



Harnessing Solar Energy: Options for India

Center for Study of Science, Technology and Policy



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Foreword

Worship the sun god, the Lord of the Universe,
a rising light with effulgent rays, revered by one and all.

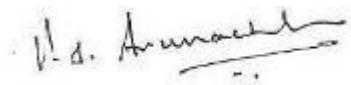
*(From the Sanskrit hymn, **Aditya Hridayam, Ramayana**)*

This century's global challenge is energy: how to increase the generation, how to make it equitable and affordable, and also how to keep the environment pristine without warming the planet or polluting the atmosphere. Among the renewable, sustainable and carbon-free energy generation options, solar stands out. One hour of sunshine on our planet, if stored adequately, can meet the global needs for an entire year. Regrettably, however, it remains largely unviable because of low collection efficiency and the large area required to receive sunshine. An installed capacity of 50 MW requires almost 100 hectares of land. Compare this with a natural gas generating station, where even 1 or 2 hectares would suffice.

An attractive option would then be to change the present pattern of energy generation. Instead of building large generation farms, is it possible to consider building small energy centres, perhaps even at homes and small stores that needs only a few watts to kilowatts of energy? These may not be grid connected, but would be as reliable and efficient as electricity from conventional sources. The challenge will then become one of making these resources efficient and economical. New innovations tend to be costly and error-prone, but with experience costs come down and efficiency and reliability increase. The scale of dissemination, and not necessarily size, will also reduce costs. At the initial stages, the support of government becomes crucial. Subsidies, tax rebates and easy-to-pay-back loans are all necessary to make this transition to solar, technologically and economically attractive.

This report on harnessing solar energy options for India, supported by the Shakti Sustainable Energy Foundation, Climateworks Foundation and SSN Foundation, discusses the routes that are viable for rural households in India. Perhaps in the coming decades harnessing solar energy on a large scale may become more efficient and affordable. Until then, distributed energy systems are a compelling option. This is largely the message of this report.

CSTEP is continuing its pursuit of studying various options for not only generating energy efficiently, but also for storing it. A few of these studies are turning out to be promising and we hope to share our results in the coming months.



Dr. V. S. Arunachalam
Chairman, CSTEP

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Executive Summary

The Jawaharlal Nehru National Solar Mission (JNNSM) announced in December 2009 envisages the installation of over 20,000 MW of grid-connected solar power and another 2,000 MW of off-grid solar power by 2022. Since the announcement, the Ministry of New and Renewable Energy (MNRE) has come up with several rounds of guidelines for various applications and the Central Electricity Regulatory Commission (CERC) with tariff orders. Given that the current installed capacity stands at merely 10 MW, to realise these targets, clear long-term policies have to be put in place and implementation of the policies and projects has to be stringently monitored.

There are three primary solar technologies that convert solar energy into useful consumable forms of energy:

- Solar photovoltaic (PV) technologies convert solar energy directly into electrical energy using solar PV cells. These can be strung together to form modules and can be scaled from a few watts to light a single bulb to many megawatts for utility-scale generation. It is this modular nature of solar PV that lends itself to decentralised generation.
- Solar thermal technologies convert solar energy into heat energy for non-electrical use, for example, in the residential and commercial sectors for heating water, in industries for thermal heat application, and in agriculture for drying. Thus, these have tremendous potential to reduce fossil fuel usage.
- Concentrated solar thermal power technologies (CSP) consist of a configuration of mirrors, called a solar field that concentrate solar energy on to a receiver, raising the temperature of the heat transfer fluid it carries, thus generating heat energy, which can be stored and transferred to a turbine for electricity generation on demand. Most CSP technologies are meant for utility-scale production.

This report discusses the applications of the first two technologies. CSP technologies are intrinsically different and merit a separate report.

Over the next few years, large outlays of public and private funds are expected for solar technologies. Therefore, it is important for the public at large to be educated on several aspects of solar energy – the techno-economics of its applications, government policies and their implications, and social, environmental, health and employment benefits. The purpose of this report is to make the basic information available on solar energy accessible to many. Hence, this report covers several topics with a broad brush stroke, while it delves into a few applications in detail.

Utility-scale generation is important for India given our large electricity shortfall. On the other hand, it is small-scale grid-connected generation and off-grid decentralised generation that can enable socio-economic empowerment to millions. About 16% of villages in India are not connected to the grid. Furthermore, many households even in electrified villages do not have grid supply due to difficulties with last mile connectivity. This is where small decentralised solar applications can help with access to clean energy for everyday needs like lighting and cooking.

The overall goal of the off-grid guidelines of the JNNSM is to achieve wider dissemination of solar technology, and a generous capital subsidy of up to 90% is offered for rural applications. Even so, there are several bottlenecks to large-scale dissemination. Primarily, the techno-economics, financing and institutional mechanisms of several solar applications are not well understood. Therefore, these form a focus of this study. In addition, this study looks at the Government of India's

solar-specific policies, targets set by the JNNSM, financial incentives, budgetary impacts, capacity addition and grid parity for solar PV technologies. Wherever they make sense and analysis supports them, policy recommendations are made. This summary provides the highlights of each of the chapters.

1. JNNSM Targets

Table 1 gives the targets announced by JNNSM for each of its three phases. A more detailed discussion the JNNSM guidelines, incentives and regulations, along with a timeline of the evolution of solar-specific and rural electrification policies of the Government of India can be found in the chapter ‘India’s Solar-specific Policies’.

Table 1: JNNSM Targets

	Current status	Phase 1 (2010–13)	Phase 2 (2013–17)	Phase 3 (2017–22)
Grid-connected	10 MW (solar PV)	1,100 MW	10,000 MW	20,000 MW
Off-grid	2.92 MW	200 MW	1,000 MW	2,000 MW
Solar thermal collectors	3.53 million m ²	7 million m ²	15 million m ²	20 million m ²

1.1. Commentary on the JNNSM

What should be the metric to evaluate the success of such a grand programme? Should it be the megawatts of installed capacity, the megawatt hours of energy output, or the wider societal impact? Given the lack of electrification and access to clean energy sources in India’s villages, coupled with transmission and distribution (T&D) losses, decentralised distributed systems make very good sense. Therefore, should the targets set for off-grid power have been bolder? While grid-connected large-scale PV can help achieve price reduction through economies of scale, there is an urgent need for off-grid decentralised distribution as well. Furthermore, the economics of several applications are very viable even at today’s high solar costs.

The target set for Phase 1 of 500 MW of utility-scale solar PV is sliced in different ways as a means of illustrating the societal and budgetary impact. The net present value of cash outlays for generation-based incentives for electricity generated from solar PV installations alone in Phase 1 will be around ₹110 billion (at a 10% discount rate). It has to be pointed out that these calculations are based on the announced tariffs. However, due to over-subscription of capacity, the investors were asked to bid for a discounted tariff and the lowest bidders are to be allocated the solar projects. On 16 November 2010, bids were received and the discounts ranged from ₹0 to ₹7. Hence, the power purchase agreements (PPAs) that will be signed by the developers will be for tariffs that are lower.

A 500 MW capacity can meet the minimum need of 14,290 villages where each village is provided a microgrid of 35 kW^a capacity based on solar energy and another renewable source. Apart from the

^a A 35 kW capacity will be sufficient to meet the minimum demand of a village of 150 households. This is computed in the section on rural electrification in the chapter ‘Solar Photovoltaic Applications’.

capital subsidy of ₹150 per W_p promised by the government, an additional generation-based incentive of ₹4.25 per kWh generated can be provided for twenty-five years of operation of the microgrids, and the net present value of this will be ₹110 billion.

Slicing the numbers differently, providing 13.5 million households each with 18 W solar PV panels will work out to be 500 MW, and would require a total investment of ₹97 billion.^a The magnitude of this must be judged in relation to the 40,000 villages and 28 million households that may still remain un-electrified in 2012.^b Hence, off-grid applications for rural electrification should be prioritised considering they make economic sense as well. Moreover, given the inadequacy of the grid, kerosene is likely to remain the mainstay for lighting in many households. Kerosene is expensive, subsidised, and has adverse environmental and health effects. The net present value of subsidising kerosene for fifteen years to 28 million households (at a 10% discount rate) is around ₹167 billion.^c This should be compared to the total expenditure of ₹ 45 billion for 28 million solar lanterns at the rate of ₹1,600 per lamp.

2. Photovoltaic Applications

Utility-scale PV plants pose few technical challenges. Though generation of electricity from solar energy is expensive today, with the generation-based tariff offered by the government, it becomes economically viable to the investor. The real advantage of solar-PV-based electricity is that it can be generated close to demand centres, thus avoiding large T&D losses. Furthermore, in India today, diesel is used by small commercial enterprises as well as large buildings (private and public) to generate electricity during grid outage. Given that power generation from diesel is highly polluting and is increasing India's dependence on oil imports, solar energy could play a crucial role here. The chapter on solar photovoltaic applications discusses several applications that are either economically viable today or will be in the near future. A brief summary of the analysis follows.

2.1. Solar PV Options for Rural Electrification in India

Simple effective solutions including solar lanterns and solar home lighting systems (SHLS) are discussed in the chapter on photovoltaic applications, along with solar-based microgrids. While solar lanterns can be a stopgap measure till electrification, SHLS and microgrids can provide sufficient power to meet residential and community-based requirements, and can easily be integrated if and when the grid does reach these areas. Microgrids based on solar energy and other renewable energy sources to meet the needs of a village or cluster of villages can be viewed as a permanent solution as long as appropriate institutional mechanisms are in place for sustainable operations. Prevailing financial, policy and institutional mechanisms for wide-scale adoption are discussed.

Even at today's high prices, solar-based microgrids offer a competitive solution to grid extensions. A detailed techno-economics of grid extension versus solar-based microgrids can be found in the section on rural electrification. Alternate subsidy regimes to the current capital subsidy are also discussed.

^a Each 18 W solar PV system is valued at ₹7,177.

^b Village electrification status from the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGYV) as of 30 March 2010.

^c Assuming per household usage of 50 litres per annum and a subsidy of ₹15.67 per litre (subsidy amount for year 2009–10) for fifteen years.

