kerosene lantern, on an annual basis. To trace the entire network of the supply chain to produce one unit of solar lantern, a lot of information and data is required about the 'cooking recipe' of the products related to solar lantern production. While the specifications of lanterns vary, for purposes of this paper, the comparison is conducted for a particular specification of solar and kerosene lanterns. For example, an aluminium frame is an integral part of every solar module considered in our specific solar lantern. Bauxite, electricity, and other inputs are indirectly required to produce one unit of aluminium frame. Further, specific amount of fuels are needed to generate electricity required to produce the aluminium frame. Using the mathematical model of the IO analysis, one can trace the complex interdependent production system in the economy.

The Indian IO table published by Central Statistical Organization every five years, represents the inter-dependence of each sector of the economy on the other, and makes it possible to estimate the indirect consumption of various goods by the different sectors of the economy. This has been appropriately transformed into an Environmental Input–Output (EIO) matrix for India in collaboration with Keio University (TERI 2010).[2] The ability of being able to estimate the indirect emissions from the manufacture and use of resources is one of the advantages of the EIO approach. While EIO matrices have not been developed and applied in the Indian context earlier, it has been used a number of times in the past to conduct comparative carbon emissions analysis (Hendrickson, Lave, and Mathews 2006).

The sector-wise indirect carbon emission per unit consumption is given by the following equation.

$$CO_2 = a_c (I - (I - M)A)^{-1} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

where

M is the diagonal matrix of import coefficients

A is the input coefficient matrix by industry technology assumption

a_c is the matrix of carbon emissions

Data and assumptions

The solar lighting technology is based on using the modules to charge a battery, which is then used at night to power an electric bulb. The lantern either uses a compact fluorescent lamp (CFL) or a light emitting diode (LED) as these sources of lighting have a higher watt per output as compared to the ordinary general lighting service (GLS) bulbs. The lighting device is housed in a plastic encasing and it is possible for individual modules to be connected to all the lanterns or to have centralized charging stations where a number of lanterns can be brought to be charged together.

This paper assumes a configuration of a single module charging a battery that will power a single lamp after dark. For the case of CFL lanterns, the paper has considered a module capacity of 10 Wp with a CFL of capacity 7 W. For the case of LED lanterns, a module capacity of 3 Wp has been taken with a LED of output 2.5 W. It should be noted that this is not the exclusive combination that may be possible for module capacity and lantern output but this combination has been chosen keeping in line with the required time for the output of the lantern. Table 1 gives the costs of the different components of the solar lantern as well as the lifetime of the different components as assumed in this paper.

In the case of modules, data was procured based on consultations with members of the solar module production industry. Table 2 gives the size and unit cost of materials that are consumed in the construction of 3 Wp and 10 Wp modules. The consumption of electricity and the cost of machinery (capital cost) for the production of solar modules have been taken after consultations with members from the solar module production industry.

Since most of the cells and wafers are imported from Japan or Germany, and the cell and wafer manufacturing industry is still at a very nascent stage, the carbon emissions from this sector have been considered to be similar as in the Japanese sector. These are summarized in Table 3.

It should be noted that where there was scope of any ambiguity in data, caution has been taken and a conservative estimate of the higher side of costs for solar modules has been considered. In case of an LED solar lantern, the life of the lantern is assumed to be 10 years and that there will be four changes of batteries during this period. In case of a CFL lantern, the life of the lantern is again assumed to be 10 years with the battery and the CFL being changed twice. The lifetime of the module is assumed to be 20 years.

In terms of consumption levels, it is assumed that a household would use two kerosene lanterns per year, each costing Rs 50 and that each household consumes 36 litres of kerosene in a year.

In the case of CFL and LED lanterns, the light sources tend to provide a higher quality of light as compared to the standard kerosene-based hurricane lantern. However, this paper does not consider the increased luminosity from shifting to solar lanterns, although this would be an additional inherent benefit.

Findings

Figure 1 provides the comparative life cycle emissions from a solar CFL lantern, a solar LED lantern, and a kerosene lantern (using around 36 litres of kerosene annually) based on the EIO approach.

On an annual basis, the LED lantern could result in saving of 93 kg CO_2, while a CFL lantern could save 89 kg CO_2 compared to a kerosene lantern.

In terms of the manufacture of solar lanterns as a whole, the largest share of emissions is on account of the solar modules (as high as 80%–88% of the emissions is attributed to the total emissions from the solar lantern as considered in this study).

Although the costs of solar modules and lanterns continue to be significantly higher than those for kerosene lanterns and fuel; costs for modules continue to decrease as developments take place in this field. Also, economies of scale can significantly reduce the cost and

[2] This paper is based on the EIO model developed jointly by Prof Kazushige Shimpo (Keio University, Japan) and the Modelling and Economic Analysis team at TERI during 2008–10. The model can be used in various life cycle emission studies for India.

Table 1 Costs and lifetime of components of solar lantern

	LED (2.5 W)		CFL (7 W)	
	Cost per component (Rs)	Lifetime (years)	Cost per component (Rs)	Lifetime (years)
LED/CFL	350	25.7	70	5.1
Battery[3]	170	2.6	640	5.1
PCB	180	10	200	10
Housing	150	20	190	20
Total	850		1100	

Source Chaurey and Kandpal 2009

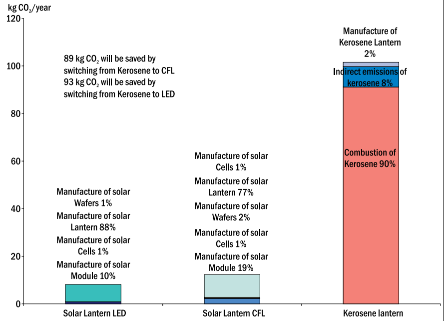

Figure 1 CO_2 from various lighting sources
Source: TERI analysis

energy consumption for the production of solar modules.

Solar lighting devices provide an important alternative to kerosene lanterns. This paper demonstrates that there is significant reduction in CO_2 emissions with the adoption of either a CFL or LED-based solar lantern as against a kerosene-based lantern. There would be a significant reduction in the energy consumption, when compared in terms of a life cycle approach. Accordingly, the adoption of solar lanterns has a role to play in terms of increasing the energy security of India as the country currently imports majority of the crude oil. A shift away from kerosene would lead to reduction in the petroleum subsidy apart from providing a clean and safe lighting solution.

Although the solar lanterns are an attractive option for the mitigation of emissions of CO_2, there are a number of barriers that stand in the way of widespread adoption of solar lanterns and modules. The main factor is the high capital cost of the solar modules as compared to the kerosene lanterns. However, it should be pointed out that the distribution of solar modules and lanterns could have a more targeted subsidy reach than kerosene.

Table 2 Quantity and cost of components of solar modules

	3 Wp module (LED) Size	10 Wp module (CFL) Size	Cost (per unit)
Frame	0.82 m	1.4 m	Rs 150/m
Glass	0.04 m^2	0.13 m^2	Rs 600/m^2
EVA sheet	0.04 m^2	0.14 m^2	Rs 750/m^2
Tedlar sheet	0.04 m^2	0.14 m^2	Rs 800/m^2

Source manufacturers websites. Cost data has been determined from the web and interaction with sector experts.

Note

(i) Although there are a number of different modules of 10 Wp available, all with different dimensions, the module that has been considered in our analysis is mid-range.

(ii) It should also be noted that the area of glass, EVA and Tedler sheet have been taken to be 1%, 6%, and 7% more than the area of the model in line with de Wild-Scholten and Alsema 2005.

Table 3 Emissions from solar cell and wafer manufacture

Component	g–C/w	g–C/3w	g–C/10w
Sillicon and ingot–wafers process	8.21	24.62973	82.09909
PV cells	4.38	13.13182	43.77273
PV modules	6.55	19.64536	65.48455
Total	19.14	57.40691	191.3564

Source: Yamada and Komiyama (2002)

The authors acknowledge the support and data received from various members of the solar industry, and in particular thank Dr P C Pant for his valuable advice. The authors also acknowledge the contribution they have received from Akanksha Chaurey, Dr Nivedita Dasgupta, Varun Gaur, Parimita Mohanty, Arvind Sharma, and Mr Jarnail Singh. Special thanks are due to Prof. Kazushige Shimpo for helping develop and set up the EIO model for India and guide this particular exercise. The analysis presented above has been conducted as an exercise. Although the authors stand by the results, there are a number of limitations to the IO analysis, which should be addressed separately for a more precise comparison on a case by case basis.

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[3] In the case of CFL lanterns, the battery will be 12V, 7Ah whereas in the case of LED lanterns the capacity of the battery is 6V, 4.5 Ah.

NEED FOR SELECTION AND DESIGN OF APPROPRIATE TECHNOLOGY FOR MANUFACTURE OF GOOD QUALITY SOLAR LED LIGHTING PRODUCT*

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At first glance, the solar light-emitting diode (LED) lighting products seem very simple. But really, there are several components of the product, which need to be selected appropriately and designed properly, in order to avoid premature and bad performance issues. A solar LED lighting product consists of critical components such as the following.

- Light source with optics
- Energy storage (generally battery storage) device
- Charging source (solar module or solar along with other charging options)
- Electronics for regulating and delivering power to the light source

The function of the LED (whether as ambient light with uniform illumination or as task light, or flashlights, or torches) should be assessed while selecting the LED. Our experience shows that it is not only critical to select the most appropriate LEDs, it is equally critical to select the positioning of the LEDs, spacing between them, and the type of diffuser and reflectors to be used along with LEDs. In some cases, the same type of LEDs (with the same part numbers) could have lighting characteristics (distribution of light, extent of glare, and so on) that differ drastically because of differences in design.

LEDs are also very sensitive to overheating. Heat not only significantly reduces the life span of the LED, but it reduces output, and also changes the colour of the light emitted. Good thermal management systems are required to achieve this purpose. Again, as per the LED manufacturer's information, thermal management of LEDs differ with the type of LEDs selected. Discrete LEDs do not require a heat sink, whereas the high brightness powered LEDs have no mechanism to radiate the excess heat generated conveniently and thus, require an efficient thermal management system. Within the domain of thermal management systems, various options can be adopted by users (large copper or aluminium heat sinks to conduct the heat away, forced air convention cooling, a new concept of solid state cooling) depending upon the type and size of enclosure, cost, reliability, and so on.

Similarly, several kinds of battery storage are available for solar LED products, such as SMF lead acid, Li-ion, NiMH, and Lithium polymer batteries. Each of these batteries has a different performance and price characteristic,

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which influence its appropriateness for a particular application. For example, the price per unit of energy storage capacity in SMF lead battery is the least out of all the batteries mentioned earlier, but their sensitivity to overcharging, deep discharge or self discharge (5%–10% per month) reduces they operational life time. On the other hand, NiMH batteries are not that sensitive to deep discharge and overcharge, but their price per unit of energy storage is about three times as high as the SMF battery. Similarly, the energy density of lithium ion and lithium polymer batteries are maximum and are about three times that of the SMF lead acid battery. The life of the lithium polymer battery is also about eight times that of the SMF lead acid battery where, the light-weight, reliability and long life are the advantages of these batteries. Its considerably higher cost [multiple times the cost of SMF lead acid batteries] makes it unattractive in most small scale applications. Further research into reducing the cost of the NiMH battery is a must to increase its efficiency and make it more environment-friendly.

In addition to the light source and the battery, the electronics of the solar LED product plays a very crucial role in the design of the solar LED product and acts as the most important interface between LEDs and batteries. The electronics has three major sections: a LED driver section, a charging section, and a protections and indications section.

From the LED driver circuit point of view, the LED should be driven at a constant current and under no circumstances should the driving current be more than the value prescribed by the manufacturers. It is observed, that in certain cases, the circuit is designed to drive the LED at a higher rate than the recommended value for getting more illuminance (lux output) from the LED lights. Inappropriate designs like these lead to overheating of the LED, significantly reducing its useful life and shifting the colour emitted by the LEDs. Similarly, the discharge current (the current drawn from the battery for driving the LED) should not be more than the recommended value for that particular type of battery. For batteries, typically for the lead acid battery, there is a correlation between the rates at which the battery is discharged (rate of discharge) with the life of the battery. If the lead acid battery, typically the SMF battery, is discharged at a higher rate than the recommended value, its life reduces. Therefore, the current drawn from the battery, which in-turn drives the LED should be optimally selected and designed.

Similarly, the charging of the battery needs to be appropriate and the charging topology should follow the characteristic of the battery. Improper charging of the battery (for example, if battery is not fully charged at the recommended rate) may lead to reduction of the capacity of the battery and thus, the useful energy that can be extracted from the battery reduces with time. Hence, the solar module or other power sources from which the battery is going to be charged should also be selected appropriately and should be capable of providing the required current and voltage.

The electronic circuit should also include all protections and indication such as protection against short circuits, low voltage, over voltage, overcharge, reverse polarity, and so on, necessary for the efficient and reliable operation of the solar LED lighting system.

SOLAR HOMES ...

maximum indoor comfort with optimum energy usage

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Introduction

More than 90% of India's geographical area falls in the hot climatic zone. Here, the houses are designed to avoid the heat by various natural and artificial means. Most of the residents have to face either unbearable indoor heat or pay high electricity bills during the summer months. As the atmospheric heat is increasing day by day, the conventional method of home design is not able to protect the indoor space from the extreme outdoor climate. Therefore, the occupants have to depend on electro-mechanical systems to achieve the desired indoor comfort. In other words, most of the modern homes are not climate responsive and responsible for maximum energy consumption.

Figure 1 shows that the residential buildings are responsible for more than 50% of the energy consumed in building sector. Therefore, it is important to develop these buildings for better occupant comfort, but taking into account principles of reduced energy use. The onus is on the architects, engineers, builders and, in fact, every homeowner to optimize the energy demand and use renewable energy (RE) technologies for energy generation in houses. Solar homes seem to be a ready solution in sight.

