environmental awareness within schools in the US. Integrated into the classroom environment, students learn about developing regions of the world, conserving energy, fighting poverty, solar energy, and what it means to serve others in need. The school-wide learning experience partnered with a fundraiser, challenges students to work together to benefit the unprivileged students living in another region of the world without adequate and safe light. They learn as to how lighting facilitates education with additional study hours for children, reduces indoor air pollution, and mitigates CO_2 from the atmosphere by saving kerosene.

Students at the Eisenhower Elementary School in Santa Clara, California, raised $3000 to donate to One Million Lights. These funds helped in providing more than a hundred solar lights for students in Northern Tamil Nadu (India). Students have an opportunity to distribute the lights themselves during their travel or through One Million Lights' channels. It is an experience that instills environmental awareness and teamwork to bring about a positive social change.

Visible change

Beyond the organization's international focus and goal of distributing one million solar lights as a safe and clean alternative to kerosene lamps is a personal element. It is this aspect of the organization that makes it stand apart from businesses and other programmes in the field of solar lighting. One Million Lights give a face to those in need of illumination and the individuals who dedicate time to help those communities. One Million Lights is an opportunity for people to connect face-to-face, to help others in need through solar lighting, and be a part of the change they wish to see in this world.

BUILDING A ROBUST SOLAR ENERGY MARKET IN INDIA

Sathya Prasad as the President of SEMI, India, is responsible for all SEMI activities in India. He also oversees the development of the association's programmes, committees, products, and services in the region. Sathya brings with him over 18 years of experience, spread across the US and India. Prior to joining SEMI, he was the Director of Strategic Planning at Cadence Design Systems, in India. Earlier, he spent 13 years at Intel Corporation (the US and India) in various engineering, marketing, and strategic planning roles and played a key role in setting up the server microprocessor development facility in Bengaluru, India. Sathya holds a Master of Science degree in Electrical Engineering from the Arizona State University and a Bachelor of Science degree in Electronics and Communications from the Bangalore University.

In an interview with Arani Sinha, Sathya Prasad talks about SEMI's role, its challenges and objectives towards building a strong and robust solar energy market in India.

Q1. SEMI, as we know, happens to be a global industry association serving the manufacturing supply chains for the microelectronic, display, and photovoltaic industries. To what extent is the common industrial knowledge base put to use across different geographical regions?

Semiconductor Equipment and Materials International (SEMI) was launched 40 years ago to address the various challenges faced by the semiconductor industry and also to promote the interest of the member companies. It has been part of the semiconductor revolution that has transformed our lives permanently and remains a key aspect of the industry landscape. In these four decades, the industry has matured and many of the member companies have diversified into several new and adjacent technologies/industries, which are expanding rapidly. To represent these new industries, SEMI has set up interest groups in photovoltaics (PV), microelectromechanical systems (MEMS), and emerging technologies.

SEMI is engaged in developing solar/PV manufacturing-related standards, promoting EHS, growing the market, and delivering value to its industry members... a key goal is to help create a robust market for solar/PV in India and to this end, SEMI, India, has successfully built an industry platform for exchange of ideas, opportunities, and meeting challenges...

SEMI has tapped the global industry knowledge across geographical boundaries in successfully formulating global standards, which have played a tremendous role in lowering cost, ensuring increased flexibility, and faster time to market in semiconductors, FPD(flat panel displays), and solar/PV. SEMI is probably the only global industry association in the area of semiconductors and is fully engaged in activities that leverage the global nature of this industry to advance the technology mandates of its globally dispersed members. The global nature also allows member companies to explore new markets across the globe with SEMI playing a supportive role.

Q2. SEMI, India has been in existence for about two years now. Could you kindly tell us about its strategic areas of focus on a long-term basis?

SEMI, India is part of the SEMI and PV Group and its mandate is to help the growth of the Indian PV industry, bring various stakeholders to help build a robust solar/PV markets, and ecosystem in India. SEMI, India's activities are guided by the SEMI, India PV Advisory Committee (PVAC), whose members are drawn from the leading PV companies.

SEMI is actively engaged in developing solar/PV manufacturing-related standards, promote EHS (environment, health, and safety), growing the market, and delivering value to its industry members. It goes without saying that a key goal is to help create a robust market for solar/PV in India and to this end, SEMI, India, has successfully built an industry platform for exchange of ideas, opportunities, and meeting challenges in technology, finance, policies, and so on, in addition to showcasing industry products in the form of SOLARCON® India.

Q3. SEMI, India, made a noticeable beginning by disseminating its widely read background white paper on "Solar PV Landscape in India" in April 2009. Have your activities moved further on this front and what are the market impacts?