2.1.1. Recommendations

- Solar lighting systems should be given high priority to provide lighting in un-electrified or electrified villages, and in urban areas. Soft loans and capital subsidies should be provided to entrepreneurs, manufacturers and service providers.
- The indicative cost of ₹300 per W_p is too low for small systems where the proportion of costs on balance of systems is higher. This inadvertently disadvantages the poorest customers and supports low quality systems. A National Bank for Agriculture and Rural Development (NABARD) circular^a stipulates that the borrowers are required to bring in 20% of the costs. Down payment requirement should be removed for loans towards solar lighting systems, and in their place the capital subsidy should be considered.
- As the maximum loan amount is 50% of the indicative costs, purchasing higher cost (better service and better quality) systems is made difficult. Furthermore, there should be more flexible loan terms for low-income households. The stipulation for a minimum lock in period of three years should be removed.
- In the case of solar lighting systems, the framework for supporting local entrepreneurs that set up central charging stations (CCS) rental services is currently unclear. Governmental recognition of this model with a mandate on appropriate working capital loans could be effective for greater distribution of lanterns.
- A generation-based incentive in lieu of or in addition to reduced capital subsidy should be considered for rural microgrids (for 10 kW_p or more) solely based on solar energy or hybridised with other renewable energies. This will ensure sustainable operation of the plants and enable the economic analysis of different subsidy regimes.
- Clear guidelines to develop methods of monitoring applications and ensuring ongoing operations should be planned.
- Merits and demerits of capital subsidies should be carefully weighed. Financial incentive schemes suitable to the end-users of different categories should be worked out carefully. Furthermore, capital subsidies should not be tied to specific models as is the case now, since this is likely to stifle innovation.
- The Reserve Bank of India should prioritise lending for solar solutions in the case of lanterns and home lighting systems. Microgrids based on hybrid solutions, solar and other renewable energy sources should also be targeted. Rural regional banks should be extensively involved in channelling these loans.

2.2. Solar-PV-based Irrigation Pump Sets

These pumps are found to be competitive at today's cost relative to diesel pumps based on cost per unit of electricity. Detailed analysis is provided for pumps of two sizes – 1HP and 2 HP – necessary to draw water from up to 230 ft and up to 530 ft respectively.

2.2.1. Recommendations

- The government must sponsor techno-economic studies that provide a comprehensive understanding of the losses incurred in using the flat-rate schemes and in providing subsidised grid electricity to farmers for irrigation. This study must take into account the losses incurred in the use of inefficient pumps, T&D losses in grid extension, theft of power, etc. Studies also must be carried out to determine the ratings of irrigation pumps in use to enable more informed

^a NABARD Circular No. 199 /DPD-NFS/ 04, dated November 1, 2010.

<http://www.nabard.org/pdf/Eng%201%20solar%20circular-01-11-10%20with%20encl.pdf>

policy choices. A comparison of this cost with the economic and technical dynamics of solar PV will provide insights into better resource allocation for the government.

- Awareness and dissemination programmes must be undertaken to urge farmers to use solar PV technology where it makes sense.

2.3. Rooftop PV Systems for diesel use abatement

Solar PV systems could prove to be viable if diesel prices were to increase or PV prices were to come down. In addition to the economics, grid-connected rooftop PV systems could face technical challenges given India's T&D woes.

2.3.1. Recommendations and Conclusions

- In order to study the transmission difficulties and evacuation of power to low voltage (LT) lines, a few grid-connected small-scale PV plants and roof-mounted PV systems have to be funded by the MNRE to demonstrate the technology.
- In regions where the grid is unreliable, off-grid PV systems should be promoted to reduce diesel usage in buildings.
- The feed-in-tariff offered for grid-connected rooftop systems should be carefully evaluated and alternate incentives should be compared.
- Given the frequent power outages, a solar rooftop PV solution needs to be carefully considered and incentivised for households. A token financial incentive such as a discount in the monthly utility bill might suffice to encourage a fair proportion of citizens to install solar PV alternatives to meet a minimum household load.
- Commercial buildings and industries should be incentivised to abate diesel usage and the size of the solar PV installations should not be a bottleneck to obtaining the subsidy. The current cap on capacity of 100 kW_p for rooftop models connected to low voltage distribution line could be removed.
- On account of high capital costs and lower efficiencies of systems with battery storage,^a solar PV is not a viable replacement for diesel generation unless:
 - the system costs falls below ₹190 per W_p; or
 - diesel price increases to over ₹80 per litre.
- With a more attractive base case, roof top solar PV systems without battery storage present more attractive and viable economics when compared to systems with a battery. A serious shortcoming is the system's complete dependence on availability of solar energy; it is not possible to reduce diesel consumption during the night or on cloudy days.

3. Solar Thermal Applications

The adoption of solar thermal technology is very low in India, in spite of the generous capital subsidy offered by the MNRE. Furthermore, several solar thermal applications are simple in design, inexpensive to manufacture, and have short payback periods. There is a severe dearth of statistics on the techno-economics of these applications, with the exception of solar water heaters, as most of the data available is based on the anecdotal experience of a few. Dissemination of information specific to the technology, its workings and its economics would in itself provide impetus in increasing their adoption.

^a Solar PV system cost assumed is ₹270 per W_p with storage and ₹180 per W_p without.

It is difficult to estimate the potential for industrial applications, as there are several to be considered here. However, taking into account India's solar potential and going by the estimates provided by the International Energy Agency (IEA) for Europe, the potential energy savings are substantial. It is felt that evaluating potential energy savings from the use of solar thermal technology merits a study of its own. The use of solar thermal technology can substantially reduce fossil fuel consumption in the domestic and industrial sectors, which would result in a considerable reduction in annual CO₂ emissions. The JNNSM target of 20 million m² of solar thermal collector area for all applications is clearly not ambitious enough, given that the potential for solar water heaters alone in the country is as high as 18.7 million m².

3.1. Recommendations

The MNRE should fund a few large-scale demonstration plants and incentivise the industries that are manufacturing and utilising solar thermal technologies. Furthermore, it should sponsor several case studies of working plants and hold workshops to widely disseminate the findings.

4. Cumulative Capacity, Grid Parity and Cost

With significant technology improvements and cost reductions, the cost of solar PV is likely to be competitive with peak electricity price by 2018–22 and with coal-based generation perhaps a few years later. The chapter 'Cumulative Capacity, Grid Parity and Costs' estimates the cumulative PV deployment in the country by using diffusion curves. Grid-connected solar PV could scale anywhere from 5,000 MW to 12,000 MW by 2022. Using learning curves, projecting the cost of solar PV system from today's ₹180 per W_p (the system cost is an assumption), in 2022 it ought to come down to ₹108 or lower.

Given the current status of CSP in India and globally, it is difficult to foresee how this technology will unfold. CSP today is fraught with uncertainties and the capacity addition is likely to be fairly low. However, for the sake of projecting total budgetary impact, the capacity addition for CSP is assumed to range anywhere from 1,000 MW to 8,000 MW by 2022. The following summarises the results if 20,000 MW of solar capacity (12,000 MW of PV and 8,000 of CSP) is installed by 2022:

- Projecting forward the generation-based incentives for PV and CSP, the total net present value of all incentives (assuming annual power purchase agreements [PPA] signed for twenty-five years) will amount to a maximum of ₹1,800 billion (at a 10% discount rate).
- The increase in grid tariff to pay for solar-based generation will be at most ₹0.26 per unit of electricity, which is not too onerous.
- The total generation in 2022 from the 20,000 MW installed capacity (assuming 20% plant load factor) will be 35.7 billion kWh.
- Solar energy can reach up to 2% of the total energy mix by 2022.^a The original JNNSM document that was released in December 2009 projects solar power purchase obligation for states to start with 0.25% in Phase 1 and go up to 3% by 2022.

4.1. Recommendations

- The MNRE should clarify several of its policy guidelines, particularly relating to the signing of PPAs. Furthermore, the roles of the state and central governments in the implementation

^a The net electricity supplied in 2009–10 was 681 billion kWh and in 2022 it will be 1616 billion kWh. A detailed explanation can be found in the chapter 'Cumulative Capacity, Grid Parity and Cost'.

of PPAs need better clarity. The entire process also has to be streamlined, and there needs to be more transparency on how the projects are going to be allocated.

- Clearly focused long-term policy guidelines have to be in place. This will enable the increase in manufacturing capacity, increased R&D investments, and help in planning for the manpower needs that will arise if solar energy is to scale up in India.
- Off-grid targets and guidelines should receive greater emphasis and focus. Financial incentives and clear policy regulations aided by sound institutional mechanisms will help the sustainable operations of small solar appliances and solar-based microgrids.

Introduction

Introduction

The Jawaharlal Nehru National Solar Mission (JNNSM) announced in December 2009 targets the installation of over 20,000 MW of grid-connected solar power (photovoltaic and concentrated solar thermal power) and another 2,000 MW of off-grid solar power by 2022. Since the announcement of the JNNSM, the Ministry of New and Renewable Energy (MNRE) has come out with several rounds of guidelines for different applications. The MNRE must be lauded for its efforts in building the confidence of investors. Large players – both domestic and international – have been eyeing the solar market in India for years and are now poised to invest large sums of money because of the government’s announcement of generous feed-in tariffs and other financial incentives. In fact, in the case of solar photovoltaics, it is expected that demand will exceed the target of 500 MW. The situation for concentrated solar thermal power (CSP) is less certain given its nascent stage not only in India, but the world over.

A large outlay of public funds is expected to help solar energy scale up in the country, and it is important that the public at large be educated about the techno-economics of solar applications, and about the health, environmental and other social benefits of solar energy. This report is an attempt in this direction. The present chapter provides the background to the basics of solar energy as well as the merits of adopting it in India.

1. The Current Energy Mix

As of August 2010, India’s installed electricity generation capacity was 165 GW^a (Figure 1), and in 2009–10 the gross electricity generation was 772 billion kWh.¹ The estimated energy and peak demand shortfalls were 11 and 12% per cent respectively,² and we estimate that technical losses in transmission and distribution network were about 18%. At a GDP growth rate of 8% per year, the cumulative power generation capacity required in 2020 will be around 350 GW.

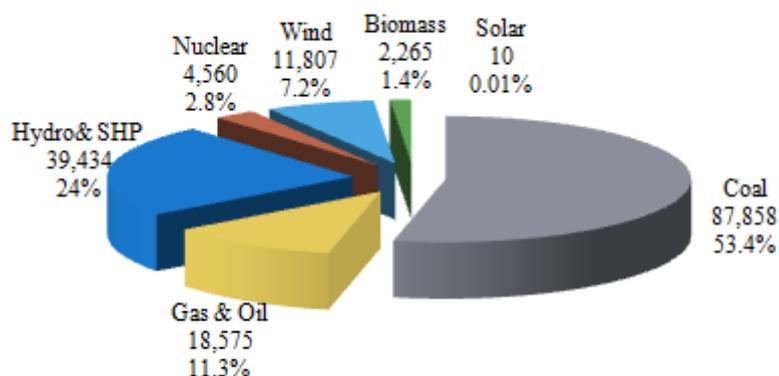


Figure 1: India’s Installed Generation Capacity Mix (MW)

(Source: Compiled from the MNRE websites:

http://www.powermin.nic.in/indian_electricity_scenario/introduction.htm

and <http://www.mnre.gov.in/>, accessed 2 November 2010)

^a This does not include captive generation, which is estimated to be around 27,000 MW.