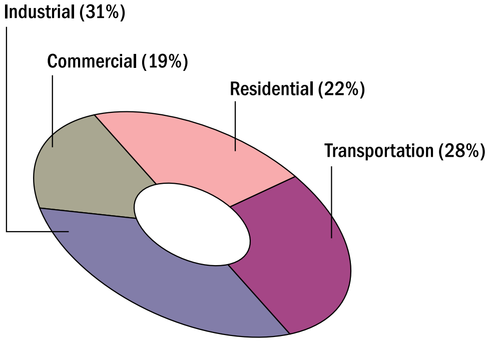
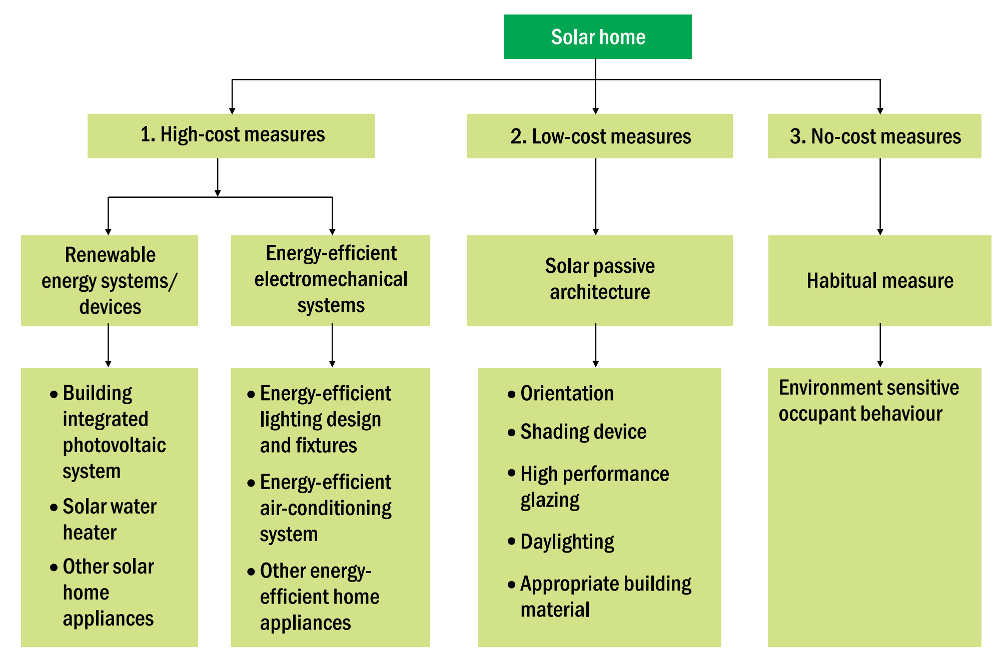


Figure 1 Global energy consumption at various sectors
Source: Energy Information Administration/Annual Energy Review 2008)

Solar home

By definition, any home that uses freely available energy from the sun for heating, cooling, ventilating, and power generation, and so on, can be called a solar home. Such homes are designed and constructed in such a way that they can optimize the energy consumption by using passive design technology, energy-efficient systems, and generate power and heat from solar energy so as to cut down the electricity consumption observed in a conventional building. To create the best standard of solar homes, the following few measures, in accordance with the investment levels, need to be integrated in the proposed home.

1. High cost or cost-intensive measures
2. Low cost or cost-effective measures
3. No cost measures



Various measures for a solar home

High cost or cost intensive measures

The high cost measure obviously needs substantial capital investment, but it has optimum return or payback through minimal operational and maintenance costs. The primary objective of this measure is to optimize the demand and supply of energy. In other words, the energy-efficient equipment optimizes the energy consumption and the renewable sources generates green energy to meet the buildings energy requirement.

Integration of renewable systems

Solar energy is available in abundance for homes in India. Depending upon the availability of resources, solar energy can be used for meeting various end-use applications at home. Solar photovoltaic (SPV), solar thermal systems, and other solar devices are the advanced technologies that can be used for this specific purpose. These measures can be incorporated in new buildings after construction and can also be retrofitted within the existing buildings.

The primary function of a SPV system is to convert the incident solar energy into usable electrical energy. SPV systems have a fixed orientation for particular latitude, which can be set at the time of installation. However, SPV systems can also make use of the sun tracking devices to collect the maximum possible radiation during the day and thus, provide higher efficiency. PV modules can be architecturally integrated in the building envelope itself and thus, can be seen as part of the building structure.

Building integrated solar photovoltaic system

Keeping the high initial capital cost in view, homeowners may have to look at the financial incentives or other opportunities provided by the state/ central government for the same.

A solar water heater is a device that uses heat energy of the sun to provide hot water for various applications. A domestic solar water heater, with a capacity of 100 lpd (litres per day), is sufficient for a family of four or five members. It can easily replace a 2 kW electric geyser and thus, can save up to 1500 units of electricity a year. It pays back the cost in three to five years, depending on the electricity tariff and hot water use in a year. After this, hot water is available almost free of cost during the remaining life of the system, which is about 15–20 years. The system is generally installed on the terrace and requires minimum maintenance.

There are various RE devices available in the market that are affordable and easy to use at homes, such as solar cookers, solar lanterns, solar home systems, and solar inverters/power pack, and so on.

Solar water heater system
Source: http://climatelab.org

Energy-efficient electrical and mechanical systems

Efficient lighting and air-conditioning systems reduce energy consumption, improve indoor comfort, and result in low electricity bills.

Efficient artificial lighting design and fixtures with lighting controls offer substantial energy savings by reducing the time of the lights on even when they are no being used.

For example

- Fluorescent tube lights and energy-efficient CFLs in fixtures are much more efficient than incandescent (standard) bulbs and lasts up to six times longer.
- T5 tube lights and 36W triphosphor tube lights are also good replacements for ordinary tube lights. They save about 30% –40% energy.
- The garden lighting / security lighting can be replaced with solar PV integrated outdoor lighting system.

Air conditioners (ACs) usually consume the highest energy amongst all the home appliances. Window ACs and split ACs are the most commonly used. These are available in different sizes ranging from 0.75–2 tonne,. Remember, an energy-efficient building envelope leads to the selection of AC with lesser

Solar outdoor lighting system
Source: http://www.lrc.rpi.edu

tonnage leading to reduced electricity consumption.

The energy consumption of an AC depends on its size. Therefore, select an AC that suits your actual requirements. As a thumb rule, a 1-tonne AC is appropriate for a 150 sq ft room, while a 2-tonne AC is sufficient for a room with 300 sq ft area and so on. The efficiency of each home appliance affects the energy consumption levels. Therefore, the home owners or occupants should always select systems with the Bureau of Energy Efficiency (BEE) star label. The number of stars on the BEE label indicates the efficiency of energy systems, such as ACs, refrigerators, washing machines, water coolers, and so on.


Energy efficient lamps and fixtures
Source: http://ablamp.files.wordpress.com

Window AC

Low cost or cost-effective measures

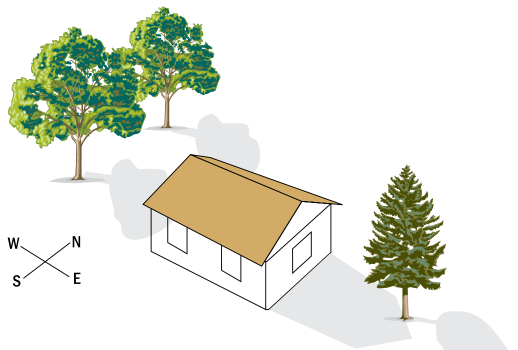
Solar passive architecture is the low cost intervention to make the building energy efficient. The solar passive building does not need a large amount of investment, but it needs careful space planning and climate responsive features within the building design itself. Solar passive features that help in achieving thermal comfort as well as visual comfort with least investment include the following.

- Orientation
- Shading device
- High-performance glazing
- Daylighting
- Treatment of wall and roof

Here, it is important to mention that these measures need to be incorporated during the design stage of new homes.

Orientation

It has been observed that the north–south direction is the ideal orientation for all heat dominating cities of India. As the re-orientation of the entire building block is not easy for many residential buildings due to various site constraints, it is recommended to provide living spaces towards the northern and southern zones of the site. Effort should also be made to minimize the openings on the eastern and western walls. Maximum opening can be provided on north and south facing walls. The radiant heat can, thus, be easily controlled on the north and south walls with minimum provision of external shading devices. The openings on the north-south wall allows minimum heat with adequate daylight into the living space.



Ideal building orientation with plantation on east and west

Window area

Window is the most crucial design element in a building envelope, through which most heat gain occurs. In most of the cities in India with generally high temperature, windows are responsible for large energy consumption in the air-conditioned buildings. Advancement in window assembly and glazing systems has significantly reduced heat gain through the window. Area of the opening is one of the most important parameters to arrive at an energy- efficient window design. In a residential building, it is recommended that the total window area should not be more than 40% of the gross exposed wall area in order to avail adequate light and ventilation.

Shading

In the hot regions of India, the major source of solar heat gain is the direct solar radiation entering through the fenestration of the building. This can increase the indoor temperature far above the outdoor air temperature. One of the most important structural means of controlling the thermal environment is the external shading device. The aim of the shading device is not only to keep the summer radiation out, but also allow the winter radiation to come in. The shading devices need to be optimized as per the solar angle on various orientations.

It has been analysed that shading has more impact on cooling load than insulation in hot climatic zones of India. Therefore, it is also important to shade the building surfaces, such as wall, roof, or courtyard, of residential buildings so as to reduce the discomfort. There are several types of façade shading available for home designers, such as Green roof, Roof pergola, Space frame or tensile structure, Green wall, Wall or Window pergola, Jallis, Plantation on east and west, and so on.

Glazing properties

In the conventional houses, heat transfer through window glazing is much higher than that of the wall (thermal mass). This is primarily because of the fact that the window with single glazing offers a path of lesser resistance. The heat gain in such windows is 10 times higher than a common concrete wall. Therefore, it is recommended to provide energy performance glazing in all the air-conditioned homes. All the rooms (wherever, indoor comfort is required) should be provided with such glazing because the energy performance of glass is not only responsible for energy conservation but also ensures indoor comfort.

The energy performance parameters of glazing are the following.

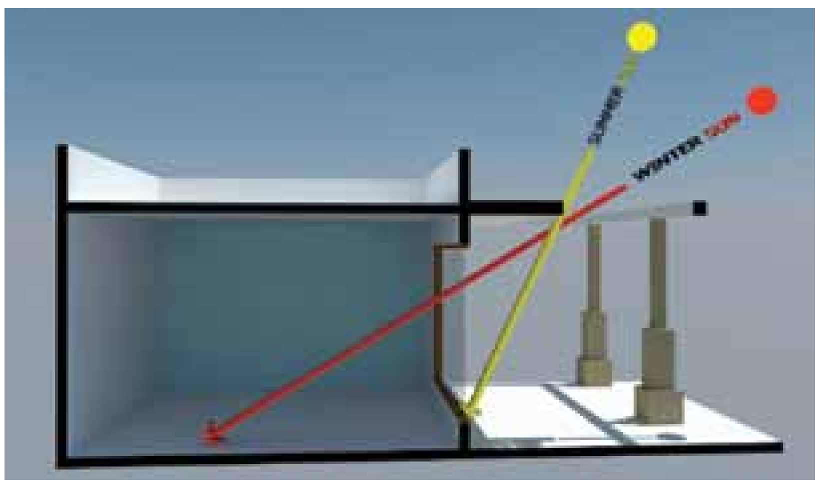
i. U-value (insulating value),
ii. Solar heat gain coefficient or SHGC (heat gain from solar radiation)
iii. Visible light transmittance or VLT (percentage of natural light).

The first two are thermal performance indicators and the last one is responsible for visual performance. These characteristics should form the basis for selection of an appropriate glazing for the home.

Daylighting

Use of daylight in a residential building is responsible for a significant reduction in artificial lighting in daytime. This aspect is essential for the occupant's well-being and enhanced productivity. The sunlight that enters the home during daytime is the glare-free natural light that can be efficiently used for different types of activities inside the living space, such as cooking, reading, playing,


Window area


Effective shading device (Image designed by Rakesh Chauhan, TERI)

doing other household work, and so on. Benchmarks have been set as per the Indian standard (SP41) for different occupied spaces for home in different hot climatic zones of India as shown in Table 1.

The penetration and spread of daylight is greater when we have tall windows. However, a proper distribution of tall windows can provide good penetration as well as a good spread of the sky component on a work plane. The shading device plays a big role in terms of obtaining heat and glare control.

Landscaping

Trees surrounding the building act as good solar radiation barriers, but can also sometimes divert wind. Proper landscape design can be used to effectively channel the wind and cool incoming winds. Vegetation also creates a pressure difference that can be even efficiently used for cross ventilation purposes.

Cost measures

Habitual measures towards energy saving are considered as no-cost measures, as they do not need any type of investment. This measure needs only sensitivity of the occupants towards the environment and appropriate awareness of optimum utilization of electricity and fuel. This no-cost measure is applicable during the operation and maintenance of the building. Habitual measures include energy efficient habits of occupants such as the following.

i. Switching off lights, fans, ACs and other appliances, when there is no user in the room.
ii. Use artificial lighting when there is inadequate daylight in the space
iii. Use the AC at higher temperatures (22–25 ^{0}C) to avoid over cooling and turn on the ceiling fan to help circulate the cool air more effectively.
iv. Avoid switching lights on and off frequently as it affects the lifespan of the lamp.
v. Use light colours on the internal surface and interiors of the house for effective daylighting and artificial lighting.
vi. Buy split ACs instead of window AC. Split ACs cost more but are much more energy-efficient and consume less electricity compared to window AC.
vii. Avoid installing AC on walls that are exposed directly to the sun.
viii. Do not expose the condenser of the split AC on the terrace/roof to direct solar exposure.
ix. Do not apply dark colour on the external side of the wall and roof of the house, as it leads to an increase in the AC load.
x. Clean AC unit's filtre periodically so as to enable efficient airflow.
xi. Try to switch off the television and AC from the main point, not just by using remote control.
xii. Switch off all the electrical appliances when not needed. The low power gadgets also consume substantial amount of energy even in the standby mode, such as, chargers, adaptors, inverters, music player, and so on.
xiii. Practise a habit of turning off the computer and laptops completely after use.
xiv. Allow enough space for air circulation around refrigerators.
xv. Avoid opening of refrigerator doors frequently as it leads to energy loss.
xvi. Do not allow hot food items to be put directly in the refrigerators.
xvii. If there are any RE systems installed in the building, then clean the surface of solar collectors/SPV panels at least once in 15 days.