The very first activity that SEMI, India, took up after its formation was to make a thorough study of the status of the Indian PV sector. After six months of hard work, a white paper was released. It was widely read and commented upon by many in India and abroad. All those companies, which were planning to enter the Indian market and entrepreneurs who wanted to make a foray, found the white paper very informative and helped them understand the Indian market. SEMI intends to publish several such white papers on topics of growing relevance and significance. SEMI has also addressed a long-standing need of India solar/PV industry by publishing the first such directory in July 2010.

Q4. SEMI PV Group has a wide range of activities from development of PV industry standards, on one hand, to networking on the other hand. How much support has been forthcoming from the Indian PV industry in this specific direction so far?

The PV industry has been very supportive of our efforts. In fact, the agenda for SEMI is set up by the SEMI India PVAC consisting of top executives from the leading PV industries. In fact, the PVAC helped with guidance on the first industry landscape white paper, policy inputs, and many other related items.

Several new companies have been established since the launch of Jawaharlal Nehru National Solar Mission (JNNSM). Many of these are new to the industry and need support on several key fronts. SEMI, India, has found itself in a favourable position to be at the right place at the right time to serve the interests of the new companies, in addition to the existing ones.

Since its establishment in 2009, SEMI has achieved reasonable success in implementing its agenda. In the coming years, SEMI will focus on expanding its activities in all the four regions of India, conducting more industry oriented seminars, network meetings, and other B2B interactions that would benefit the PV industry at large.

The long life and field performance reliability of PV modules is taken for granted. However, this can be ensured only if high quality materials are procured and quality standards are followed at each stage of manufacturing.

Q5. Could you please familiarize us with your views on the existing and desired orientation of the Indian PV programme, mainly from the viewpoint of quality standards that are being maintained, both within the industry environment and field operating conditions?

The long life and field performance reliability of PV modules is taken for granted. However, this can be ensured only if high quality materials are procured and quality standards are followed at each stage of manufacturing. Any compromise, therein, would result in module performance deteriorating prematurely, which in turn, would lead to a lower energy yield and revenue loss. Also with new technologies coming in, there is a dire need to evolve new standards and adopt them.

The industry is also concerned that different government agencies have set up different standards, thus, resulting in a need for multiple certification. This can be a costly affair, both in terms of time and money. SEMI will work with the industry and other stakeholders to arrive at an optimal set of certifications that can help alleviate this problem.

On the Bureau of Standards (BOS) front, there is a need to evolve a lot many standards for various components and systems much in tune with the local needs and operating conditions. SEMI would soon be setting up a standards committee to work with the industry and key national and international agencies to evolve the standards.

Q6. SEMI, India, is expected to build up strong initiatives in solar capacity building, especially under the ambit of the recently initiated JNNSM. Have you drawn up any such plans with an active support of various interested groups/individuals so far?

SEMI is actively engaged in contributing to the successful rollout of the JNNSM. Early this year, SEMI jointly organized an Industry–MNRE meet to deliberate on the implementation of the solar mission. SEMI, along with other industry associations, interacted with Central Electricity Regulatory Committee (CERC) during the process of fixing the feed-in tariff. SEMI also strongly advocated that a larger proportion of the installation targets be assigned to PV.

The annual industry promotion event "SOLARCON India", organized by SEMI this year, had its conference theme woven around an active implementation of the JNNSM. The topics covered and discussed included policies, technology, project management, financing, and standards.

As JNNSM goes through the initial steps towards implementing Phase I of the programme, it is natural that a number of challenges will be encountered and key inferences and lessons learnt. However, as and when these challenges are addressed, it would lead to a smoother rollout of the future phases of JNNSM. SEMI endeavours to engage with industry and other stakeholders in addressing these challenges and ultimately contributing to the successful implementation of the mission.

Q7. Would you please like to convey any special message to the readers of The Solar Quarterly magazine?

India is just one amongst the few countries that realized the potential of solar energy long before terms like climate change and Carbon Emission Reduction (CER) gained popularity. With the launch of JNNSM, India has taken a big step forward to realize the potential of PV in the context of addressing its future energy needs and energy security. To implement the ambitious targets of the mission over the three phases, several known and unknown, anticipated and unanticipated hurdles have to be crossed. Knowledge, sharing of experiences/learnings, and critical analysis with feedback from all the stakeholders is key to finding solutions and realizing the goals of the mission. The role and contribution of a professional magazine like, The Solar Quarterly is very important, and SEMI would indeed be happy to join and contribute in this effort.