The Indian power sector is highly dependent on coal as fuel – 52% of the total installed capacity is coal based. India imports at least 10% of coal required for power generation and imports 70% of its oil consumption. Given the constraints on coal and other fossil fuel supplies, and the concerns of greenhouse gas (GHG) emissions, India needs to look at renewable sources of energy to meet at least part of its demand for its energy security and for a sustainable low-carbon growth trajectory.

2. Why Solar?

Solar energy has the potential to generate virtually unlimited, essentially clean, carbon-free electricity. Given that it holds great promise, with most parts of the country receiving plenty of sunshine – four to six hours a day for over 300 days a year – India should look to the sun to reap the benefits of its energy.

The announcement of the JNNSM will hopefully provide solar energy the impetus it requires. Installing solar panels in a mere 400 km² of land can result in 20,000 MW of solar power, even under conservative assumptions. Hence, getting to the target of 20,000 MW by 2022 may not appear that challenging, but given that at present India has only 10 MW of grid-connected solar power generation and considering the high cost of solar energy today, even achieving a fraction of the target would be quite ambitious.

Utility-scale photovoltaic (PV) plants pose few technical challenges. With the generation-based tariff offered by the government, it becomes economically viable to the investor despite the high cost of the technology at the present time. However, considering that a solar PV plant will need an area of 5 to 6 acres per MW of capacity, finding large tracts of suitable land can be vexing.

About 16% of villages in India are not connected to the grid. Furthermore, many households even in electrified villages do not have grid supply due to difficulty with last mile connectivity. Households that are un-electrified and use kerosene for lighting make up about 42% of the total number of rural households.³ The real advantage of solar-PV-based electricity is that it can be generated close to demand centres, thus avoiding large transmission and distribution losses. Beyond this, decentralised solar energy can make a real social impact with benefits that include local job creation and economic empowerment. This study focuses on the techno-economics of a few decentralised applications in the chapter, ‘Solar Photovoltaic Applications’.

The advantages of solar energy extend beyond the socioeconomic. Power generation from solar PV does not produce noise or air pollution, and the replacement of kerosene with solar lighting will have significant positive effects on family health. Furthermore, in India today, diesel is used by small commercial enterprises as well as large buildings (private and public) to generate electricity during grid outage. The exact installed capacity of captive generation from diesel and furnace oil in the country is unknown, but it is said to run into tens of thousands of MW. Given that power generation from diesel is highly polluting and is increasing India’s dependence on oil imports, solar energy could play a crucial role. The chapter, ‘Solar Photovoltaic Applications’ has economic and policy analyses on diesel abatement in urban buildings and in diesel based irrigation pumps.

Solar thermal technologies have far-reaching benefits beyond the reduction of fossil fuel use. The manufacturing is simple and yet cost effective for many applications. There are only a limited number of solar thermal installations in India despite the benefits it can offer. For example, the use of solar dryers in agriculture can reduce wastage and improve the income of farmers. If hostels and large institutions were mandated to augment or supplement fossil fuel with solar energy for cooking, their savings on fossil fuel could be substantial. Similarly, solar box cookers can help families who do

not have access to a clean energy source for cooking and reduce indoor pollution. Several industries that need low to medium heat energy can easily reduce their carbon footprint by replacing at least some of their fossil fuel usage by solar thermal technology. This is discussed in the chapter 'Solar Thermal Applications'.

3. Solar Radiation

The total global solar radiation striking a given surface has two components, direct beam radiation and diffuse radiation. Direct beam radiation (commonly referred to as 'direct normal irradiance' or DNI) comes as parallel beams from the sun. On sunny days with clear skies, most of the solar radiation is direct beam radiation. On overcast days, when the sun is obscured by clouds, direct beam radiation can become negligible. As solar radiation passes through the earth's atmosphere, some of it is absorbed or scattered by air molecules, water vapour, aerosols and clouds. The radiation that has been scattered out of the direct beam is diffused solar radiation. Radiation, whether diffused, beam or global, in a particular region is measured in kilowatt hours per square metre per year. Typical solar PV technology can generate electricity even with diffused radiation. However, the generation of energy from concentrated solar thermal technologies requires bountiful DNI.

Apart from capital and operating costs, the amount of solar radiation a region receives and the amount of solar energy that can be converted to a useful form by a particular technology together determines the economic viability of the solar technology in a particular region. Hence, before zeroing in on a site and the technology, site-specific radiation data is absolutely necessary. Global radiation data is more readily available for many locations, but diffused and DNI may not always be. The measurement of any two of the three variables – global, DNI or diffused – will help us estimate the possible range for the third. To derive a detailed solar radiation map of a region and to estimate the solar energy potential, extensive accurate measurements at the ground level are necessary from a large number of stations covering different climatic zones. This, however, is difficult and expensive.

On a clear day, the solar insolation on a surface perpendicular to the incoming solar beam will be around $1,000 \text{ W/m}^2$ at peak time. As an illustration, let us assume that the solar-to-electric conversion efficiency of a solar technology is 10%. In that case 100 Wh/m^2 is the amount of energy produced during such a peak generation hour. Assuming a 10% net efficiency, and an average daily sunshine of five to six hours for 320 days a year, 160 to 200 kWh can be generated annually per square metre of solar PV panel.

The cost of generating electricity from solar technologies depends on the annual hours of sunlight a region receives, efficiency of the particular technology used (conversion of solar to electric energy) and capital cost. The price per watt of solar PV module today is in the ballpark of ₹100 (~ \$2). To this, adding the price of an inverter and the balance of the system, the price of a solar PV system will be around ₹180 per watt. At the current price, a unit of electricity produced from solar PV is at least two to three times as expensive as that from coal, excluding any battery if needed; however, the cost of solar energy has been declining with the decrease in cost of PV modules and increase in module efficiency.

4. Solar Technologies: The Basics

There are three primary groups of technologies that convert solar energy into useful forms for consumption.

Solar PV technologies consist of semiconductor or other molecular devices called photovoltaic or solar cells that convert sunlight into direct current (DC) electricity. PV modules consist of multiple cells assembled on a common platform, connected in series and sealed in an environmentally protective laminate. If the power provided by one PV module is not enough, then multiple modules are linked together to form an array to supply power ranging from a few watts to many megawatts. In addition to the modules, other components (for example, inverters, batteries, charge controllers, wiring and mounting structure) maybe required to form a complete PV system.

Solar thermal technologies heat water or air, and other possible working fluids, for non-electricity uses of energy. Solar water heaters can displace conventional electrical water heaters in homes and in commercial establishments. Hot-air-based thermal collectors can displace fossil fuel use in cooking, agricultural drying and more generally in industrial heat processing. In India, solar water heaters have been commercialised and are an economically viable option for many regions. Other applications are still in nascent stages.

Concentrated solar thermal power technologies first convert solar energy into heat energy and then into electrical energy. Most CSP technology options, namely, the parabolic trough, Fresnel mirror system and central tower, are meant for utility-scale use. Further, with thermal storage, these three CSP technologies can provide electricity several hours after sunset. However, a less proven CSP option, the Stirling engine system, can be used in 10 to 25 kW decentralised applications, and can also be easily aggregated for utility-scale plants. Unlike other CSP technologies, this requires little water, but it also lacks inherent storage of thermal energy.

Subsequent chapters in this report discuss PV technology and solar thermal technologies. As it was felt that CSP-based technologies merit a study of their own, it is not covered in this report.

Photovoltaic Technology

Photovoltaic Technology

1. Types of PV cells

Most commercially available solar cells have a lifespan of at least twenty to twenty-five years. Out of the following types of PV cells, only the first two are commercially available globally.¹

- **Crystalline silicon** (c-Si) modules represent 85 to 90% of the global annual market today. These are subdivided into: i) monocrystalline (mono-Si); and ii) polycrystalline (poly-Si). Metallurgical grade silicon is refined to form close to 99% pure silicon. Silicon ingots are obtained from molten polysilicon. Wafers are made by wire-sawing block-cast silicon ingots into very thin (180 to 350 micrometre) slices. Two sides of the wafer are doped with two different dopants – one side is left electron deficient (the p-layer) and the other side has an excess of electrons (the n-layer). This forms a P–N junction a few hundred nanometres below the surface, which creates an electric field across the junction (PN junction).
- **Thin films** currently account for 10 to 15% of global PV module sales. These are subdivided into three main families: i) amorphous (a-Si); ii) cadmium telluride (CdTe); and iii) copper indium diselenide (CIS) and copper indium gallium diselenide (CIGS). Thin film modules are created by coating entire sheets of glass or steel (called substrate) with thin layers of semiconductor materials rather than growing, slicing and treating a crystalline ingot.
- **Emerging** technologies include advanced thin films, dye-sensitised cells and organic cells.
- **Concentrator photovoltaic** (CPV) technologies use an optical concentrator system that focuses solar radiation onto a small high-efficiency cell.
- **Multijunction cells** are a subclass of photovoltaic cells developed for higher efficiency. These use multiple layers of semiconductor material (from the group III and V elements of the periodic table) to absorb and convert more of the solar spectrum into electricity than is converted by single-junction cells.²
- **Heterojunction with intrinsic thin layer** (HIT) solar cells are composed of mono thin crystalline silicon wafer surrounded by ultra-thin amorphous silicon layers.

2. Performance

Performance of solar energy panels can be evaluated based on several criteria, and the three most important measurements are:³

- **Rated power at standard test conditions:** This rating is simply a measurement of how much power, measured in peak watts (W_p), that a solar panel will generate under a set of conditions called Standard Test Conditions (STC), namely, 1,000 W of solar irradiance delivered per square metre of surface, module temperature of 25°C and solar spectrum of air mass (AM) 1.5 (at noon on a clear day at sea level). STC are ideal conditions rarely seen in the field; however, they allow for a comparison of the relative performance of different solar modules.
- **Rated power per square metre:** This measures the amount of power generated, under STC, per square metre of the solar panel area. It is also known as power density. This measurement is useful because the higher the efficiency of the solar panel, the less are needed for generating a certain amount of energy.
- **Efficiency:** Solar panel efficiency is simply the ratio of output power to input power.

Factors affecting performance:

- **Temperature:** At higher temperatures, the performance of the PV modules drops.
- **Shading:** A PV module's electrical output is extremely sensitive to shading.
- **Dust:** Particles of dust and other lint on the surface of the module can absorb sunlight and thus reduce the amount of light that actually strikes the cells. Thus, maintenance of the PV panel is imperative; else the amount of electricity generated will drop.

3. Technology Trade-off

Electricity production from solar PV is free of noise and without the release of any toxic substances. However, during the manufacture of solar cells there are varying degrees of technological challenges coupled with issues of efficiency, economy and environmental impact. In this section we discuss the challenges associated with different solar PV technologies.