Table 1 Recommended daylight levels for residential buildings (in lux)

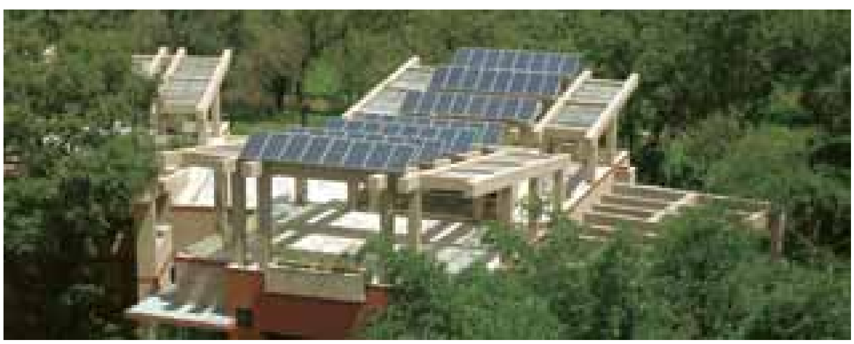
	Composite	Warm-humid and temperate	Hot-dry
Kitchen	200	225	263
Living room	50	56	66
Study room	152	171	200
Circulation	25	28	33

Note Derived from GRIHA benchmark standard

Daylighting inside living space
Source: http://www.buildinggreentv.comcom

The final gain

In this article, it is clear that solar homes are not an expensive solutions. Only this is an integrated approach of all possible measures that includes cost intensive, cost effective, and no-cost measures. A solar home does not only mean expensive building material or equipment, but is a composition of climate responsive building design, efficient equipment/ systems, utilization of solar energy, and sensitivity of the occupants towards the environment. Homes are lifelong investment for each home owner. Hence, homes should attain the goal of adequate comfort with optimum use of resources. Since, today, India is facing a perpetual shortage of electrical energy, solar home is not only the requirement of the future but is the need of the hour.



CHANDIGARH THE SOLAR CITY

Shirish S Garud, Fellow, TERI <shirishg@teri.res.in>

▲ Satellite image of Chandigarh city
Source www.Googleearth.com

Introduction

With 6%–8% per annum growth rate for last few years, today, Indian economy is one of the fastest gowning economies of the world. Economic development often results in rapid urbanization of the societies and Indian society is no different. Successive census data shows that the Indian society is rapidly urbanizing, and various studies project that by 2050, India will have more than 50% of its population in cities and that is a large number to handle. A recent report by McKinsey & Co predicts that by 2030, 590 million Indians will live in cities, which is more than the population of the United States. About 70% of the net employment will be generated in cities thus, attracting the youth from across rural areas. Thus, the urban sector is also going to be a major development challenge in the next few years. This also means that the energy needs in the urban areas are going to increase manifold and effective energy planning and efficient energy use, along with increasing use of renewable energy (RE) resources in the urban sector will be the need of the hour for the Indian energy sector.

Internationally, it is now acknowledged and recognized that special efforts are required to make urban development sustainable and climate responsive. As a result of this realization, countries and cities across the world have initiated programmes to tread low carbon development paths. These efforts are now being recognized as 'solar city' initiatives.

Solar city initiatives

As mentioned earlier, solar city initiatives typically consider strategies to reduce fossil fuel consumptions and replace them with RE or sustainable energy resources. Thus, broadly the strategies include a) energy efficiency measures and b) integration of RE. It is difficult to define the norms or standards to term a particular city as 'solar city', however, solar city initiatives include the following.

1. Setting up goals for RE integration
2. Setting up goals for CO_2 reduction
3. Specific goals for installation of RE devices, such as solar water heating systems, solar PV systems
4. Low energy building designs
5. Transport initiatives such as energy-efficient public transport, alternate fuel transport, and so on
6. Setting up demonstration projects and conducting awareness campaigns

Along with these initiatives, achieving goals based on pre-decided time frames also form part of solar city initiatives.

The term 'solar cities' defined by several initiatives such as International Solar cities, Initiatives and European Solar cities initiatives, also include a climate-stabilization aspect, whereby cities responsibly set per-capita targets for future greenhouse gas (GHG) emissions at levels consistent with stabilizing future levels of atmospheric carbon dioxide and other GHGs and also includes introduction of GHG emissions reduction strategies over the long term.

A number of international institutions are now working and promoting solar city initiatives. These include the following.

- International Solar Cities Initiatives (ISCI)
- European Solar Cities Initiatives (ESCI)
- Solar City Task Force
- International Solar Energy Society (ISES), European Solar cities Projects
- European Green Cities Network
- Energie Cites Association

Solar city initiatives in India

In India, the state of Gujarat took the lead in implementing the concept of solar city and The Energy and Resources Institute (TERI) carried out the first ever study for the Indian city to prepare the solar city master plan for the city of Gandhinagar in Gujarat. Subsequently, the Chandigarh Administration, and Chandigarh Renewable Energy, Science and Technology Promotion Society (CREST) also took initiative to develop a solar city master plan for the city of Chandigarh. Again, due to its competence in preparing similar reports, TERI was awarded this prestigious assignment.

This article is based on the findings of the work carried out under this assignment.

Solar city initiatives by the Central Government/MNRE

In this context, the Ministry of New and Renewable Energy (MNRE) has also initiated a solar city programme for Indian cities during the Eleventh Five-year Plan.

Objectives of solar city initiative

The goal of the programme is to promote the use of RE in urban areas by providing support to the Municipal Corporations, for preparation and implementation of a road map to develop their cities as solar cities. The objectives of the programme are as follows.

- To enable/empower urban local governments to address energy challenges at the city level
- To provide a framework and support for preparing a master plan, including assessment of current energy situation, future demand, and action plans
- To build capacity in the urban local bodies and create awareness among all sections of the civil society
- To involve various stakeholders in the planning process
- To oversee the implementation of sustainable energy options through public -private partnerships

The master plan will set a goal of minimum 10% reduction in projected total demand of conventional energy at the end of five years, to be achieved through energy saving from energy-efficiency measures and generation from RE installations.

Physical targets

An indicative target of 60 cities/towns with at least one in each state has been set for the Eleventh Five-year Plan period. The targets will be achieved by providing support for preparation of a master plan for their city, setting up of a 'Solar City Cell' in the council/administration, organizing training programmes/ workshops/ business meets for various stakeholders such as elected representatives of the municipal bodies, municipal officials, architects/engineers, builders, and developers, financial institutions, NGOs, technical institutions, manufactures and suppliers, RWAs, and so on. Typically, a master plan contains the following.

a. Baseline of energy utilization and GHG emissions
   - Residential
   - Commercial / industrial
   - Institutional
   - Municipal services
   - GHG emission

b. Energy Planning (by sector)
   - Resources
   - Option for energy saving and demand reduction
   - Supply side option based on renewables
   - Techno-economics of energy conservation and measures

c. Projection for energy demand and supply for 10 years
   - By sector
   - Total

d. Year wise goals of saving in conserving energy through demand side management and supply side measures based on renewables

e. Master plan for achieving the set goals and expected GHG abatements

f. Budget estimates and potential sources of funding from respective sources (both public and private)

Chandigarh: background

Chandigarh—also known as the modern India's first planned city—is a classic example of modern city planning and development. The city of Chandigarh is unique in many ways. It is the capital city of two states—Punjab and Haryana—besides being a union territory. It is situated at the foothills of the Shivalik Hill range. As per the 2001 census, Chandigarh city had a population of 0.9 million in 2001. It is expected to be about 15 million by 2021.

Chandigarh city covers an area of approximately 114 sq km (28169.9 acres). In addition, 25.42 sq km of hilly catchments area is declared as wildlife sanctuary. It has been observed that the residential and commercial sectors cover the maximum area of the city. This sector covers an area of 73.9 sq km, followed by agriculture and water bodies (11.36 sq km), industrial (5.75 sq km), public/semi-public (10.71 sq km), and transportation (1.28 sq km) and about 9.65% (11 sq km) is categorized as special area. The land use pattern of Chandigarh is presented in Figure 1. As per the figures released by the Directorate of Economics and Statistics, the per capita income of Chandigarh for 2006/07 is Rs 99 262 at current prices and Rs 70 361 at constant prices making it India's richest city.

Chandigarh energy profile

Chandigarh is a predominantly residential and commercial city with a very small industrial and agriculture sector. The energy consumption analysis was carried out for the following two major categories.

1. Electricity consumption
2. Fossil fuel consumption, mainly petroleum products and coal

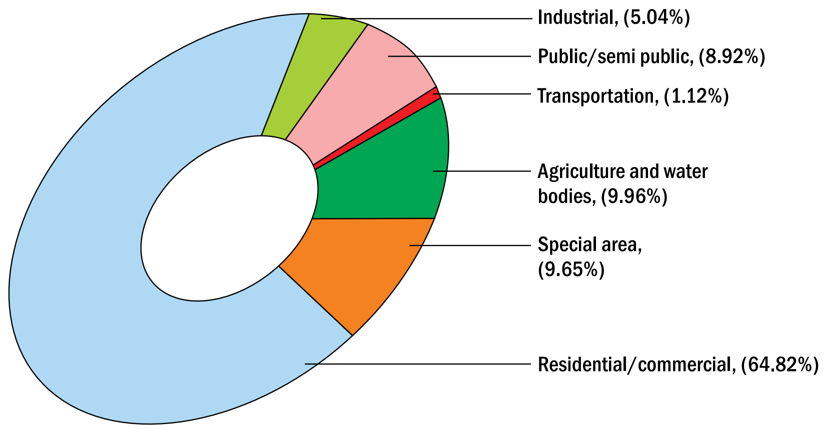


Figure 1 Land use pattern of Chandigarh
Source: http://chandigarh.gov.in/knowchd_stat_ab07.asp

Electricity consumption

Chandigarh's peak electricity demand was about 284 MW for 2007, which is being met from different central/state generating stations.[1] Chandigarh has no generating capacity of its own. At present, the city receives 67% of its power from Mohali, Punjab State Electricity Board (PSEB), about 10% through Dhulkote Bhakra Beas Management Board (BBMB), and the remaining 23% from Nalagarh. The connected load of Chandigarh is reported to be 901.78 MW, while the maximum demand is approximately 284 MW. The connected load of public lighting has been reported as 3.51 MW.

Chandigarh city ranks first in India in the Human Development Index,[2] quality of life, and e-readiness. Hence, per capita electricity consumption of the city is much higher than that of India. The per capita consumption of electricity in Chandigarh has increased from 253 kWh in 1967/68 to 1224 kWh in 2007/08. Accordingly, the electricity consumption has increased from 0.138 MU per day to 5.5 MU on a particular day.

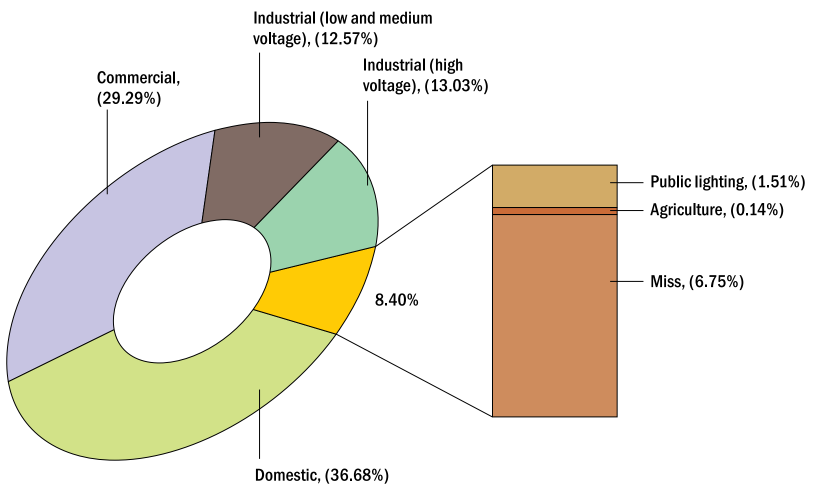


Figure 2 Sectoral electricity use pattern of Chandigarh
Source: www.chandigarh.nic.in/statistics and Data provided by Engineering Department (Electricity wing), Chandigarh Administration

Sectoral electricity consumption

The residential sector of Chandigarh is the major electricity consumer and utilizes 36.68% of the total electricity consumption of the city as per the Engineering Department (Electricity Wing), Chandigarh Administration. Further, the commercial and industrial sectors consume 29.29% and 25.6% of electricity respectively. Figure 2 presents the sectoral electricity consumption pattern of the city in 2006/07.

The salient features of the power scenario are shown in Table 1 and 2.

Table 1 Power scenario of Chandigarh for 2007/08

Installed capacity	79.9 MW
Total energy sales	1161.09 MU
Peak demand	275 MW
Peak met	275 MW

Source: Energy Consumption and Conservation Potential in Chandigarh, Bureau of Energy Efficiency, Delhi, 2010

Table 2 Sector wise break up of energy sales in MU (2007-08)

Sector	Total sales during 2007/08 (MU)	Total sales in percentage
Residential	435.66	39
Commercial	351.92	30
Industrial (LT and HT)	255.4	22
Public water works and sewerage	28.03	2
Public lighting	14.72	1
Agriculture	1.31	0.1
Others (traction	74.31	6
TOTAL	1161	100

Source: Energy Consumption and Conservation Potential in Chandigarh, Bureau of Energy efficiency, Delhi, 2010

The load distribution pattern in the residential sector of Chandigarh has been assumed to be similar to a planned city, which shows energy consumption pattern in domestic applications. The break up of

[1] http://chandigarh.gov.in/engg_web/pages/about_us.html
[2] The Human Development Index (HDI) is an index used to rank countries by level of 'human development', which usually also implies to determine whether a country is a developed, developing, or underdeveloped country.

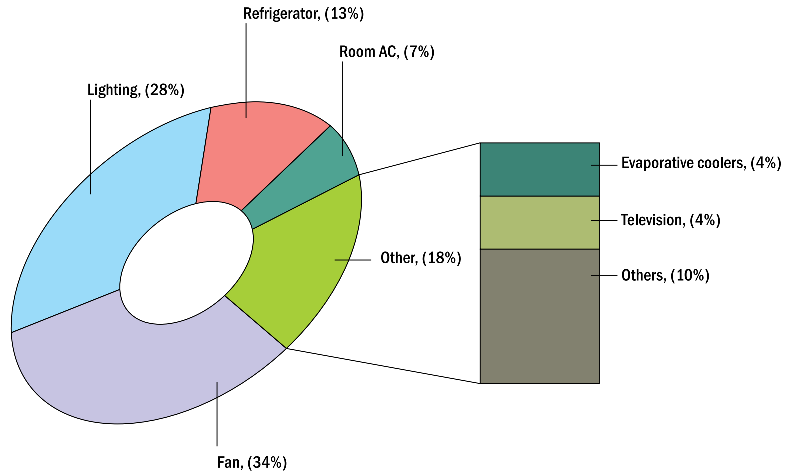


Figure 3 Electricity consumption pattern in the residential sector
Source: Steps towards Energy Efficient Building[3]

the electric consumption in the residential sector is presented in Figure 3, which shows that cooling and lighting consumes more than 70% of the electricity.