3.1. Technological Challenges

Crystalline silicon solar cells have a large surface area and relatively high conversion efficiency. However, these cells require high inputs during manufacturing (that is, energy and labour) and are heavily dependent on pure solar grade silicon, which has had a limited supply base. In contrast, thin film technology has the advantage in terms of better cost economics for electricity generation; lower material (silicon) usage; and lower energy requirements. However, the land requirement for this technology is higher.⁴ Organic PV cells have large band gaps that reduce efficiencies. Both organic and dye-sensitised PV cells have stability issues related to the materials used in production.⁵ This problem needs to be resolved before these technologies become viable. The most promising technology is the multijunction cells used in conjunction with CPV.

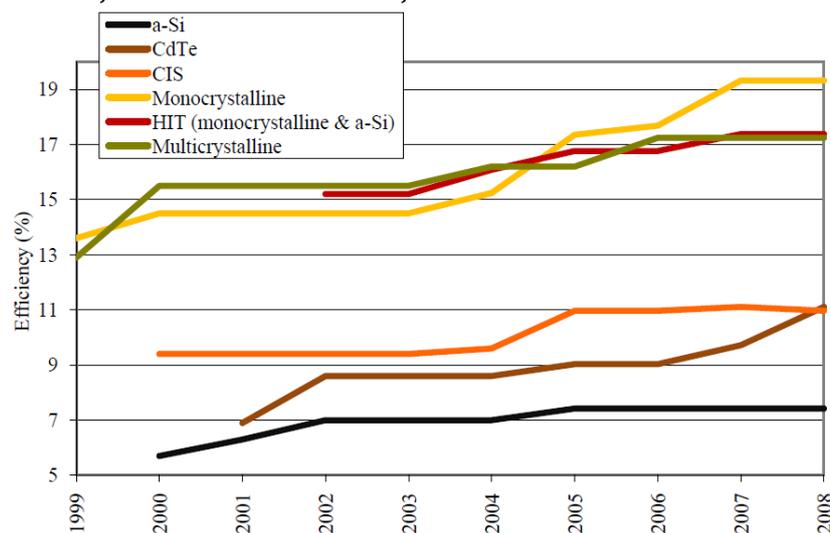


Figure 2: Commercial Module Efficiencies

(Source: India Semiconductor Association and National Manufacturing Competitiveness Council, Solar PV Industry: Global and Indian Scenario, 2008, http://nmcc.nic.in/pdf/ISA_NMCC_September2008.pdf, accessed 28 October 2010)

3.2. Efficiency Challenges

Cell efficiency has been on the rise, and polycrystalline cells today have an efficiency of 18% and monocrystalline almost 23%. With increasing standardisation of manufacturing equipment and

improving efficiencies of modules, it is expected that PV system efficiency will improve in the near term.⁶ Figure 2 shows module efficiencies from 1998 to 2008. As is evident, c-Si efficiencies are at 17 to 19% and the thin film efficiencies are at 7 to 11% as of 2008.

In research laboratories, multijunction cells combined with light-concentrating optics and sophisticated sun-tracking systems (essentially CPV) have demonstrated the highest sunlight-to-electricity conversion efficiencies of any PV technologies at 41.6%. Other research cell efficiencies range from 20% to almost 28% for c-Si cells; 12% to almost 20% for thin film; and about 5% up to 11% for the emerging PV technologies organic cells and dye-sensitised cells respectively.⁷

3.3. Environmental Challenges

In terms of toxicity, only low environmental effects are expected for c-Si technologies. However, CdTe and CIS cell technologies are considered more problematic due to their high content of cadmium (Cd), selenium (Se), tellurium (Te) and copper (Cu). In addition, during the manufacture of CIS modules gaseous toxic substances (for example, hydrogen selenide [H₂Se]) may be produced, which are generally associated with a certain environmental hazard potential. The environmental impact of thin film silicon cells is similar to that of the wafer silicon cell, but reduced in magnitude because of the smaller volume of silicon used. On the whole, the environmental effects related to solar cell manufacture are equivalent to those of the overall semiconductor industry.

4. Manufacturing Supply Chain

The solar PV industry is one of the fastest growing areas in the energy sector, and over the past few years has seen tremendous growth worldwide.

World solar cell production reached 9.34 GW in 2009, up from 6.85 GW a year earlier, with thin film production accounting for 18% of that total. China and Taiwan now account for 49% of global cell production, which reached 3,304 MW in 2008 in these two countries, with Europe at 1,729 MW ahead of Japanese production at 1,172 MW in the same year.⁸

India's annual solar PV module production capacity has reached close to 1 GW or nearly 10% of the global production capacity. However, most of the production is exported. The manufacturing capacity of solar PV modules is expected to grow at a rate of 20 to 25%, and will hit 2.6 GW by 2015.⁹

Currently, India does not have the infrastructure for raw material production (polysilicon), and is entirely dependent on imports for the same. However, there are about fifteen players manufacturing around 600 MW of solar cells and over twenty players assembling over 1 GW of modules annually. Furthermore, there are more than fifty players in solar systems integrators.¹⁰

5. Global Policies and Installed Capacities

Globally, as of December 2009, the installed capacity of PV was close to 23 GW, which produces about 25 TWh of electricity annually. Just a year prior, in 2008, the installed capacity was just 16 GW. Germany has the maximum installed capacity of 16 GW, followed by Japan (2.6 GW) and the US (1.6 GW). Due to a very generous feed-in tariff, the installed PV capacity in Spain was close to 2.6 GW

in 2008; however, this tariff was reduced and the total number of installations was capped at 500 MW for 2009–10. China shot up into the top ten in 2009 and is likely to remain a major player in coming years (see Figure 3). A clearly defined policy mechanism along with financial incentives has led to the growth of PV in these countries. It has been observed that long-term stability of the policy framework leads to increased confidence in investors, which makes them more willing to invest in the industry.

China, which forayed into the solar market barely a few years ago, now manufactures over half of the solar panels in the world, and 95% of the production is exported to countries like Germany and the US, where attractive subsidies are offered for deployment. The rise of China’s solar industry, which has relied on land deals and cheap state-supported loans, have helped bring down global solar costs. However, it is unclear if this is sustainable in the long run.¹¹

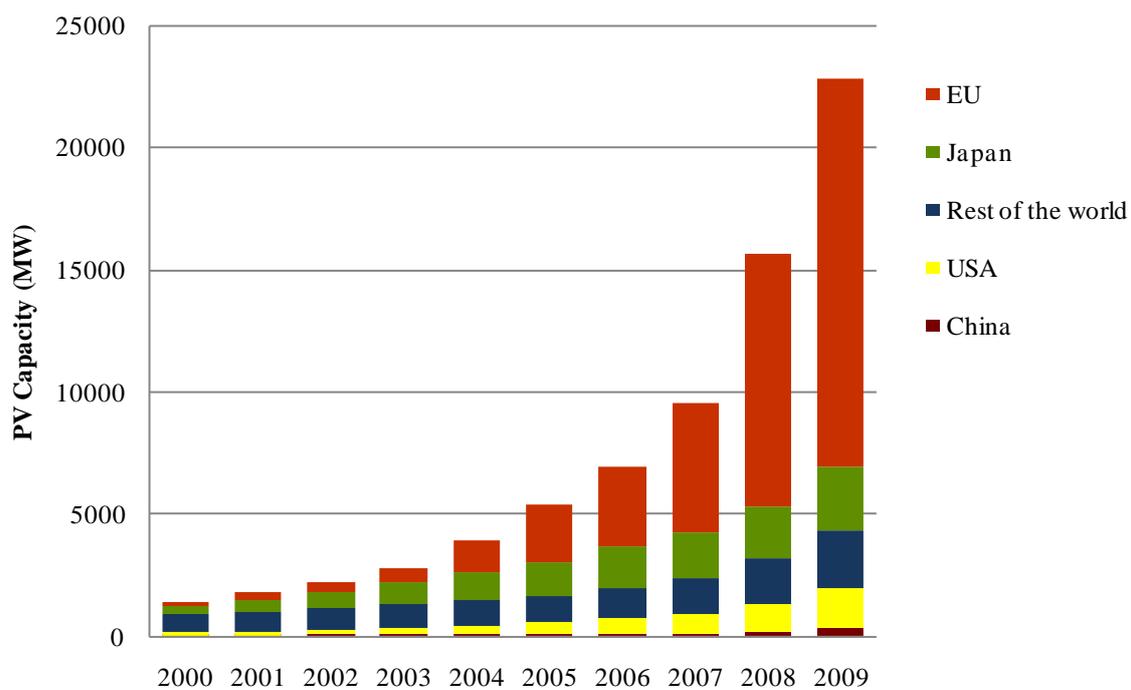


Figure 3: Global Cumulative PV Capacity

(Source: European Photovoltaic Industry Association, *Global Market Outlook for Photovoltaics until 2014*, 2010 update, http://www.epia.org/fileadmin/EPIA_docs/public/Global_Market_Outlook_for_Photovoltaics_until_2014.pdf, accessed 2 November 2010)

5.1. Germany

The main reason for Germany’s leading position is its existing regulatory framework and incentive mechanism – the feed-in tariff (FIT). Germany permits customers to receive preferential tariffs for solar-generated electricity depending on the nature and size of the installation. In addition to tariff support, the German federal government provided manufacturing incentives to promote production capacity in the country. The Renewable Energy Law implemented two important and innovative features:¹²

- **Degression of tariffs:** From 2003 onwards, the tariffs for new installations were lowered for each subsequent year. This was done to provide an incentive for manufacturers to systematically reduce production costs and to offer more efficient products every year.
- **Differentiated nature of tariffs:** The tariffs for the different technologies defined in the Act were determined based on the yield and generation costs of each particular plant. Additionally, differential tariffs were set based on plant size and location.

On 9 July 2010, the German Bundestag and Bundesrat agreed on a two-phase plan that would amend the Renewable Energy Sources Act and ultimately decrease feed-in tariffs by 11 to 16% by the end of 2010. The plan is separated into three installation categories.¹³

5.2. Spain

The 2004 Royal Decree 436/2004 set up the general framework for supporting renewable energy and provided incentives for new installed capacity of renewable energy sources. Generators could choose one of the following payment options:¹⁴

- Generators who sold their production to a distributor received a fixed tariff based on the generation technology.
- Generators who sold their electricity on the free market received the negotiated market price of electricity, an incentive for participating and a premium.

Spain added close to 2.6 GW of grid-connected solar PV in 2008, and in a single year overtook Japan to become the country with the second largest installed capacity of grid-connected solar PV in 2008.¹⁵ The feed-in tariff offered was €0.44 per kWh, which led to explosive growth, but ultimately was too generous. The main problem with the tariff was that it had no long-term provisions to react to the market. As a result, Spain reduced tariffs for solar PV because its 2010 target was already achieved, set 10% annual tariff reductions, and also instituted a 500 MW solar PV capacity cap for both 2009 and 2010.¹⁶

5.3. The USA

The USA was one of the early movers in the use of solar energy globally. However, its solar industry was overshadowed first by Japan and more recently by Europe (particularly Germany) due to stronger incentives offered by those countries. In the USA, the incentive framework for solar energy is fairly complex, with incentives being available at the federal as well as the state level. However, the growth of the solar industry has been largely due to state-level programmes, with California dominating the market.

5.4. Japan

Japan has focused on manufacturing and R&D in the solar PV area, and as a result it is one of the leading countries in solar PV manufacturing. In 2008, Japanese companies produced more than 1.2 GW of PV cells.¹⁷ Japan has also targeted driving the domestic demand for solar PV, with national and prefectural governments giving installation subsidies in addition to net-metering.¹⁸ Electric utilities are obliged to purchase excess electricity generated through PV systems.¹⁹ Japan also has a Renewables Portfolio Standards Law, which imposes an annual obligation on electricity retailers to use a certain amount of their retailing electricity from renewable sources. Utilisation targets for each fiscal year have been set, leading up to a target of 16 billion kWh in 2014.^{20, 21}

5.5. China

Although the cumulative installation of PV in China is low (about 305 MW by end of 2009),²² it has now become the leading manufacturer of PV modules. In 2007, the National Development and Reform Commission, the economic planning ministry, under its renewable energy plan set out a target of 1,800 MW of installed solar capacity by 2020.²³ Under the new energy stimulus plan, China revised its 2020 targets for installed solar capacity to 20 GW. The government also approved a subsidy of 20 yuan per watt (₹132 per watt) for solar PV systems larger than 50 kW fixed on building roofs. For ground-mounted projects, the government is paying a feed-in tariff instead of a subsidy, based on the project's capacity.²⁴

6. Conclusion

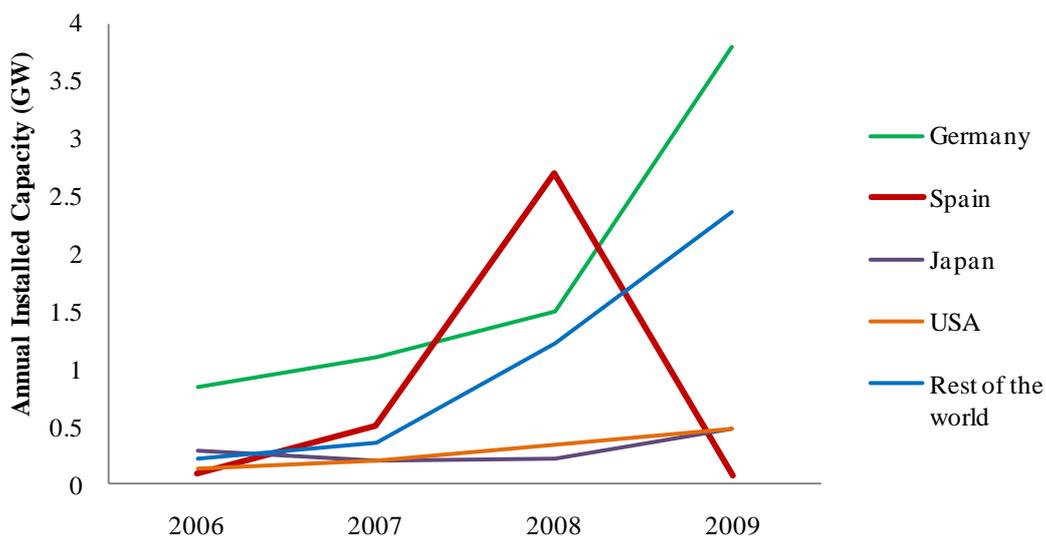


Figure 4: Annual Installed Capacity of Solar PV

(Sources: Compiled by authors from NREL, *2008 Solar Technologies Market Report*, 2010, <http://www.nrel.gov/analysis/pdfs/46025.pdf>, accessed 28 October 2010; EPIA, *Global Market Outlook for Photovoltaics until 2012-Facing a Sunny Future*, 2006, http://www.epia.org/fileadmin/EPIA_docs/publications/epia/EPIA__MarketPublication_18feb.pdf, accessed 28 October 2010)

Though solar PV technology is booming, it is yet to be seen if it can have a sustainable growth in the absence of subsidies and governmental support. The Spanish PV market is a good case in point, where the deployment dropped considerably in 2009 when the government withdrew its subsidy, as can be seen in Figure 4. Germany on the other hand has had another year of stellar growth. The effect of the recent decrease in feed-in tariffs in Germany remains to be seen.

India's Solar-specific Policies

India's Solar-specific Policies

The first half of this chapter gives a timeline of India's solar-specific policies and policies related to rural electrification. The second half contains comments on the targets set and the policies announced by the Jawaharlal Nehru National Solar Mission (JNNSM).

1. History of Indian Solar Policy and Universal Electrification: A Timeline

For the timeline, see Table 2.

2. Policy Guidelines of the National Solar Mission

Under the JNNSM, the target for grid-connected utility-scale projects is 20,000 MW with a fifty-fifty share proposed for solar photovoltaic (PV) and concentrated solar thermal power (CSP). The JNNSM has adopted a three-phase approach, spanning the remaining period of the Eleventh Plan and first year of the Twelfth (up to 2012–13) as Phase 1, the remaining four years of the Twelfth Plan (2013–17) as Phase 2, and the Thirteenth Plan (2017–22) as Phase 3. At the end of each Plan, and mid-term during the Twelfth and Thirteenth Plans, there will be an evaluation of progress, and review of capacity and targets for subsequent phases based on emerging costs and technology trends at both domestic and global levels. As per the JNNSM, plans have been made to ramp up capacity of grid-connected (33 kV and above) solar power generation (solar PV and CSP) to 1,000 MW within three years, that is, by 2013; and an additional 3,000 to 9,000 MW by 2017 through the mandatory use of a renewable purchase obligation by utilities backed with a preferential tariff. This capacity is planned to reach 20,000 MW installed power by 2022 or more, based on an enhanced and enabled international finance and technology transfer. The target for off-grid applications has been set at 1,000 MW by 2017 and 2,000 MW by 2022. The current status, along with the targets set for the three phases of JNNSM are given in Table 3.

Table 2: Timeline of Indian Policy

Year	Policy	Description
1974–79	Minimum Needs Programme (MNP)	Overall objective was to cover at least 60% of villages in each state and union territory under the rural electrification programme by 1990; a target of 46,464 additional villages were fixed for the Sixth Plan under the MNP. The actual achievement, however, was estimated at 34,489 villages.*
1988–89	Kutir Jyoti Scheme	Launched for extending single-point light connections to households of rural poor families below the poverty line, including Harijan and Adivasi families.
5 February 2004	Definition of electrified village under the Ministry of Power's Memorandum No.42/1/2001-D(RE)	The definition of an electrified village was changed (among other things) to at least 10% of the total number of households in the village being electrified.
April 2005	Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY)	This was a major initiative towards universal electrification. Under the programme, 90% grant is provided by the central government and 10% as loan by the Rural Electrification Corporation (REC) to the state governments. The REC is the nodal agency for the programme.
2006	Rural Electrification Policy	<ul style="list-style-type: none"> • Access to electricity for all households by 2009. • Quality and reliable power supply at reasonable rates. • Minimum supply of 1 unit per household per day as a merit good by 2012.
2007	Semiconductor Policy	<ul style="list-style-type: none"> • To encourage semiconductor and ecosystem manufacturing, of which solar PV is also a component. • A capital subsidy of 20% for manufacturing plants in Special Economic Zones (SEZ) and 25% for manufacturing plants outside of SEZs, based on the condition that the net present value (NPV) of the investment is at least US\$ 212 million (₹10,000 million [₹1,000 crore] @ US\$ 1 = ₹47).
3 August 2009	Draft of National Solar Mission approved by prime minister	The plan has an ambitious target of generating 20,000 MW solar power by 2020; the mission strategy consists of three phases.
14 November 2009	JNNSM	Release of mission document.
3 December 2009	Central Electricity Regulatory Commission (CERC) announces tariff for renewable energy power generation	For solar power, the tariff period has been specified as twenty-five years. The CERC has determined a tariff of ₹18.44/kWh for solar PV projects and ₹13.45/kWh for solar thermal projects commissioned in FY 2009–10.

Year	Policy	Description
11 January 2010	Launch of JNNSM	The mission targets 20,000 MW of solar generating capacity by the end of the Thirteenth Five-Year Plan (2022).
17 June 2010	JNNSM off-grid guidelines	Guidelines for off-grid and decentralised solar applications, and rooftop and other small power plants released.
25 July 2010	JNNSM grid-connected guidelines	Guidelines for selection of new grid-connected projects with CERC determined tariff of ₹17.91/kWh for solar PV projects and ₹15.31/kWh for solar thermal projects commissioned in FY 2010–11 and 2011–12.**
15 September 2010	CERC tariff order***	The tariff for solar projects where PPAs are signed after 31 March 2011 have been revised to ₹15.39 for PV and ₹15.04 for solar thermal projects.

Source: Compiled by authors.

Notes: *See <http://www.planningcommission.gov.in/plans/planrel/fiveyr/7th/vol2/7v2ch19.html>, accessed 28 October 2010.

** CERC Tariff Order, 2010, http://www.cercind.gov.in/2010/ORDER/February2010/53-2010_Suo-Motu_RE_Tariff_Order_FY2010-11.pdf, accessed 28 October 2010.

*** See http://www.cercind.gov.in/2010/November/Signed_Order_256-2010_RE_Tariff_FY_11-12.pdf, accessed 22 November 2010.

Table 3: Snapshot of the Current Status and Targets Set by the JNNSM

Application segment	Policy	Current status as on 30.6.2010	JNNSM targets		
			Phase 1 (2010–13)	Phase 2 (2013–17)	Phase 3 (2017–22)
Solar PV	<ul style="list-style-type: none"> Connected to high tension (HT) (> 33kV) 	12.28 MW	500 MW		
	<ul style="list-style-type: none"> Connected to HT (<33 kV) Capacity of 100 kW_p to 2 MW_p 	-	90 MW		20,000 MW
	<ul style="list-style-type: none"> Connected to LT (400V for 3-Phase or 230 V for 1-Phase) Capacity < 100kW_p 	-	10 MW	4,000–10,000 MW	
CSP	<ul style="list-style-type: none"> Connected to HT (>33 kV) 	-	500 MW		
Off-grid solar applications	Solar lanterns	797,344 nos.			
	Solar home lighting systems	603,307 nos.			
	Solar PV streetlights	119,634 nos.	200 MW	1,000 MW	2,000 MW
	Solar PV irrigation pumps	7,334 nos.			
Off-grid solar PV (micro grid)	<ul style="list-style-type: none"> ₹150/W_p for micro grid (with battery) 	2.92 MWp			
Solar thermal application	<ul style="list-style-type: none"> Solar thermal collectors (million m²) 	3.53*	7	15	20

Source: Compiled by authors.