Fossil fuel consumption

The transport, industrial, and domestic sectors are the major consumers of petroleum products (petrol, diesel, liquefied petroleum gas (LPG), and so on). LPG and kerosene are consumed mainly in domestic and commercial sectors, while other products are mainly consumed by industries and vehicles. Table 3 presents the year wise consumption of various petroleum products in the city. It has been noticed that consumption of petrol is consistently increasing due to increase in the vehicular population of the city; while that of light diesel oil (LDO), furnace oil, and low sulphur oil petroleum products is getting reduced due to reduction/shift of the industrial sector out of the city. The use of Kerosene has significantly reduced over the year because of the shift towards LPG and electricity.

GHG emissions

Chandigarh receives 52% of its power from Mohali (PSEB), about 8% from Dhulkote (BBMB), and remaining 40% from Nalagarh. Due to significant changes in the grid structure, the Indian electricity system is now divided into two main grids, namely new Integrated Northern, Eastern, Western, and North-Eastern regional grids (NEWNE) and the Southern Grid. In Chandigarh city, the power is drawn from the NEWNE Grid. The average specific emission factor for NEWNE grid has been reported as 0.81tCO_2/MWh as per the Central Electricity Authority.[4]

For the year 2007, the LPG consumption had been estimated based on the population growth rate, which assumed that per family, 2 cylinders of 14 kg were required per month. LPG consumption during 2007 in Chandigarh was 93 375.29 tonnes. Similarly, kerosene consumption of the city was been reported to be 14060 kilo litres in 2007.

The GHG emission has been estimated based on total electricity consumption, LPG consumption, and kerosene consumption of the city up to 2007. The emission factor has been taken as 0.81tCO_2/MWh for electricity generation, while the emission factors[5] 71.5 tCO_2/TJ and 63.0 tCO_2/TJ have been taken for LPG and kerosene, respectively.

It has been estimated that the GHG emission from electricity consumption was 937316 tCO_2, 271190 tCO_2 by LPG, and 35889 tCO_2 from kerosene in 2007, which is mainly by major energy consuming sectors namely residential, commercial, and industrial. The GHG emission in Chandigarh city from 2004–2007 is presented in Figure 4.

Table 3 Consumption pattern of petroleum products in Chandigarh

Year	Petrol Incl. ULP (Kilo Litres)	High speed diesel (Kilo Litres)	Kerosene (Kilo Litres)	Light diesel oil (Kilo Litres)	Furnace oil (Metric Tonne)	Low sulphur heavy stock (Metric Tonnes)	L P G connections (Numbers)
1999/00	89 332	93 764	19 547	5217	10 235	18 888	266 281
2000/01	71 390	76 707	17 628	2699	3359	2829	277 186
2001/02	65 737	72 900	17 162	1192	1047	4850	285 404
2002/03	76 570	65 218	17 570	3116	9219	9219	295 731
2003/04	81 190	71 576	17 026	1640	4470	5094	308 508
2004/05	85 104	76 682	15 740	728	12 322	5702	290 090
2005/06	101 090	89 810	15 560	675	13 108	4938	305 000
2006/07	107 445	100 340	14 060	515	5330	5571	324 000

Source: Environment Information System (ENVIS Centre), Chandigarh

Proposed measures to make Chandigarh a solar city

As can be seen, the energy consumption reduction potential for Chandigarh is high in residential, commercial, and municipal services sector.

The measures suggested for implementation can be summarized as in (Table 4).

The above is based on TERI estimates and calculations.

[3] Goel V., (2006), Steps Towards A Energy Efficient Building, in proceeding of Workshop on Developing energy efficiency and conservation programme for Delhi, TERI New Delhi.
[4] http://cea.nic.in/planning/c%20and%20e/Government%20of%20India%20website.htm
[5] http://cdm.unfccc.int/UserManagement/FileStorage/6HGTVUO4OT44ZX5O5BQBHK1AEEAOI1

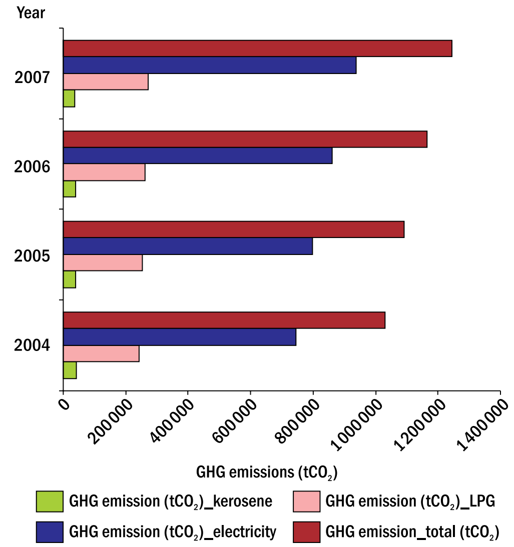


Figure 4 GHG emissions based on electricity, LPG, and kerosene consumption of Chandigarh

Table 5 Potential for energy saving and generation

Proposed measure	Sectoral consumption (MU)	Saving potential per year (MU)	Potential for generation
1. Energy conservation*			
1.1 Residential sector	435.66	87 MU (20%–25%)	
1.2 Commercial sector	352	36.12 MU (20%–30%)	
1.3 a Municipal sector (water pumping)	28.03	5.61 MU (20%)	
1.3 b Municipal sector (street lighting)	14.72	3.68 (25%)	
2. Coverage of solar water heating systems in residential buildings	435.66	130 MU (26%) considering 100% coverage	
3. Rooftop solar energy based electricity generation (total 10 MW by 2018)			16 MU per year
4. 5 MW solar energy based electricity generation at landfill site			8 Mu per year
5. 25MW solar energy based electricity generation at Patiyala ki Rao site			39.7 MU per year

Table 4 Targets for energy conservation generation and GHG emission reduction

Description	Target		
	Short term (till 2012)	Medium term (till 2015)	Long term (till 2018)
1. Energy conservation*	Reduction in present energy consumption		
1.1 Residential sector	10%	15%	20%
1.2 Commercial sector	10%	15%	20%
1.3 a Municipal sector (Water pumping)	20%	20%	60%
1.3 b Municipal sector (Street lighting)	20%	20%	60%
2. Coverage of solar water heating systems (as a proportion of total heating demand in residential and commercial sectors)	20%	50%	80%
3. Rooftop solar energy based electricity generation	2.5 MW	5.0 MW	10.0 MW
4. Large solar energy based electricity generation at landfill site	3.0 MW	5.0 MW	5.0 MW
5. Large solar energy based electricity generation at Patiyala ki Rao site	5.0 MW	15.0 MW	25.0 MW
GHG emission reduction (tCO2/annum)	110413	289300	559598

* As a percentage of reduction in energy consumption over projected consumption in BAU scenario

As can be seen in Table 5, solar water heating has highest potential for energy saving in the residential sector.

Additionally, focus on use of alternate fuel vehicles for personal transport, and public transport are other options, which can be explored for improving energy performance of the transport sector. CREST is already implementing subsidy schemes for electric two wheelers and cars to promote these vehicles.

The way forward

It is possible to convert Chandigarh into an international, iconic solar city by implementing the above strategy in coming years. The measures suggested are in line with the current policies and acts such as Energy Conservation Act, 2009, Jawaharlal Nehru National Solar Mission under the National Action Plan of the Government of India, and so on. The Chandigarh Administration and CREST has already taken steps to implement the action with support from MNRE.

A budget of Rs 800 million has already been sanctioned by the MNRE to make Chandigarh into a model solar city. Equal amount is expected to be invested by the Chandigarh administration. If the citizens of Chandigarh and industries involved in the business of solar energy and energy conservation come forward and join hands with the administration, Chandigarh can soon become an example for rest of the India to follow. This also shows the immense potential for energy savings and use for RE in the urban centres of India. The need of the hour is to have strong policies and strategic planning, backed by strong financial commitments. International support, especially in terms of low-cost long-term finance, to implement these projects is also an essential element to make it a success.

PV GRID-CONNECTED POWER PLANT

ISSUES, CHALLENGES, AND OPPORTUNITIES

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Background

Solar energy has started playing a pivotal role in the overall renewable energy mix the world over. Amongst the relatively new applications, the grid-connected solar photovoltaic (PV) market is growing very fast. The Jawaharlal Nehru National Solar Mission (JNNSM) has motivated quite a few potential project developers to set up solar power plants across the country. As per the latest available information, the government is on the verge of approving about 15–20 projects under this mission, that will entail an investment of about Rs 200 000 million within the next 2–3 years. However, there are certain issues, challenges, and opportunities related to these power plants, which merit some serious attention. The PV-grid power system should fulfill the technical requirements from the grid side as well as from the PV system side so as to ensure reliable and safe operation of the grid. This articles deals with all such issues from a variety of end-use considerations.

Understanding a grid-connected PV system

Grid-connected PV systems can be built in small sizes including building integrated PV (BIPV) and rooftop systems ranging from just a few kilowatts to several megawatts. Current techno-economic analysis shows that grid-connected BIPV application is still not economical. However, this technology should be promoted, mainly due to its huge potential in terms of environmental protection and, thereby future development. Generally, in off-grid PV power plants, storage requirement exists so as to utilize the maximum capacity of PV, but in case of on-grid PV systems the grid itself can act as storage medium for the power produced. It can immediately utilize this power at some other need based locations depending upon the power availability conditions.

The major elements of a grid-connected PV system without storage

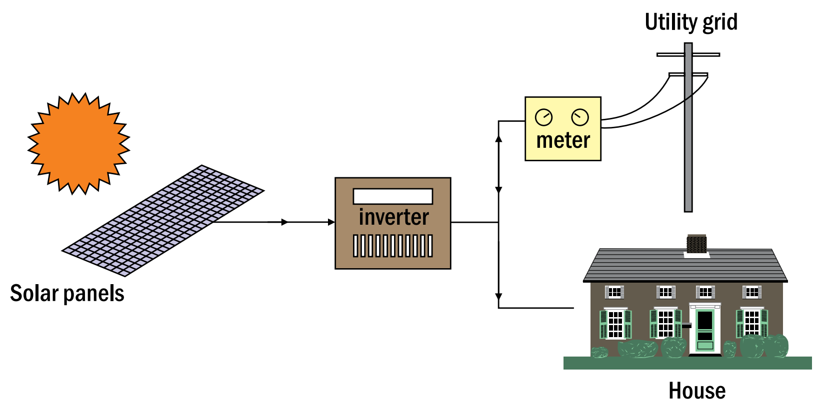

Figure 1 Grid-connected PV system without battery bank

are shown in Figure 1. The inverter operates in this phase with the grid (unity power factor), and generally delivers the maximum possible power within the given irradiance conditions.

The issues with grid-connected PV system

PV systems with grid interconnection involve two major areas of concern—plant side and grid side. Both the concern areas are discussed in detail in the following section.

Issues

The main objective of the PV power plant is to achieve the maximum possible power with adequate reliability and safety. There are a number of issues, which need to be considered for achieving the desired objectives. Some of them are discussed in this article.

Site issues

Site location is a very important issue with grid interactive PV systems, as there are various factors, which affect the PV system output such as the following.

- Suitability of a technology to be used for a particular site and weather conditions
- Tilt and azimuth of the PV generator, that is, the solar modules
- Consideration to nearby buildings, mountains, trees, and so on, which may cause shadowing
- Alignment of the PV arrays that may cause reciprocal shadowing

While locating the site of the PV power plant, the shadowing of modules is also an important aspect, which needs to be considered. The plant site should be free from trees, mountain shadow, building shadow, and so on. PV array arrangement should be such that no module will cast shadow on the same or other string. Shadowing of modules can reduce the power from it drastically. Research studies shows, even if one cell is shadowed; the net power from modules reduces by almost 33% for three bypass diode-based module.

Choosing the right technology

As of now, the following are some of the PV technologies available for the purpose of grid power generation.

- Crystalline silicon (mono crystalline, polycrystalline)
- Thin-film amorphous silicon
- Cadmium telluride
- Copper Indium di-selenide
- Copper Indium gallium di-selenide
- Concentrator based technology

Practically, a project developer can opt for any of these technologies. However, it is quite a desirable feature to choose a technology in accordance with the site specific parameters, such as solar radiation availability. If the site receives a generous sprinkling of diffuse radiation, then it may be appropriate to utilize just the thin-film modules. This is primarily the reasons why thin-film modules respond better to diffused light. However, one should also remember that the modest efficiencies associated with thin modules generally result in a higher demand for land area availability unlike crystalline silicon modules. Contrast this with the availability of significant amount of direct radiation and limited land availability, and the crystalline silicon options suits the most. As such, cost-benefit analysis of all possible options needs to be undertaken for the site under consideration.

DC/AC power generation issues

System should be designed for a particular direct current (DC) load and remaining alternating current (AC) power for injection into grid. There will be losses

associated with electric conductors. These losses are important in DC, when the voltage is low. Voltage drop in a particular section is again a critical issue and should not be more than 1.5%. Hence, the size of the conductor should be chosen accordingly. It is also important to place the PV generators quite close to the inverters, and to work at the maximum DC voltage that panels and inverters can withstand. This will ensure an increased conversion performance and reduction in resistive losses in the system.

Modules mismatching issue

A PV field is normally composed of a number of parallelly connected strings, each string formed of certain number of series connected modules. It is important to remember that mismatching in working conditions of such series connected modules can occur, essentially because of the following.

- Discrepancies in module parameter values caused by manufacturing tolerances
- Different module ageing effects
- Different orientations of modules
- Different solar irradiance levels on modules, caused by different shadowing effects.

On the other hand, the maximum current that a PV module is able to generate, the short circuit current, strongly depends both on its intrinsic characteristics

and on the solar irradiance intensity. In contrast, the maximum voltage of a PV module, the open circuit voltage, has lesser dependence on the solar irradiance intensity, but substantially depends on the operating temperature. For these reasons, when modules are differently shadowed and/or irradiated by the sun, that is to say, if important module mismatching conditions occur, the short circuit current of different modules of the same string can be significantly different among them. The string generated current is physically imposed to be equal to the minimum current value, corresponding to the current generated by the most unfavourably irradiated module of the string, and, finally, the whole power generated by the string can be unfavourably reduced with respect to the maximum available power. In order to alleviate the aforementioned problem, traditionally, a bypass diode is connected in parallel with each PV module of a string.

Grid specific issues

Solar power produced by the modules is injected into the grid, which makes it important for a PV system to follow the norms of the grid. The underlying objective is to maintain both the stability and reliability of the grid. For this specific purpose, some standards are also defined, which deal with the power quality, islanding, protection, penetration level, and so on. Selected issues related to grid power connectivity are discussed in the following sub-sections.

Inverter issues

Inverter technology is the key to have reliable and safe grid interconnection operation of a PV system. It is required not only to generate high quality power from AC utility system, but also do so economically at a reasonable cost. The inverter must also be able to detect an islanding situation, and take appropriate measures to protect both man and the machine. By means of high frequency switching of semiconductor devices, power generation from high efficiency conversion with high power factor and low harmonic distortion is possible. The microprocessor based control circuit accomplishes PV system output power control. The control circuit also has protective functions, which provide safety to grid interconnected PV systems. Following are some of the general features that an inverter should exhibit.

- Less harmonics in output
- Controlled DC power injection
- Islanding protection
- High efficiency
- Low cost

Islanding issue

Islanding is the continued operation of the inverter, when the grid has been removed on purpose either by accident, or due to some damage. The term 'anti-islanding' refers to a feature of a grid- tied inverter that senses a power outage and shuts down on its own. Thus, it stops electricity production. There is a common misconception among solar panel consumers that if there was a blackout, their grid tied system would still keep them going through an outage. Well, this is not true because the anti-islanding feature of a grid-tied inverter will stop the production of electricity, when the grid goes down. If anti-islanding is not done, it can cause safety problems to utility service personnel and related equipments. Consequently, utility companies and PV system owners require that the grid-connected PV systems include the non-islanding inverters (IEEE Std. 1547 2003; IEEE Std. 929 2000).

The available detection schemes are normally divided into two groups: active and passive.

- Passive methods do not have any influence on the power quality, since they just monitor the grid parameters.
- Active methods introduce a disturbance into the grid for monitoring the effect. This may affect the power quality, and problems may arise with multiple inverters put up in parallel with the grid.

Power quality issues

Approximately 70%–80% of the power quality problems are because of faulty connections and/or wiring. Besides this, power frequency disturbance, electromagnetic interference, transients, low power factor, and harmonics are

Table 1 Power quality issues with reference to various standards

Power quality issues	IEC61727	IEEE1547	EN61000
Nominal power	10 kW	30 kW	(16A*230V)3.7 kW
Harmonic currents	4%	4%	2.3 A
Maximum current total harmonic distortion (THD)	5%	–	–
Power factor @ 50% of rated power	0.9	–	–
DC current injection	< 1 % of rated output	< 0.5% of rated output	< 0.22 A
Voltage range for nominal operation	85% -110%	88% - 110%	–
Frequency range for normal operation	50 +/– 1 Hz	59.3–60.5 Hz	–

the other important problems related to the nature of source and load. The IEEE and IEC standards put limitations on the maximum allowable amount of injected DC current into the grid. The purpose of limiting the injection is to avoid saturation of the distribution transformers. Table 1 highlights the most important parameters as given by various standards for grid connection.

Amongst the above mentioned problems, the problem of harmonics problem is predominant as it affects the system most severely. According to the IEEE standard, this could be of two types.

- Harmonic current limit that can be injected at point of common coupling (PCC)
- Harmonics in voltage supplied at PCC

These harmonics could be introduced because of various reasons. The power electronics converter injects harmonics to the grid and poor voltage profile can lead to injection of similar kind of current harmonics. In a PV system, fluctuations in solar irradiance and cloud conditions affect the voltage profile of low voltage grid with high penetration of PV. This could lead to an unstable system and should be avoided. Thus, for an effective operation of PV based power plant, it is necessary to control the quality of power supply that is fed into the grid. This also leads to improved grid reliability.

Penetration level issues

The penetration level is defined as the ratio of nameplate (manufacturers) PV power rating (Wp) to the maximum load connected on the distribution feeder (W). If, the penetration of PV system is high, the clouds and other factors may affect the stability of the grid in terms of power swing and frequency control. In various existing grid connected systems, the allowable maximum penetration level was found to be 15% approximately. The limit is being imposed by the transient capabilities (ramp rates) of the conventional generators.

Following areas need to be considered for the penetration level assessments.

- The effect on the system in steady state and during slow transients (including cloud transients)
- PV response under fast transients, such as switching events, islanding, faults, and lightning surges
- PV effect on harmonics in the system
- Overall performance of the distribution systems

As per a study by the International Energy Agency (IEA), maximum PV penetration will be equal to whatever the minimum load is on that specific feeder. If the minimum load was assumed to be 25% of the maximum load on the feeder and if the PV penetration was 25% of the maximum load, then insignificant over voltages occurred. At minimum loading conditions, any higher PV penetration level increased the over voltages to an unacceptable level.

Protection issues

A grid-tied PV power plant must have various protective features, such as short circuit protection, auto reconnection capability after trip and lightning protection, and so on. Protection should also be for various equipments and for personnel involved in a routine plant operation. There should be isolators, circuit breakers, and fuses at different level of PV modules and strings of modules. These should be fully protected from external environmental effects.

Various field studies have stressed on the need to keep the following points in view while dealing with the PV-grid interfacing.

- The tendency of over-sizing PV system capacity in relation to the inverter can affect the inverter's life and thus, should be avoided.
- Balanced conditions occur very rarely for low, medium, and high penetration levels of PV systems. The probability that balanced conditions are present in the power network and that the power network is disconnected at that exact time is virtually zero. Islanding is, therefore, not a technical barrier for the large-scale deployment of a PV system in the residential areas.
- Balanced conditions between active and reactive load and the power generated by the PV systems do occur very rarely for low, medium, and even high penetration levels of PV systems.
- The probability of a balanced condition does not depend on the number of houses connected to a feeder.
- Inverter failure is the most common occurrence. It was mostly caused by the lack of initial experience in the production stage. However, newly designed inverters have good field performance reliability. Nonetheless, proper consideration should be given to the inverter selection.

The era of PV-grid connected power plants, especially in a megawatt capacity range, has just started in India. As such, core issues merit serious consideration right at the stage of system designing itself. It is equally important to share the field performance data with all those concerned so as to evolve still better operational practices.

Taking advantage of relevant Experiences

Learning from solar power supply in the Sundarban Islands

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Introduction

India has a long-standing record of installing a large number of off-grid solar photovoltaic (PV) systems, under the ambit of a country-wide demonstration programme. However, not many installation programmes have been as successful as the installation in the Sundarban Islands of West Bengal. The Sundarban Islands—largest estuarine mangrove forest in the world—presents a classic case of PV installation and operation from a variety of end-use considerations. This article gives a vivid account of on-the-spot experiences gained by an international team of experts with diverse backgrounds.

Teaming up for a purpose

We had not quite realized who he was, the man, who accompanied us from Kolkata to Namkhana harbour and Moushuni Island in the Sundarbans. At the Bagdanga solar PV power plant, he explained to us the basic setup and operation of the plant. He patiently answered various kinds of critical questions from a group of 24 curious visitors drawn from four continents, some with technical background and others with qualifications in social sciences or business management. This man told us about the ever-increasing demand for electricity on the islands, plans for battery replacement in several of the solar power plants, and an 'entrepreneurial model' for distribution and sale of power from the plants in the future. He mentioned that because of lack of capacity, all those who did not have a connection to the solar mini-grids would get subsidized solar home systems. He also explained why this was a part of West Bengal Renewable Energy Development Agency's (WBREDA) future strategy.

Fifteen years of experience in solar mini-grids: a rare and precious asset

We came to know that our guide, Angshuman Majumder, a divisional engineer with WBREDA, has been involved with the planning and practical work, ever since WBREDA started to supply renewable electricity to the islanders more than 15 years ago. With his experience of solar mini-grids, solar-hybrid mini-grids, and other forms of new and renewable energy power systems, Majumder became our key source of information. Our purpose was

to try and understand the different steps that had been taken, the challenges that had been met, and the lessons that had been learnt on various aspects of local solar power supply. For someone with a strong ownership of the electricity project in question, Majumder was open and self-critical in his approach. These clearly resulted from his commitment, in line with the commitment of other WBREDA staff whom we met during our three week-long visit, to continuously adjust and improve the performance of an emerging technology. Also, their willingness to share experiences seemed motivated by a genuine interest to help establish sustainable renewable electricity systems elsewhere.

Because of our background study, the name that we did know was that of the former director of WBREDA, S P Gon Choudhury. Choudhury is a pioneer in this field and, in fact, a driving force behind the project from the very beginning in 1995/96, until he retired. With funding from the central government (Ministry of New and Renewable Energy, Government of India) as well as from various sources within West Bengal, he played a pivotal role in the development of the system design, the organizational structure, and the implementation strategies for the solar mini-grids in the Sundarbans. The strategies gradually evolved based on actions and experiences. During all these years, Majumder had been working in close association with Choudhury in the process of building and sustaining the mini-grids in these islands, interacting with different actors at the local level, facilitating local participation, involving contractors for the operation and maintenance, organizing the tariff collection, and so on.

There are many who argue that it is difficult to reproduce the success of the installation of solar energy in the Sundarbans, mainly because, in this region, there has been a strong drive and motivation from individuals, which seems to be missing in most other places. But such a drive is, of course, possible to create by other enthusiastic individuals in other places too. For example, in our team from Kenya, which visited the Sundarbans, we had people with a strong wish to do something innovative in the solar energy field in their country, and somebody in the group even started to talk about one of them as the 'Gon Choudhury of Kenya'. It is also clear from the history of technological change in society, for example Thomas Alva Edison and his introduction of electric lighting in New York and Chicago, that we need pioneers to promote new and promising technological solutions and integrate them in the society.

Viewing a solar mini-grid for the first time: a dream come true

To us, the field visit to the solar mini-grids in the Sundarbans, in the vast delta of the holy river Ganges, was a very exotic and exciting experience. We had first heard about the WBREDA solar power plants in 2003. As a Norwegian student, Kirsten Ulsrud did her field work in New Delhi in order to study some of the experiences of key people who had been involved in the implementation of solar energy activities of different kinds in India. Some sources told her about a promising model for the use of solar PV technology in the rural areas—small solar power plants with local electricity grids distributing the power to people. Their advantages were that the users did not have to be responsible for the capital investment and the maintenance of the systems, as they usually have to for the solar home systems. These systems also made it possible to supply a little bit of electricity for few income generating activities.

Ulsrud wanted to pursue a research project, whereby Indian experiences on solar mini-grids could be studied in-depth by a multidisciplinary team, so that other upcoming solar energy efforts in other places could take advantage of these experiments and experiences. After spending some time on developing research ideas, writing proposals, putting together a team of researchers and practitioners from different countries, and raising funds for the research and travel for many people, we, the Solar Transitions research team, finally went to Sundarbans for the first field visit along with guests from various countries. Thereafter, we were to do some field work in two of the islands as smaller research teams.

Sitting in a boat, on the way to Moushuni and Sagar Islands in the Sundarbans, there was a strong feeling of excitement in some of the passengers, because after studying about village-scale solar power plants for so long, we were going to see it for the first time. Now the time had come for actually getting there and finding out what had happening and the current situation in the 'solar villages'. In fact, it felt rather unreal—and for everyone most of the things were very exotic, even for our colleagues from India—the wooden boat, the group of people from four continents with so much to talk about despite very different backgrounds, the landscape of flat islands encircled with mangrove forests and high embankments, the extreme tide-differences, and the image that we had of this region from Amitav Ghosh's book, *The Hungry Tide*. There was also a small, underlying concern that our fascination with the success stories on solar mini-grids in the Sundarbans would lead to some kind of disappointment, as we cam face to face with the reality on the ground. Maybe some of our illusions and hopes for finding suitable working models for implementing and organizing off-grid solar power supply would be broken.

Why are we interested in India's experience?

The research done in India is the first part of the research activities for the Solar Transitions team, comprising researchers and practitioners from Kenya, India, Norway, and Austria. The second part is the transfer and adaptation of the Indian experiences to Kenya, through action-oriented research. India and Kenya have been selected for the research pursuit, because they are amongst the leading countries within decentralized, distributed use of solar electricity, even though solar electricity still constitutes a very small fraction of the overall electricity supply in both these countries. In Kenya, the diffusion of systems has to a large extent been market driven, while in India, the government has actively promoted solar technology. Partly due to this, India has a higher diversity in terms of the various types of systems, including a significant number of solar mini-grids. The solar energy activities in Kenya are mostly concentrated on the use of very small household systems, although some larger systems are installed at schools and tourist camps, and the government is gradually becoming more involved in the solar energy efforts. In Kenya, the solar home system market is thriving. The Indian experiences were of special interest for the Solar Transitions research team, that is, the implementation, organization, use and socio-economic impacts of village scale, solar powered mini-grid systems. Until now, these experiences have practically been unknown to the Norwegian and Kenyan solar and renewable energy actors, who find them highly relevant for many developing countries.

Why have we chosen to study the solar mini-grid cases in the Sundarban Islands?

We were aware that the WBREDA solar mini-grids in the Sundarbans were not the only ones that we could have studied, since solar mini-grids exist in many other places in India, including Lakshwadeep Island, Chhattisgarh, and other areas. In all these places, actors have made use of the government support systems and other funding opportunities to develop such activities and systems. We are also aware of the recent Norwegian projects that are being implemented in cooperation with the Indian government. It would have been relevant to investigate all of these projects. However, we are convinced that given the long-term experience, and the gradual, dynamic changes in the way the population and involved stakeholders both relate to and influence the solar power supply, the Sundarbans is a very useful and interesting case and a good source of knowledge and information. There has been a steady growth in activities during these years, lessons have gradually accumulated, and the effects of the strategies have been emerging and becoming more and more visible. In addition, to the Sundarban experiences, the activities that have taken place in Chhattisgarh, during the last five years, is also very interesting and some information is also being collected from there.