Note: *Solar water heaters.

Solar project developers (SPDs) can enter into a power purchase agreement (PPA) with the National Thermal Power Corporation's (NTPC's) subsidiary NTPC Vidyut Vyapar Nigam (NVVN), which has been designated as the nodal agency. These PPAs will follow CERC-determined tariffs for a period of twenty-five years. The Ministry of Power shall allocate equivalent megawatt capacity (not exceeding 1,000 MW for Phase 1, including capacity under migration guidelines) from the unallocated quota of the central stations at a rate determined by the CERC. The power from the SPDs will be bundled with this and sold to the distribution companies (DISCOMs at CERC-determined tariffs. This is referred to as the Bundling Scheme in these guidelines.^a In essence, this is analogous to a cross-subsidy mechanism. This mechanism will hold for all solar plants set up before March 2013 and connected to 33 KV and over. Figure 5 is a schematic diagram of the operational framework of how a SPD will sign a PPA and receive the tariff.

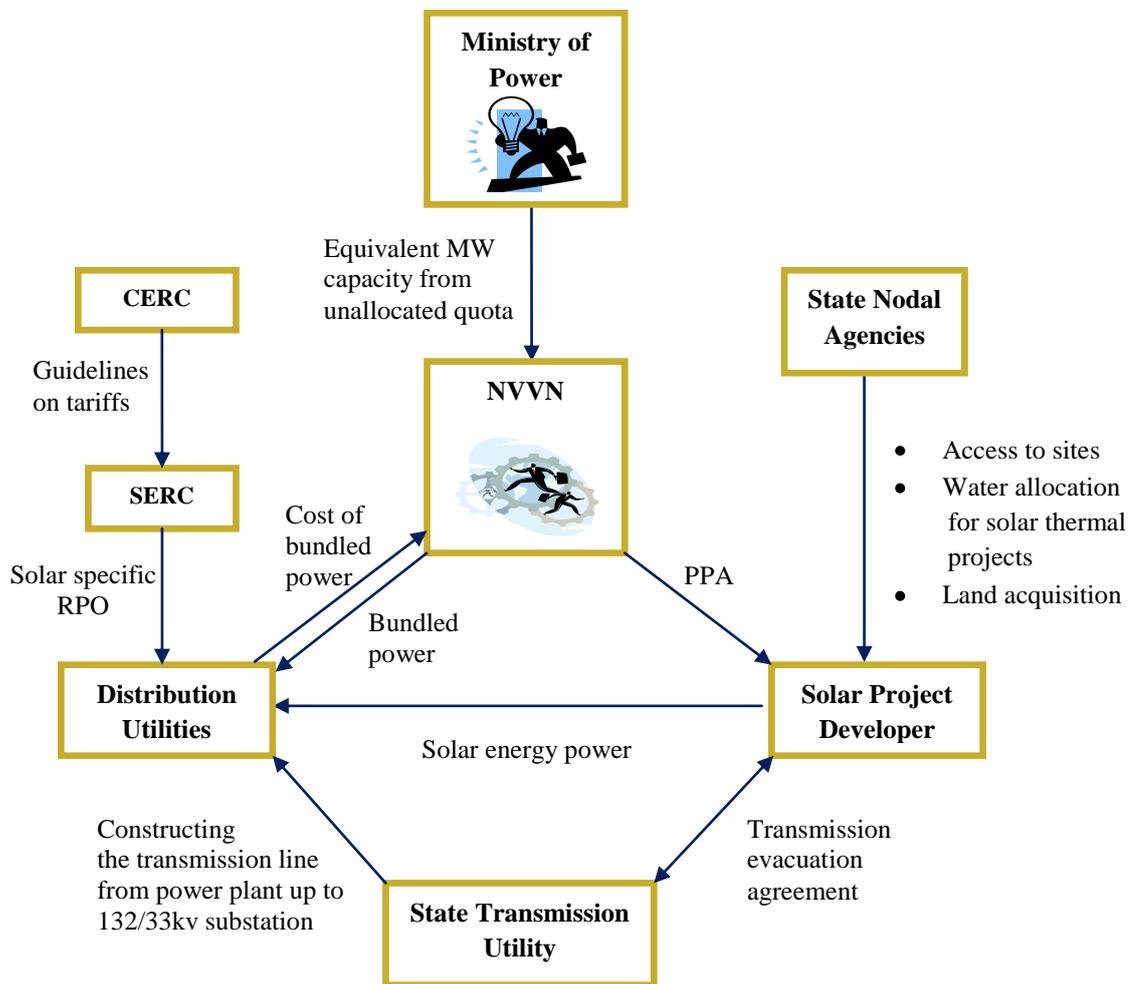


Figure 5: Schematic of the Operational Framework

(Source: Compiled by authors)

^aGuidelines for Selection of New Grid Connected Solar Power Projects, Jawaharlal Nehru National Solar Mission.

Table 4 gives an overview of JNNSM guidelines for grid-connected solar applications. The guidelines will be reviewed and modified if needed one year after the first set were issued. Further details of JNNSM guidelines for off-grid and rooftop applications for PV and solar thermal technologies are given in subsequent chapters.

Table 4: JNNSM Policy Framework for Grid-connected Solar Projects

Policy framework	<ul style="list-style-type: none"> • CERC (Terms and Conditions for Tariff Determination from Renewable Energy Sources) Regulations, 2009. <ul style="list-style-type: none"> ○ Determination of capital cost norms for solar PV projects (FY 2010–11, 2011–12) and solar thermal (FY 2010–11, 2011–12, 2012–13). • Guidelines for selection of new grid-connected solar projects under Phase 1 of JNNSM. • Guidelines for migration of existing under-development grid-connected solar projects from existing arrangements to JNNSM.
Rationale for bundling	To reduce the tariffs paid by the DISCOMs by averaging the cost of generation of solar power and inexpensive coal-based generation as per CERC order.
Tariff determination for PPA (CERC)	<p>Single part tariff structure consisting of fixed cost components:</p> <ul style="list-style-type: none"> • Return on equity • Interest on loan capital • Depreciation • Interest on working capital • Operation and maintenance expenses <p>Tariff period will be twenty-five years.</p>

Selection of SPDs	<p>Existing projects under development of grid-connected SPDs have been selected to migrate to the JNNSM (54 MW of solar PV and 30 MW of solar thermal have been selected as of 25 July 2010).</p> <p>Existing projects under development of grid-connected SPDs can migrate to the NVVN.</p> <p>New projects will be selected such that the maximum aggregate capacity (including migrated projects) is 1,000 MW with a fifty–fifty share of solar PV and thermal based on the following criteria:</p> <ul style="list-style-type: none"> • Capacity: For solar PV, 5 MW +/- 5%; for CSP, minimum 5 MW and maximum 100 MW. • Net worth of the company should be at least ₹3 crore/MW (\$638,000/MW) for the past three years. • Land in possession at least 1 hectare/MW. • Transmission evacuation agreement with State Transmission Unit (STU) regarding evacuation of power at 33 kV or more. • Technical requirement as approved by the Ministry of New and Renewable Energy (MNRE): Only commercially established and operational technologies to minimise technological risk. • Undertaking for domestic content to be submitted as under: <ul style="list-style-type: none"> ○ For solar PV: <ul style="list-style-type: none"> ▪ FY 2010–11: Mandatory for projects based on crystalline silicon technology to use modules manufactured in India. ▪ FY 2011–12: Mandatory for all projects to use cells and modules manufactured in India. ○ For CSP: 30% of local content in all plants and installations. • NVVN could ask for the project developers to share a percentage of the CERC tariffs with it, as a mechanism to share the administrative costs. At the time of preparation of this report, the total bid received for utility scale PV was multiple times the allocated capacity. Hence, NVVN has requested the PV developers to submit bids stating the percentage of the tariff they are willing to share with NVVN. The project developers offering the maximum percentage will be chosen.
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Source: Compiled by authors.

As mentioned in Table 4, about 84 MW worth of existing projects have been selected for migration to the JNNSM as of 25 July 2010, of which solar PV accounts for 54 MW and solar thermal the rest. The selected projects are in the states of Maharashtra, Punjab and Rajasthan.¹ The goal of the JNNSM for solar PV for the year 2010–11 is 150 MW, which includes 54 MW of migrated projects. The remaining 350 MW out of the 500 MW of target set for phase I for solar PV will be sanctioned in the year 2011–12.²

On 16 November 2010, bids from solar developers were received by the NVVN, with offers of discount on tariffs. For solar PV, the maximum discount to tariff offered is around ₹7, bringing down the tariff to under ₹11 per kWh. In the case of CSP, the discount has been around ₹3 to ₹4 per kWh, bringing down the tariff to around ₹10 to ₹11 for plants of 50 to 100 MW.³

Some states like Gujarat and Karnataka have instituted independent solar policies and generation-based tariffs that a developer will receive on signing a PPA with the state electricity authority. The Gujarat Energy Development Agency (GEDA) has signed MOUs with developers for 365 MW of solar PV and 351 MW of solar thermal capacities.⁴ The Karnataka Power Corporation Limited has taken the lead and has commissioned 6 MW (two 3 MW plants) solar PV capacity, and is soon commissioning one more 3 MW plant, bringing the total installed capacity of PV in Karnataka to 9 MW. Other states such as Rajasthan and Haryana are in the process of instituting solar policies. The Haryana Renewable Energy Development Agency (HAREDA) has been promoting solar in a big way.

3. Renewable Energy Certificates

The rationale, policy framework and principles governing Renewable Energy Certificates (RECs) are given in Table 5. Figure 6 describes the operational framework governing renewable energy purchase obligation (RPO) and RECs.