In the proposal that led to the funding of the Solar Transitions research project, which has now allowed us to do research on the Sundarban solar mini-grids, says, "through the years of experience with the implementation and social organization of these solar power plants in the Sundarban Islands, a considerable amount of learning has undoubtedly taken place. This project aims to contribute to the understanding of success factors and lessons learnt in the process of implementation and use of these solar power plants as well as how such experiences can be transferred and adapted to other communities and countries, developing their solar energy sector as well as their distributed energy provision in general."

The organizational details matter

In our social science led research, we are interested in learning about as many aspects as possible of these solar power systems—how they are designed in the technical sense, how the operation and maintenance is organized, how the subscription and tariff collection works, which solutions have been developed for an effective load management, which economic model has been used, what funding sources are available, and what kind of cost recovery has been aimed at. We look at how all this has worked, and why, and what adjustments have been done in the programme in order to successfully meet the challenges. We also want to learn about how the electricity supply is perceived by and works for the customers. Who are, and who are not customers, and why. How the electricity supply is linked to opportunities for income generation, improved health and education services, access to information and communication opportunities, and so on. Here, a central element is to explore the linkages between the ways the

energy supply is organized and the impacts it has on the local socio-economic development. The role of the framework conditions is also part of the research questions.

The research is being undertaken by an international and interdisciplinary group of social scientists, technical solar energy experts, and stakeholders from development and solar energy agencies. The project has five partners from Kenya, four partners from Norway, one from India, and one from Austria. Through action research, the project will facilitate interaction amongst the researchers and three local communities in Kenya, as well as renewable energy actors, NGOs, and policy-makers in the process of the 'South–South–North' learning on social and technological innovations. The interdisciplinary and the diverse backgrounds of the team members help covering a diversity of aspects of the solar power supply, and this approach is considered crucial for understanding the systems at large.

Field work

We did field work in six villages with solar mini-grids in Sagar and Moushuni Islands in Sundarbans. These were Mrityunjoynagar, Natendrapur, Kaylapara, and Khashmahal in the Sagar Island and Bagdanga and Baliara in the Moushuni Island. We also visited the diesel-wind-biomass gasifier hybrid mini-grid in Gangasagar in Sagar Island. The mini-grids had installed capacities from 25–120 kW each, and each of these systems supplied electricity to 80–300 customers through local electricity grids, for 2–5 hours per night. At optimal performance, the systems supplied five hours of electricity each night, but the batteries, which are a weak technical part of this kind of technological solutions, were now ready for replacement in many of the plants, so therefore, the supply was for a shorter duration. In Mrityunjoynagar, the plant was not working at the time of the visit. In each of these power plants, there are one or two operators. They are responsible for switching the power supply on and off (starting from 1800 hours), keeping record of the power sent out, and generally supervising the system (charging and re-charging), which to a large extent is controlled automatically. Also, they are responsible for maintenance, including the cleaning and maintenance of PV plant/solar panels and maintaining battery banks, for example, by topping up with distilled water. These operators also take care of the maintenance of distribution lines and other parts.

Local politicians and teachers had been involved in the planning of the power plants, and the main involvement of local stakeholders goes through the Beneficiary Committees (BC), which has been set up for each plant, whose members represent the customers. They also have the responsibility to look after over-drawal of power by the customers. Customers either have a three or a five flat point contract based tariff, and consumption is not metered. Currently, connection rates are Rs 1000 for three points and Rs 1500 for five points. Monthly tariff is between Rs 80–130, respectively. In comparison, households we met without electricity connection said they spend anywhere from Rs 18–194 on purchase of kerosene for lighting per month, with spending of Rs 100 being quite common. In the Sagar Island, revenue collection is handled by an Energy Cooperative, whereas in Moushuni Island, a man has been hired to do the revenue collection.

The informants in our research team included operators and other staff at the solar mini-grids and hybrid mini-grids including tariff collectors, the Sagar Rural Energy Development Cooperative, village beneficiary committee members, schools and school hostels (boarding schools), families and businesses with or without connection to solar mini-grids, companies supplying solar power systems, contractors for operation and maintenance, and state agency staff, such as WBREDA. Other types of informants were people on a waiting

THE SOLAR TRANSITIONS PROJECT

The full name of the Solar Transitions project, which is funded by the Research Council of Norway, is 'Village-scale solar power plants, transfer of social and technological innovations between India and Kenya'. The project was initiated by the University of Oslo, the Department of Sociology and Human Geography, Faculty of Social Sciences, and lasts from 1 April 2009 to 1 April 2013.

THE SOLAR TRANSITIONS PARTNERS

The partners are Camco, Kenya; African Centre for Technology Studies (ACTS), Kenya; Integrated Energy Solutions, Kenya; Norwegian Church Aid East Africa, Kenya and Norway; SunTranser, Kenya; The Energy and Resources Institute (TERI), India; Inter University Centre of Technology, Work, and Culture (IFZ), Austria; The University of Oslo, Norway; Noragric at the University of Life Sciences (UMB); and SWECO Norway AS, Norway.

list for connection or subsidized solar home systems, people who could not afford to get connected, people who had their own solar home systems, and local governing bodies.

Insights from the research

After the first field excursion for 24 people from Kenya, Norway, Austria, Brazil, and India and the subsequent field work in the islands for this team, the research is still in progress, but preliminary findings are emerging. While the research findings will be presented exhaustively at a later stage, here, we wish to highlight a few points based on our immediate observations. It is very clear from the field work in the villages in the Sundarbans that many positive results have been achieved by the involved actors in the village-scale solar power supply. Families and small businesses have received an opportunity to modify their everyday life in a way that they would otherwise not have had. They now use a little light for some hours every day, charge their mobiles, and watch television, and this represents a major shift. In fact, people's positive experiences with solar electricity has produced a demand that is becoming too big for the existing systems to meet. At the same time, it is clear that the task of providing stable electricity has been, and remains, challenging. Some difficulties are partially created by the technical limitations, especially in the battery technology, which also produces challenges in terms of the social organization, operation, maintenance, and user friendliness of the power plants. For example, too quick discharging can damage the battery, and this increases the need for preventing the customers from drawing more power than what is stipulated in the contract. Furthermore, the operator has to make some unpopular decisions sometimes, in terms of turning off the power supply earlier than what the customers expect, so as to protect the battery bank.

In other words, there are technical aspects in the systems that make the social aspects (maintenance, operation, expectations of paying customers) more complicated than they could have been, if some of the technical elements had reached an advanced stage. When the quality of power supply reduces, the contract with customers is also jeopardized and non-payment may result, as had happened in several villages during the last year. However, there was a good record for tariff collection and payment for most of the years that the power plants had been in operation. As a means to meet such challenges embedded in the technically weakest part of solar systems, which also requires care in operation and maintenance, WBREDA is planning to use a new type of contract for the maintenance of the inverter, charge regulator, and battery, and the use of the best available charging and discharging regulators and advanced inverters to avoid some of the battery problems. They also underlined their financing philosophy, which regards batteries (also replacement) as investment in line with PV cells and other installed equipment. This is subsidized by the central authorities and thus, financially separated from operation and maintenance costs, which are supposed to be covered by customers through the collection of tariffs.

Furthermore, as indicated, it is also a challenge to meet everybody's demands and needs, and to ensure that the energy is used in an efficient way. It is also not so straightforward to create an equitable, practical, and locally based system for tariff collection. Because of these and similar challenges and WBREDA's willingness to share them and adjust their procedures, there is much to learn from the Sundarban experience for those, who would like to implement similar systems in other places, like our Solar Transitions team hopes to manage in Kenya.

Society and technology develop in mutual interaction with each other

As pointed out in the social science research, new technological systems (like for example decentralized solar power supply) gradually develop and take shape through a long-term process, where the users of the technology, as well as the technology implementers, suppliers of the technical equipment, and other actors who are involved, gradually develop the way the technology is organized and used. This process is influenced by the preferences, needs, and actions of the involved actors, and how people also adjust themselves, their habits, and preferences to the opportunities and limitations of the technology. Through such mechanisms, technology and society develop together in a process of common evolution at various social levels, and a constant interaction between human beings and technical equipment takes place.

In the case of Sundarban Islands, we can see such an interaction between technology and society, for example, in the dynamics between power supply and growing demand. Such dynamics become very visible in the off-grid power supply systems, where the installed capacity locally is what you can use. In the Sundarbans, after the early stages of the implementation processes in the villages, when the implementers first worked to get a sufficient number of people interested to connect to the power supply, the interest soon exploded. Most of those, who have applied for connection after the capacity of the power plants was saturated, have ended up on a waiting list. For the Sagar island, however, there are plans to connect the island to the main grid of West Bengal so as to meet the present, high demand. In Moushuni island, people's chances of getting new connections are little, because there are few plans to extend the existing power supply. Here, solar home systems are considered by WBREDA as the means to achieve full coverage, and a subsidy scheme was just being commissioned at the time of our fieldwork.

Thus, consumption increases over time because more people want a connection. At the same time, all those who already have electricity supply find innovative ways of using more than the ascribed kilowatt-hours, (either through charging practices or drawing more electricity from each of the light/electricity points than what has been mentioned in the contract. In any case, every customer's demand is also rising with time. The total increase in demand demonstrates electricity's popularity. The solar power supply, although providing power only for some hours in the evening, has meant a significant change in peoples' lives. The fact that businesses and families want more of this good reveals that they find electricity to have some distinct financial and social advantages.

Somebody must take the risk and be the pilot

Prior to our field work, we had wondered as to what extent we would gain access to the more difficult sides of the implementation, operation, and use of the solar power plants and mini-grids in Sundarbans. Sagar has been described as 'the Solar Island' due to the 13 solar plants it hosts. Would our findings support a corresponding 'sunshine story'? Our previous experiences had told us that there are always challenges involved in technology transfer. But since Angshuman Majumder and his colleagues are hoping that their information and experience can contribute to the general progress in the field of solar power supply, they saw it as important to share both their positive and negative experiences.

Our immediate conclusion is that some of the factors that have led to the success of the solar power project in the Sundarbans have been WBREDA's focus on including local groups in the process and applying a financing model, that has ensured poor people's access to affordable, renewable electricity. However, one also needs to mention the implementer's monitoring and awareness of the pitfalls and their willingness to change practices along the way. They have created the solar power systems with a considerable amount of trying and failing (learning) and some of the lessons during the 15 years have been learnt the hard way. It is tough work to be pioneers of new technological solutions. But without such dedicated efforts, new technological systems do not develop. And it is important to make the knowledge and experience available for others who plan to attempt to implement solar or other renewable energy supply in off-grid, village scale systems. This is what the Solar Transitions project aims to contribute. WBREDA is now in the process of upgrading many of the Sundarban power plants and thus, renew the organizational business models for their operation and the distribution of electricity, and the results of these ongoing efforts and experiments will be interesting to follow.

THE RESEARCH

The Solar Transitions project investigates factors that influence poor people's access to solar energy solutions, as well as the role of solar energy supply for climate adaptation and poverty reduction. The project also facilitates social learning processes for the creation of social and technological changes. The research focuses on two aspects of socio-technical learning. First, the project concentrates on how to implement and socially organize local energy supply with solar energy in ways that benefit people, including marginalized groups, and embeds the technology in local communities and climates. Secondly, the project initiates and analyses a process of South-South transfer of social and technological innovations between India and Kenya.

UNDERSTANDING THE VITALS OF PFS, FS, AND DPR FOR SOLAR ENERGY PROJECTS

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Introduction

Solar energy projects are almost similar to other technical projects. These require sound planning and coordination outlook and are often constrained by budgetary allocations. They demand enunciation of a clear set of objectives, so that the most suitable feasibility approach is selected. Success of any project undertaken depends on the quality of the pre-feasibility study (PFS), feasibility study (FS), and finally the detailed project report (DPR) preparation.

Understanding the vitals of these three types of studies for solar energy projects can be summarized in the following few strategies.

- Finding the best locations for new solar energy systems
- Reducing the time and cost of pre-feasibility solar studies
- Securing success of solar development
- Increasing the efficiency and effectiveness of policy development

At the time of investigating the solar resource within a given land area, several approaches are available for use. The preferred approach will depend on the objectives of the solar energy programme and on previous experiences with solar resource assessment. Therefore, adopting effective and efficient solar development

projects with accompanying goals and issues must be defined in the framework of articulating the obstacles for solar development along with specific measures to remove them. In fact, two of the most important vitals have to do with the risk factors and economic limitations.

Solar energy is an unlimited energy resource, set to become increasingly important in the long run, for providing electricity and heat energy on a large scale. It is an energy resource that could be used in large, centralized power generation plants; smaller distributed heat and power plants; or scaled down, at the individual consumer level. Solar energy technology is technically well proven and draws on an inexhaustible primary energy resource.

Definition and purpose of FS, PFS, and DPR

PFS examines solar energy options for electricity generation in a given location. It can be argued at this stage as to which solar energy technology is preferred. There are two major alternatives—solar photovoltaic (SPV) and solar thermal energy technologies. Solar PV technology collects and converts solar radiation directly into electricity. Solar thermal generation systems collect solar energy to generate steam for use in an otherwise conventional thermal electricity generating plant (steam turbine). Low intensity solar energy is used for water heating and, less commonly, for air/space heating, solar ponds, and solar chimneys. However, it is high temperature solar systems that seem to be the most appropriate for large-scale power generation. These require solar radiation to be concentrated so as to achieve temperatures high enough to be thermodynamically useful, and are also known as Concentrating Solar Thermal (CST) systems. CST is best suited for relatively large generation plants, which are different from the smaller household rooftop PV systems.

The PFS study examines solar electricity generation technologies, undertakes a brief analysis of those that could be considered suitable, and identifies a preferred technology for further techno-economic evaluation.

The review and selection of a preferred technology includes the following.

- An assessment of the technology
- Consideration of the practical status of the technology and commercial experience
- Consideration of the solar resource in the location
- Cost and risk investigation

A solar FS study, however, is defined as an evaluation or analysis of the potential impact of a proposed solar project or programme. It is basically conducted to assist decision-makers in determining whether or not to implement a particular solar project or programme. The feasibility study for solar projects is based on extensive research on both the current practices and the proposed project/ programme, along with its impact on the proposed project. This study will deal with extensive data related to financial and operational impact, advantages and disadvantages of both the current situation, and the proposed plan of the solar project.

Goal of the FS

FS report is prepared to support the investment proposal. Feasibilities related to various technical, commercial, and financial aspects are examined in detail by the experts designated for the purpose. FS report is normally termed as a techno-economic FS. It is the primary report for the formulation of the investment proposal. Investment decisions are taken based on the details incorporated in the study. Thus, feasibility is prepared only for the formulation and investment decision-making. The first step in FS is the need-based analysis. The purpose is to define the overall objectives of the system proposed to be designed. The second and perhaps the most important thing is system identification. This is referred to as activity analysis of the following nature.

- Project justification
- Resource identification for project development
- Technology selection
- Capacity determination
- Process description and layout plans
- Infrastructure availability
- Evaluation of available facilities
- Capital cost assessment
- Profitability analysis
- Project schedule and implementation plan
- Design and flow diagrams

Following the preparation of a FS report, it should be subjected to a thorough scrutiny by the subject area experts. Modifications, if any, must be carried out based on their opinions.

Preparation of DPR

Preparation of a DPR is the next logical step in firming up a project proposal. It is appropriate to firm up the capital cost once an investment proposal has been approved on the basis of a functional report. Key elements of DPR may include the following.

- Technology assessment
- Technology detailing
- Broad technical specifications
- Evaluation of the existing resources
- Schedule plan
- General layout
- Volume of work

Hence, these reports are to be made before investing in any project. Thus, formulation of investment is based on the studies initiated. These can be considered as pre-investment decisions. Detailed project report is not only for the investment specific decision-making approval, but also for the execution of the project and preparation of the plan. DPR, additionally, includes the following.

- Project description
- Planning and implementation of the project
- Specifications
- Layouts and flow diagrams

As per the above paragraphs, DPR will be a complete document for investment decision-making, approval, and planning. Thus, while FS report is a base document for investment decision-making, DPR is a base document for planning and implementing the project.

Defining successful solar design

In defining a successful solar design, achieving of targets set through the three stages of studies must be optimized and the obstacles noted. The few obstacles, which hinder successful solar energy project development are as follows.

- additional (unexpected) administrative expenses
- long, non-transparent, and costly permission procedures
- uncertainty about successful application / failed projects
- high market-entry barriers
- potential changes in future regulation
- risky market environments
- uncertainties regarding the direction and effect of technology development (lock-in)
- industrial bottlenecks and limited growth

Solar energy resource

The evaluation of the solar resource for a specific project requires an understanding of the basic principles of solar radiation. Every part of the earth gets sunlight, at least for some part of the year. However, the amount of sunlight reaching the earth varies according to geographical location, time of the day, and season.

Factors are responsible for variations in the amount and quality of sunlight that the earth receives are as follows.

- The shape of the earth
- The earth revolves around the sun in an elliptical orbit
- The earth rotates on a tilted axis

Since the earth is round, the sun strikes the surface at different angles ranging from 0° (just above the horizon) to 90° (directly overhead). When the sun's rays are vertical, the earth's surface gets all the energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse. Since the earth is round, the frigid polar region never gets a high sun. Because of the tilted axis of rotation, these areas get no sunlight for some part of the year. Because the earth revolves around the sun in an elliptical orbit, it is nearer to the sun during most parts of the year. When the sun is nearer to the earth, the earth's surface receives more solar energy. The earth is close to the sun when it is summer in the southern hemisphere and winter in the northern hemisphere. However, the presence of vast oceans moderates the hotter summers and colder winters.

Nature and use of solar radiation

The amount of sunlight falling on specific locations at various times of the year is usually measured to estimate the amount of sunlight falling on regions at the same latitude with similar climates. Measurements of solar energy are typically expressed as total radiation on a horizontal surface. Radiation data for photovoltaic (PV) systems, which produce electricity, are often represented as kilowatt-hours per square metre (kWh/m^2). The sun is a reliable source of energy and the earth receives this on its surface as relatively diffuse energy. It has a maximum flux of about 1 kW/sq m in Australia compared to India's 4–7 kWh/ sq m. There is a variable daily cycle with seasonal variation and may be intermittent, influenced heavily by meteorological conditions, such as cloud. Solar energy, being radiant energy, cannot be stored directly.

Solar insolation or the total amount of solar radiation received at a given point on the earth, is made up of two components—direct and diffuse insolation. Calculating the amount of sunlight available for a solar energy system is complex and challenging. Atmospheric conditions, the changing position of the sun, and the local terrain interact to moderate the solar resources at a given time and place. Historical data about weather, climate, and air pollution are vital for designing a solar energy system for a specific site. The sun's position throughout the year must be considered. Also, care must be taken to use published information about solar radiation that applies to tilted, south-facing collectors. And there must be basic understanding on how seasonal weather patterns affect sunlight, and also how they affect solar energy system requirements. Whether sunlight is direct or diffuse can significantly affect solar energy system performance. Solar electric systems require direct sunlight.

Collectors for solar heating systems, including passive solar buildings, capture both direct and diffuse solar radiation. In some areas, solar energy systems will capture significant amount of sunlight reflected from nearby white surfaces such as light-coloured sand. We need to account for the surface reflection where they exist.

Direct radiation

This type of solar radiation is received directly from the orbit of the sun and is of interest for solar concentrators used in CPV and solar thermal systems. Direct estimates of solar energy may also be expressed as watts per square metre (W/sq m). Radiation data for active and passive solar energy systems, which produce heat, are usually represented in British thermal units per square foot (Btu/ sq ft).

The following equation can be used to convert from one system of measurement to the other.

$$317 \text{ Btu/ft}^2 = 1 \text{ kWh/m}^2.$$

Diffuse radiation

Solar radiation, which get scattered while passing through the earth's atmosphere is referred to as diffuse radiation and includes reflected solar radiation and solar radiation re-reflected from the earth. Assessing climate helps define system requirements for solar projects. Seasonal weather patterns affect heating and cooling requirements as well as the solar resource. During winters, heat loss is affected by the outdoor, or ambient temperature. The colder it is outside, the faster a solar collector will lose heat, thus reducing its efficiency. Low temperatures also increase heat loss from the buildings. Lower the daily average outdoor temperature, higher the heating requirement will be. Winter heating requirements usually increase when there is less solar energy available. For this reason, it is better to design solar-based projects to capture the maximum amount of energy from the winter sun. Then the principles of climatic design can be applied to keep the system from producing too much heat during summer. Figure 1 shows the radiation network in India.

Global radiation

Global radiation comprises both the direct and diffuse components and is of interest for flat-panel and tracking PV power generation systems. The amount of solar radiation of all types received is influenced by the location of the receptor on the earth's surface and by its orientation. Fixed receptors oriented toward the sun collect less solar energy than those that track the sun. It is important to note that concentrating systems use the direct beam component of global (total) solar radiation and as with many renewable energy solutions, weather conditions, such as cloud, haze, and fog, play an integral role in system performance. Direct or normal beam radiation data is, in general, less readily available than other solar energy data. The most common type of PV system in India is the flat-panel collector or module, which is typically inclined at a latitude angle. This usually is the best compromise between minimizing cost and maximizing annual energy collection. The same is true for a solar hot water collector. An alternative form of installation is sun tracking, where the solar collector panel is mounted in a mechanism that tracks the sun. This can be on one or two axes and results in higher energy collection for the same size solar collector, but comes at a higher

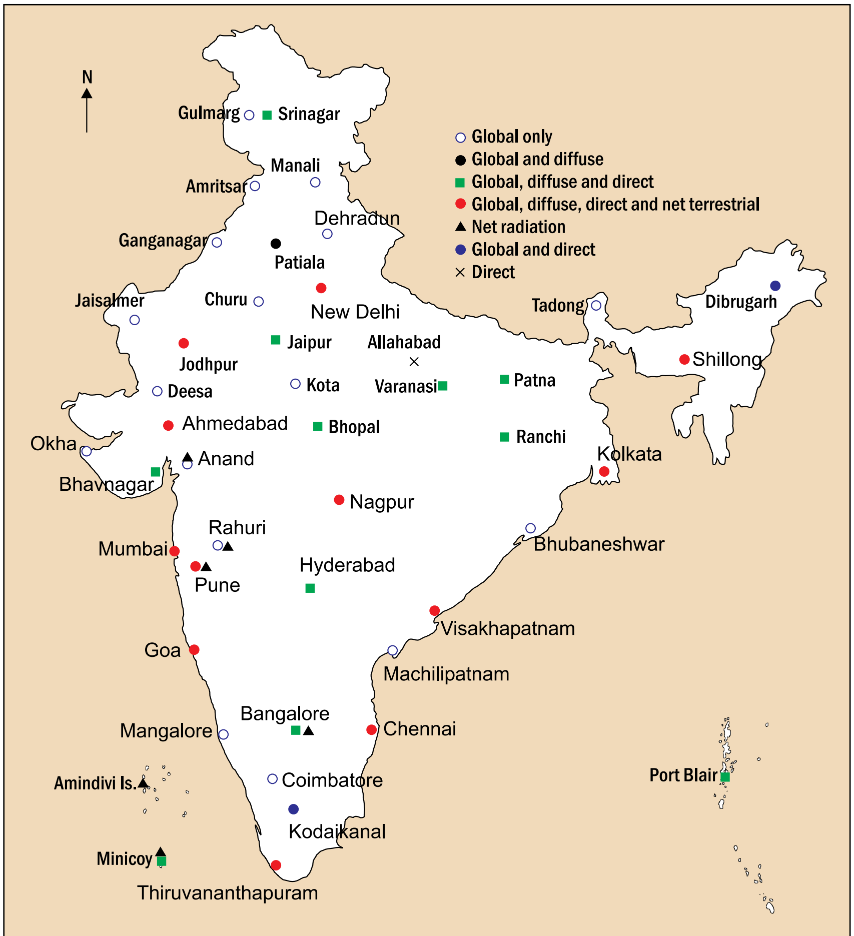


Figure 1 Radiation network in India

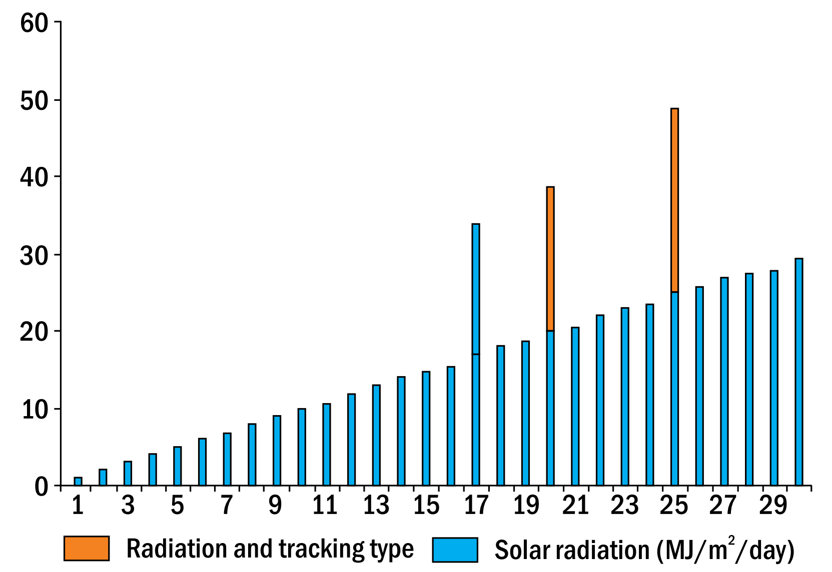


Figure 2 Solar radiations in Canberra

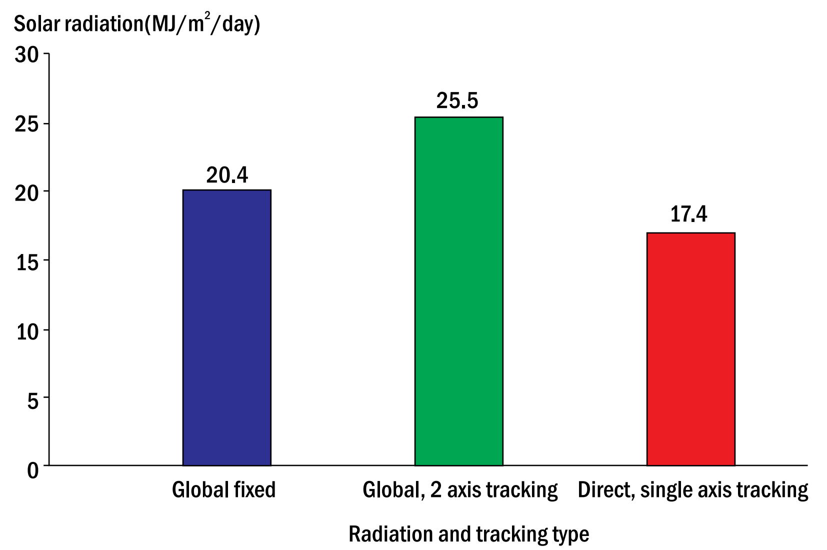


Figure 3 Impact of solar radiation in Canberra

cost. The impact of tracking on energy collection is illustrated in Figure 2, Figure 3, and Figure 8 and Figure 10.

Solar concentrating systems are usually of a sun tracking type.

Estimation of average daily global radiation

Angstrom proposed the following empirical correlation for computing the average daily global radiation on a horizontal surface.

$$\square/\square_c = \hat{a} + \square\, \hat{S}_a/S_p \qquad (1)$$

where

$\square$ = monthly average daily radiation on a horizontal surface

$\square_c$ = average clear sky daily radiation for the location and month in question

â , $\square$ = empirical constants

$\hat{S}_a$ = monthly average daily actual hours of sunshine

S_p = monthly average daily possible sunshine hours

There is an ambuity in defining clear day and hence, to get $\square_c$, the above formula was modified using extraterrestrial solar radiation, $\square_o$

$$\square/\square_o = a + b\, \hat{S}_a/S_p \qquad (2)$$

where

$\square_o$ is the extraterrestrial solar radiation on a horizontal surface and can be calculated as

$$\square_o = 12 \times 3600/\Pi \times I_{sc}\,[1 + 0.033\, os(360/365)n][\cos L \cos\delta \sin W_s + \Pi W_s/180(\sin L \sin\delta)] \qquad (3)$$

where

W_s is the sunset hour angle in degrees, n is the average day for the whole month, and Π is in radians

$\hat{S}_a$ is measured value of actual sunshine hours and can be calculated for any place from this relation

$$S_p = 2W_s/15 = 2/15 \cos^{-1}(-\tan L \tan \delta) \qquad (4)$$

Equation (2) can be used for calculating average daily global radiation at a location when data on actual sunshine hours, S_a, possible sunshine hours, S_p, extraterrestrial solar radiation, H_o, and values of a and b are known for a place, is found out by plotting a graph between known values of $\square/\square_o$ and $\hat{S}_a/S_p$, as shown in Figure 9. This figure shows the estimation of average daily global radiation.