Table 5: RECs and RPOs

Rationale for RECs	The State Electricity Regulatory Commissions (SERCs) are mandated to set the RPOs for each state. However, due to the heterogeneity in the availability of renewable energy sources across states, the minimum percentage varies significantly. In the absence of an REC, there is no incentive for utilities to purchase RE power beyond the stipulated RPO.
Policy framework	<ul style="list-style-type: none"> • The National Tariff Policy 2006 requires SERCs to allocate a minimum percentage of the power purchased by distribution utilities to be sourced from renewables. • CERC regulation on RECs, January 2010, provides a framework to institutionalise RECs.
Principle of RECs	Renewable Energy power has two components: plain electricity and the ‘green’ nature of the generation. RECs separate the green aspect of it (1 REC is equivalent to 1 MWh). An Renewable Energy power generator can choose to sell the power to the local utility at normal tariff and sell the REC separately. RECs can be used by other state utilities toward their RPOs
For solar	There will be solar-specific RPOs stipulated

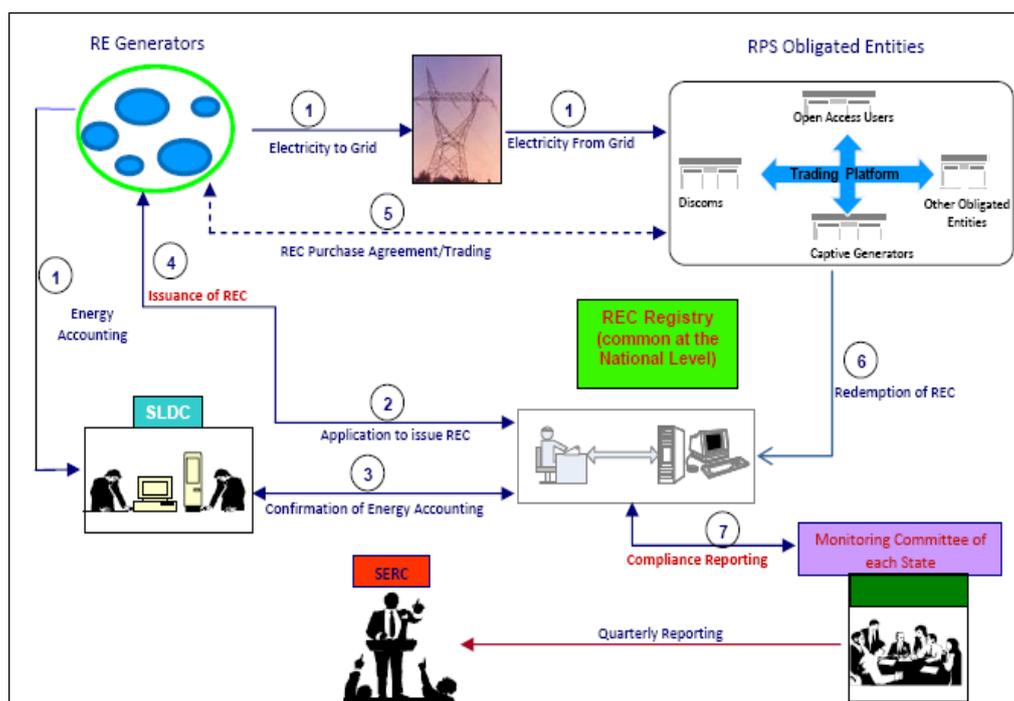


Figure 6: Operational Framework for RECs

(Source: Report on Conceptual framework for Renewable Energy Certificate Mechanism in India, ABPS Infrastructure, submitted to the MNRE)

4. Commentary on JNNSM Policy Guidelines

With the announcement of the National Solar Mission (NSM) in December 2009, there have been considerable discussions at all levels of society on solar technologies, investments, policy and regulations in India. The Ministry of New and Renewable Energy (MNRE) has made laudable efforts in attracting investors, having released several rounds of guidelines for different applications. The demand for solar PV is already expected to exceed the target of 500 MW, though the future of CSP is less certain given that it is early days for the technology not just in India, but globally.

What should be the metric to evaluate the success of such a grand programme? Should it be the total installed capacity, energy output or wider societal impact? The new guidelines and incentives announced by the MNRE are a marked improvement over previous policies. However, given the large outlay of public funds expected in the next few years, steps should be taken to ensure that the impact of solar energy goes well beyond installed capacity. The following sections provide an analysis of the policy and budget outlay of the JNNSM.

4.1. Photovoltaic Policies

The target set for Phase I of 500 MW of utility-scale solar PV are sliced in different ways as a means of illustrating societal and budgetary impacts.

4.1.1. Utility-scale Targets

A tariff of ₹17.91 per kWh of generation has been promised for twenty-five years for 5 MW plants that are commissioned in 2010–11 for a total capacity of 150 MW. Tariffs in subsequent years are likely to decrease with a total cap on capacity for Phase I of 500 MW of installed capacity. The net present value of the tariff payments for Phase I will be around ₹108 billion (at 10% discount). This entire sum is envisaged to come from higher electricity tariffs. See Table 6 for details.

Table 6: Net Present Value of Outlay towards Phase 1 of the JNNSM

	2010	2011	2012	2013
Annual installation	30	120	120	230
Generation (million kWh)	53	210	210	403
Price/W _p	180	170	159	150
Tariff/kWh	17.91	17.91	16.3	15.4
Net present value of cash outlay of installations in that year (billion ₹)	8.54	34.2	31.1	56.3
NPV of Phase I (billion ₹)	108			

4.1.2. Off-grid Targets

The mission targets 200 MW of off-grid solar PV installed capacity by 2013 and 2,000 MW by 2022. Given the lack of electrification and access to clean energy sources in Indian villages coupled with T&D losses, decentralised distributed systems make very good sense. Therefore, the targets set for off-grid capacity could be bolder. A capital subsidy of ₹150 per W_p is available for rural microgrids as against ₹90 per W_p for other applications. The problem associated with the current capital subsidy is that the projects might not be self-sustainable and there is no incentive to continue operation of the microgrid plant once it is set up. Even if all the 200 MW was allocated to rural microgrids, the total subsidy would amount to only ₹30 billion (this outlay is expected from tax revenues). Even if the capacity is increased substantially (set aside for utility-scale PV), the total subsidy would work out to be still considerably less than the incentive offered for the utility scale.

Just to demonstrate an alternate subsidy regime, a load of 35 kW, as worked out in the section on rural electrification, to meet the minimum electricity needs of a village of 150 households is considered. At this level, a 500 MW capacity can meet this minimum need of 14,290 villages. The total capital subsidy for this would be only ₹75 billion. If a generation-based tariff of ₹4.25 per kWh is added to this subsidy, the additional cost would be ₹32 billion. Hence, the total cost to providing minimum electrification to 14,290 villages will be in the same ballpark (Table 7) as the budget to pay investors for generation from 500 MW.

Table 7: Alternate Use of Capital Outlay

Micro-grid based on solar power	
Number of villages (chosen so total capacity is 500 MW)	14,290
Load per village with 150 households (kW) (minimum load to supply lifeline support)	35
Total capacity solar-based microgrids (MW _p)	500
Current policy of capital subsidy (₹/W _p)	150
Capacity utilisation factor of solar energy (%)	20
Annual gross generation by solar energy (million kWh)	876
Supply at bus bar after 5% auxillary use (million kWh)	832
If in addition a generation-based tariff offered (₹/kWh)	4.25
Annual outlay for GBI (billion ₹)	3.54
NPV of GBI over twenty-five years (billion ₹)	32.1
Total outlay of capex + GBI (billion ₹)	107

Slicing the numbers differently, providing 5.5 million households each with 37 W panels or providing 4,000 villages with 50 kW_p microgrids will each work out to be 200 MW. The magnitude of this must be judged in relation to the 75,000 villages⁵ and 28 million households that are currently un-electrified.^a Hence, off-grid applications for rural electrification should be prioritised considering it makes economic sense as well. Moreover, given the inadequacy of the grid, kerosene is likely to remain the mainstay for lighting for many households. Kerosene is expensive, subsidised and has adverse environmental and health effects. The net present value of providing kerosene subsidy for fifteen years to 28 million households (at a 10% discount) will be over ₹166 billion.^b

To support the aforementioned, even at today's high prices, solar-based microgrids offer a competitive solution compared to grid extension. A detailed techno-economics of grid extension versus solar-based microgrids can be found in the section on rural electrification. Moreover, solar PV is ideally suited for generation near demand centres. Furthermore, there is an urgent need for meeting the electrification needs of rural India. Increasing the proposed capacity for rural electrification via decentralised options would have a far greater impact than grid extension. Perhaps it would have made more sense to have increased off-grid capacities in the earlier years of the mission.

^a Village electrification status RGGYV as of 30 March 2010.

^b Assuming per household usage of 50 l per annum and a subsidy of ₹15.67 per l (subsidy amount for year 2009–10).

4.1.3. Policies for Grid-connected Solar Power

- At present, the financial health of utility distribution companies have raised concern among developers and investors that this might impede the possibility of loans to solar projects. However, with the discounts offered by potential bidders, the tariffs are lot lower than those announced by the CERC. This might ease the budgetary constraints on the DISCOMS; however, they might decrease the profitability of investors. The NVVN should ensure that there is no confusion surrounding the execution of PPAs to give confidence to investors.
- There should be clear long-term policy mechanisms in place to ensure that interest in solar investment remains. The current tariff of ₹17.91 is for PV plants commissioned in the year 2010–11. Infusing certainty into the system with a degression algorithm, much like the German model, could go a long way in providing certainty and resulting in sustained investor interests.
- It is not at all clear to any of the stakeholders what the mechanism to buy solar power in Phases 2 and 3 will be. Without a clear roadmap, targets alone will not lead to any of the prerequisites for reduction in the cost of solar power, namely, manufacturing set-up, corporate R&D or high-level human resources development (HRD). It is necessary to clearly define the objectives and possible ways and means to achieve them, as well as the financing needs and the ability of Indian markets to absorb the capacity addition. Some of the specific action points emerging from this are:
 - Assessing financing needs and possible sources of funding the solar mission, including international support.
 - A target-driven R&D policy for developing indigenous solar technologies.
 - An aggressive initiative on HRD to ensure adequate availability of manpower for ground-related (implementation, operations and maintenance) as well as high-level research work.
- With most of the country facing a tremendous shortage of electricity, it is unclear where this ‘unallocated quota’ used for bundling of power comes from. This mechanism has several limitations and several uncertainties. For example:
 - Some of the states that were receiving this unallocated quota will not be able to get it any more, worsening their power situation.
 - Even if it is presumed that the bundling would work well for the first phase and higher commitments can be ascertained from DISCOMs, that provides no clarity on the quantum of unallocated quota available or to be made available for second and third phases.
- Currently SERCs have the power to mandate RPOs, which is the proportion of total power purchased from renewables by distribution companies. Since the solar mission and the targets therein refer to a national-scale RPO, central intervention is a must; otherwise states may not set up the solar-specific RPOs. Legislation on renewable energy would be of great help if the targets under the NSM in particular and the National Action Plan on Climate Change (NAPCC) (15% by 2020) in general are to be met. The mechanism of renewable energy certificates, which is in advanced stages now and needs some push from central and state governments, will also help in achieving NSM targets.