Reliability and measurement of solar radiation

Global solar radiation data is readily available and reliable for all locations. The same is not true in case of direct radiation specific data. Data is available on direct solar radiation in Delhi, and the extent to which the available data has been verified is very clear. The success of a solar thermal project depends heavily on the quantity and quality of the resource data. It is recommended that site specific monitoring be carried out at one or more potential sites. There are a few organizations with the capability to

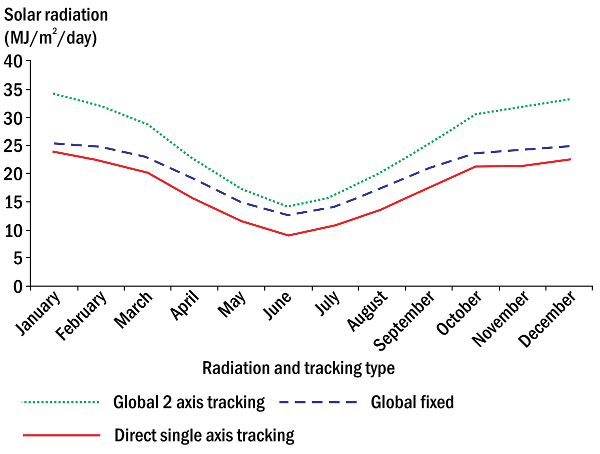


Figure 4 Monthly solar radiation in Canberra

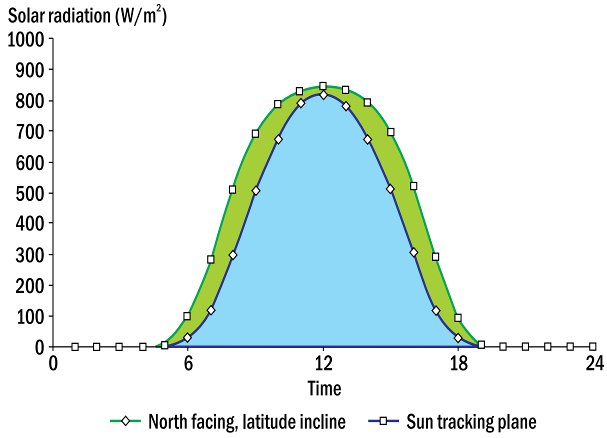


Figure 5 Hourly solar radiation in Canberra

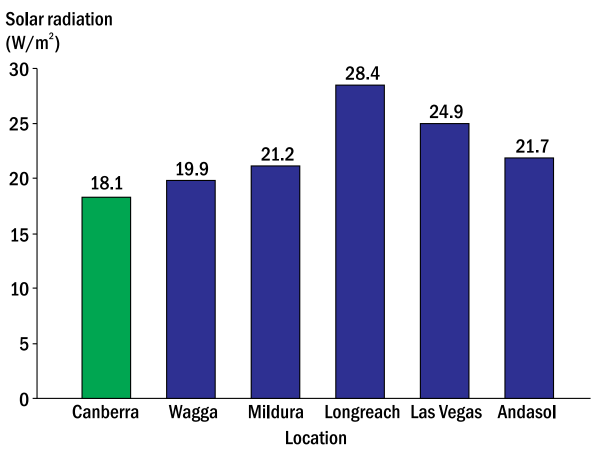


Figure 6 Solar insolations at other locations in Australia

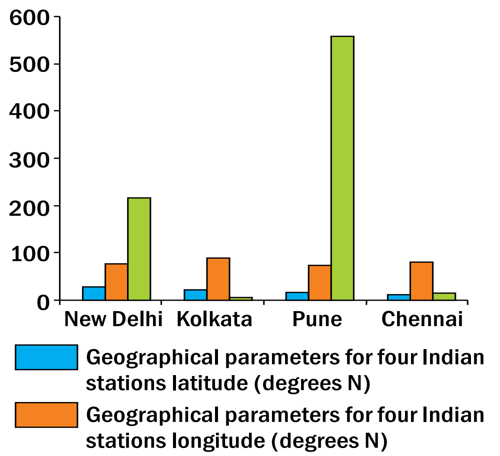


Figure 7 Geographical parameters for four Indian stations

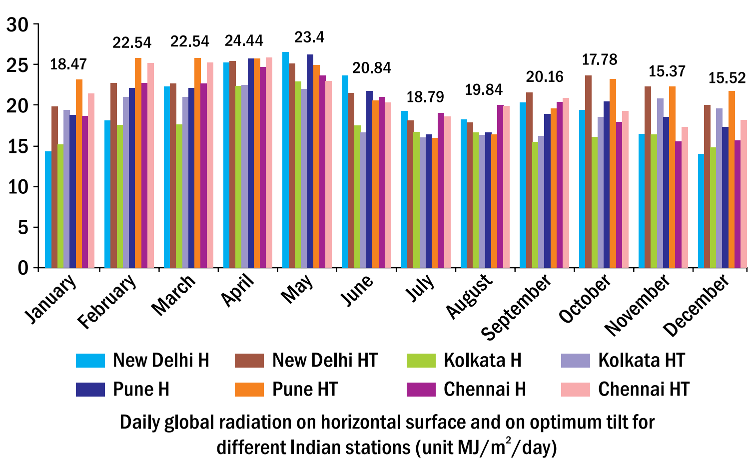


Figure 8 Daily global radiation on horizontal surface and optimum tilt for four different Indian stations

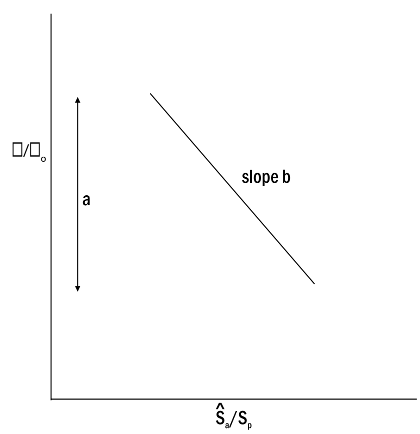
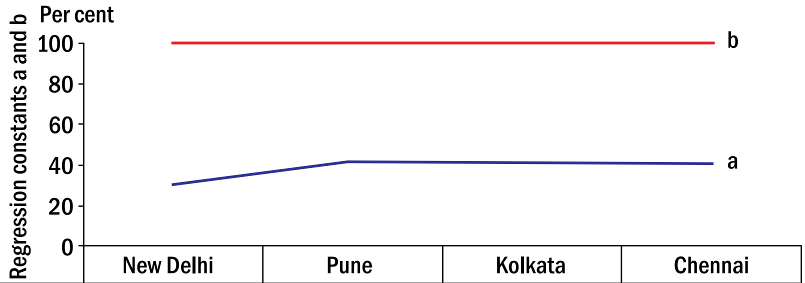


Figure 9 Graph of □/□$_o$ against $\hat{S}_a/S_p$



	New Delhi	Pune	Kolkata	Chennai
b	0.57	0.43	0.42	0.44
a	0.25	0.31	0.28	0.3

Figure 10 Annual solar radiations at other locations in India

measure, record, and verify direct solar radiation and to correlate it with existing stations.

In India, such capability is probably limited to a few organizations such as the India Meteorology Department (IMD), Solar Energy Centre (SEC) of the Ministry of New and Renewable Energy, (MNRE), Indian Institute of Tropical Meteorology, and so on. It is often necessary to recommend that discussions be held with these organizations with a key objective of scoping and costing a monitoring and data verification programme. There is also a need for correlating this with other direct radiation data from the weather monitoring stations put up at the aviation centres. Until a programme of work is fixed, it is inappropriate to establish the cost of an associated measuring and verification programme. This scope of work should include the identification of the differences that exist among the sites in the same region. For instance, the existence of local conditions like dust, cloud, or haze could significantly affect the quantum of available solar energy. This, in turn, would impact the power output available from a solar energy system.

System requirements and climate

A good project designing takes into account climate specifications and prevents over heating during the summer months. Such issues should be considered during the PFS. Obtaining specific data on the solar resources in any area will help design the most effective solar PV system.

Climates can play an important role at the following four stages in the solar energy system design process.

- The evaluation of the solar resource
- The definition of system requirements, including the impact of climate-related factors on system project design
- The analysis of existing site-specific micro climates
- The design of systems, buildings, and landscapes to maximize performance.

Until recently, solar projects involved series of complex calculations to determine the size of the solar resource, figuring out heating and cooling requirements in different parts of the country at various times of the year, and deciding the optimal size and orientation of a solar heating or electric system. Once this information is obtained, integration of the various plans for a new solar project or building and the landscape can be done. Today, the design process is made easier because of the number of resources available on the Internet or on CD-ROM. However, accurate prediction of latitude and longitude with a detailed analysis of local solar resources along with information on long-term weather patterns can be very useful.

Other resources for climate and design, which are vital during the studies include the following.

- Green design checklists
- Strategies for finding the best locations for new solar energy systems
- Strategies for reducing the time and cost of PFS
- An easy-to-use method for estimating the performance of PV systems connected to the power grid
- A programme that calculates the location of the sun in the sky—any place, any day, any time

Detailed assessment of risk factors and potential administrative barriers

Solar power behaves quite differently than conventional power generation. If solar and other renewable power sources are to be integrated rather than simply added to conventional power systems, then procedures need to be developed to analyse their risk contributions that are part of their unique characteristics.

The deterministic approach for allocating operating reserve based on the loss of the largest operating unit does not recognize the inherent probabilistic nature of system behaviour and component failures and therefore, cannot estimate the system operating risk appropriately.

Categorization of risk factors

Infrastructure projects, such as solar projects, require capital on a large scale and a long congestion period is involved. Development of infrastructure projects is vital for the economic growth of any country. These projects provide forward and backward linkages to the industry. Development of solar projects is capital intensive due to the technological requirements and gestation period is high owing to its constant unavailability.

Return on capital in case of solar projects is small as well as slow. Hence, investors are shy to invest capital in solar projects, unless some special incentives and privileges are provided.

Technical risk

Under the technical risk, it is examined whether the design and technology used in the project are viable to the country or not, coupled with the following.

- Volume of fuel input
- Investment costs
- Operation and maintenance costs

- Plant availability
- Expected plant lifetime

Political risk

Political and regulatory risks are inherent in doing business. They affect all aspects of a project, from site selection and construction through completion, operations, and marketing.

- New market designs
- Changes in subsidy structure
- Changes in taxation
- Building plan approvals

Market risk

Economic risk of the project is to examine whether the projects' expected cash inflows will have the positive net present value, and how much time the project will take to recover the initial cash outflow, issues concerning policies, and regulatory frameworks. Amongst these the following are vital.

- Electricity price
- Competition
- Input fuel price are vital

REVENUE = Technological risk + Political risk + Market risk

Risk perception

Like most technical projects, solar energy projects require planning and coordination and are constrained by budget and schedule limitations. These projects demand a clear set of objectives, so the best feasibility approach is selected. Through the various stages of studies carried out, it will be easy to have an overview of the impending dangers or risk. These can be detailed under the survey report submitted to the prospective client for consideration.

Technical factors

Technical performance risk arises because of the operating conditions of the project, whether the project will bring desired revenue or not.

- Investment
- Production
- Availability
- Lifetime
- Operations and maintenance

Market factors

Financial risk arises based on how the projects are funded—the capital structure of the project. The capital structure directly affects the market value of the project. Risks related to foreign currency arises when the project is sponsored by some foreign company. Fluctuations in forex rate affects the profitability of the parent company along with the following factors.

- Exchange rates
- Interest rates
- Electricity prices

Political factors

Political factors include politically-motivated embargo or boycott of a project, debt repayments, or shipment of product, which may reflect the foreign policy of the country. Political factors also consider circumstances where the host country cannot permit transfer of funds for debt service because of its own economic problems, which include the following

- Production support
- Investment support
- Building permission

Mitigation measures

Improved efficiency lowers cost, which in turn increases demand. To ensure that increase in efficiency actually reduces energy use, a tax must be imposed to remove any cost savings from improved efficiency. Energy conservation is the practice of increasing the efficiency of the use of energy, in order to achieve higher output for the same energy consumption. This may result in increasing the environmental value.

Environmental Due Diligence (EDD) is the collection and assessment of data, relative to environmental conditions or impacts, prior to a transaction to identify and quantify environment related financial, legal, and reputation risks.

The general intention of a due diligence review is to ensure that a projected investment does not carry financial, legal, or environmental liabilities beyond those that are clearly defined in an investment proposal as presented during the course of the FS.

Risk mitigation: measure I

There is a growing realization in energy and environmental policy and research circles that procedures for renewable energy technologies (RETs) are poorly defined and financiers must often adopt ad hoc procedures for environmental review. Although, most RETs are environmentally sound in theory, all of

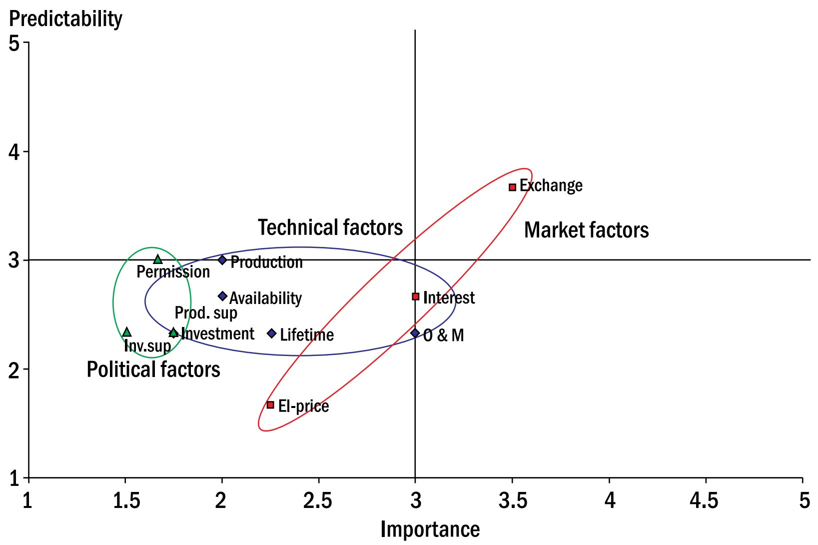


Figure 11 Risk and solar PV: the results of securing long term success with solar energy development