4.2. Solar Thermal Policies

The capital subsidy provided by the MNRE by all accounts is sufficient to make solar thermal technology attractive. Even so, the adoption of solar thermal applications is low. The use of this technology can substantially reduce fossil fuel consumption in the domestic and industrial sectors, which would result in a considerable reduction in annual CO₂ emissions. There are only a limited

number of solar thermal installations in India in spite of simple and inexpensive manufacturing and short payback periods. Most of the data available at present is based on the anecdotal experience of a few, and there is a severe dearth of statistics on the techno-economics of solar thermal applications. Dissemination of data specific to the technology, workings and economics of solar thermal systems would provide impetus in increasing the adoption of these technologies. A few of the important steps that the MNRE can take to increase adoption is given at the end of the chapter 'Solar Thermal Technologies'.

Cumulative Capacity, Grid parity and Cost

Cumulative Capacity, Grid Parity and Cost

In India, with significant technology improvements and cost reductions, the price of solar photovoltaic (PV) technology is likely to be competitive with peak electricity within a few years and with coal-based generation perhaps in a decade. Since solar energy production cannot be scheduled as per electricity demand, consequently its value to the grid is lower than power than can be scheduled. An ideal comparison of solar and conventional sources of electricity ought to take this into account. However, such an analysis is beyond the scope of this report.

The present chapter estimates the cumulative PV deployment in India using diffusion curves. Three possible scenarios of capacity addition till 2022 are developed. Furthermore, future costs of PV systems using learning curves are projected. Based on this, future costs in the absence of any subsidy and price per unit of energy generated by PV are determined along the three scenarios. However, in reality the cost curves for each technology will be different; the estimates given here are more to give an idea of a range of values.

It has to be noted that the cumulative installed capacity of a new technology over a period is difficult to estimate. This will depend on several factors, including costs coming down and consistent government policy support. Moreover, there has not been much precedence globally of the scaling up of a country's solar power generating capacity in the way that it has been envisaged under the Jawaharlal Nehru National Solar Mission (JNNSM). Today the total global installed capacity of PV is around 20 GW, which is the targeted capacity in India by 2022. However, in the case of concentrated solar thermal power (CSP), the total installed capacity globally is less than 1 GW. Furthermore, most of the installations are of one particular technology – the parabolic trough. On top of that, in India there are no working CSP plants, and even the ones that are likely to emerge in the next few years will be based on imported technology to a large extent. Given the scarcity of data on CSP, any projection of future costs or capacity addition will have a larger degree of uncertainty.

1. Solar PV Cost Curves and Grid Parity

PV systems have three main parts: the solar modules or panels, the inverter and the balance of system (BOS) components. The BOS includes supporting racks, wiring and switches. The manufacturing of panels has undergone significant efficiency improvements and material shifts over the last couple of decades. For example, the cost per watt has decreased from \$6 to \$2 in the period from 1990 to 2005.¹ The inverter technology is fairly mature and any cost decrease is likely to be the result of economics of scale rather than technology improvements. The cost of the BOS depends on costs of raw materials, manufacturing and labour. This has not factored in any battery, which would not be applicable for a grid-connected system.

Though solar PV is booming, it is unclear if it can have a sustained growth in the absence of subsidies and government support. Recall the example of the Spanish PV market, described in a previous chapter, which dropped when the subsidy was withdrawn.

1.1. Cost Projection of the Solar PV System

In determining the price curves of PV systems, those of the three components – module, inverter and the BOS – are individually evaluated. The methodology of determining these cost curves is laid out in the following paragraphs.

The module costs are linked to global markets much more than the rest of the components, and currently account for roughly half of the system's price. Global factors – technology, economics and policy – have a direct bearing on the costs of modules. The 'experience' or 'learning' curve phenomenon is the most popular model to demonstrate how prices decline with cumulative production – cumulative experience in production, technology and deployment. The most common learning curve consists of costs dropping by a specific percentage for every doubling of cumulative capacity. The equation for this is given by:

$$C_t = C_0 (Q_t/Q_0)^{-b}$$

where C_0 , Q_0 are initial cost and initial capacity, and C_t and Q_t are cost and cumulative capacity respectively at time t , and b is the rate of innovation or learning coefficient; b will be negative as costs come down with capacity.^{2,3,4}

Historical observation suggests that costs drop by 20% for every doubling of capacity:⁵ here $b = \log_2(0.8)$. If Indian PV deployment were to grow as the National Solar Mission (NSM) dictates to over 10 GW by 2022, the Indian share of the global deployment might be significant and hence will have a bearing on global cost curves. Hence, it is unclear what the true cost curves will be. Given the number of uncertainties and to keep the analysis simple, historical cost behaviour is assumed.

During the period 2000–2009, the global PV capacity increased at an annual rate of 36%^a The following steps describe the procedure used to arrive at the per watt system cost in 2022:

- The system cost per watt peak in 2010 is assumed to be ₹180 per W_p : ₹100 for the panel, ₹35 for the inverter and ₹45 for the BOS.
- Going forward, we assume this growth rate decreases annually by 10% for the next twelve years till 2022; in other words, the cumulative annual growth rate will be 21.3%. The global capacity will increase from the current level of 22 GW to 185 GW in 2020, and to 232 GW by 2022. This is within the ballpark of the International Energy Agency's (IEA) projection of 210 GW.⁶
- Using these formulae, the panel cost in 2022 will be ₹51.9.
- The learning curve for the inverter and BOS have not been studied as widely as modules⁷ and hence we have made our own assumptions:
 - As the inverter technology is fairly mature, any significant cost reduction is likely to be because of economies of scale. Hence, the price reduction is a nominal 3% annually.
 - In the case of the BOS, the cost of labour and raw materials might increase at least with inflation, whereas learning by doing would bring down the costs. Again, a nominal 3% annual reduction in price is assumed.
- This results in system cost of ₹108 per W_p by 2022.

Using this cost curve obtained, the levelised cost of electricity from a PV plant was calculated for the years 2011–22 using a discount rate of 10%. Furthermore, the price per unit of electricity, which includes profit margin of the solar developer, was calculated assuming an internal rate of return (IRR) of around 10%.

^a Installed capacity in 2000 was 1,428 MW and at the end of 2009 was 22,878 MW.

The price of peak electricity in 2010 is assumed to be around ₹6.50 per unit. If carbon cess becomes a reality, the cost of generation of thermal power will increase substantially in the coming years. Using inflation rates of 5%, 6% and 7%, the peak price is projected till 2022. Figure 7 shows the peak price of electricity from the grid increasing, while the per unit price of electricity from solar PV decreasing. Grid parity, it appears, will happen anywhere between the years 2018 and 2020.

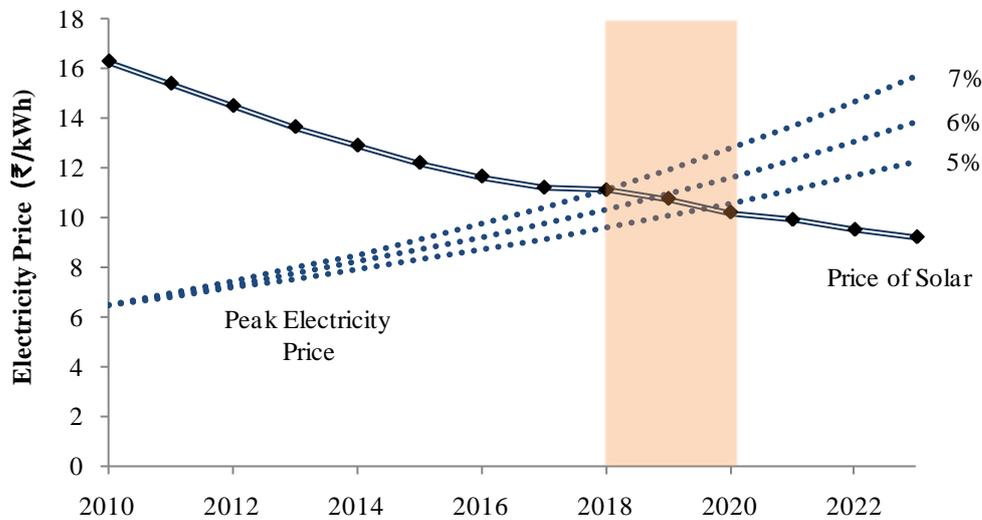


Figure 7: Price of Solar Energy and Peak Electricity

2. Solar PV Capacity Addition in India

At present, the total installed capacity of grid-connected PV in India is around 10 MW. This is one-tenth of a percentage of 10,000 MW, the target for installed capacity for PV for 2022. The probability of meeting the target and the path taken to achieve it are unknown.

Are There Lessons to be learnt from Wind Energy?

As of March 2009, India had an installed capacity of 10,243 MW of wind energy, with Tamil Nadu being the frontrunner with 4,304 MW. Up to 1992, the installed capacity in the country was a mere 41 MW. However, government support in the form of accelerated interest subsidies, depreciation benefits and feed-in tariffs have encouraged the growth of wind energy in India.

Three scenarios are projected: pessimistic, moderate and optimistic. While all three are assumed to achieve the target of 500 MW by 2013, the cumulative capacity achieved by 2022 is assumed to be 5,000 MW, 7,500 MW and 12,000 MW respectively. The gross generation^a for each of the scenarios would be 8.8 billion kWh, 17.5 billion kWh and 21 billion kWh respectively.

^a Assuming 20% capacity utilisation factor (0.2*24*365 hours of operation in a year).

3. Concentrated Solar Power Projections

Given the current status of CSP globally and in India, it is difficult to foresee how the technology will unfold in India, and what the market share of each of the three technologies – parabolic trough, linear Fresnel mirrors and the power tower – will be. Even the price quoted per megawatt for CSP technologies varies a great deal, with most price points being drawn from the parabolic trough technology. Keeping in mind the difficulties here, cost curves are not projected. The generation-based incentive is projected as follows: till 2013 it is held fixed at ₹15.31 (current tariff), reduced at 5% annually till 2017 (end of Phase 2), and then reduced at an annual rate of 10% till 2022. For capacity addition, three scenarios are projected for 2022; 1,000 MW, 4,250 MW and 8,000 MW will be the cumulative deployment in 2022. The assumption here is that scaling up CSP in India is difficult under normal circumstances. Even in an optimistic scenario, the achievement will be lower than the JNNSM target.

4. Additional Tariff per Unit of Electricity

Under the three scenarios considered, the total installed capacity of PV and CSP together would be 6,000 MW, 14,250 MW and 20,000 MW respectively. Considering the weighted average of generation-based incentives (GBI) of PV and CSP, for capacity additions in each of the scenarios, the annual outlay for the payment of tariffs would be ₹940 million in the fiscal year 2010–11, assuming a total capacity addition of 30 MW of PV by the year end. The total outlay for tariff payments in 2022–23 would be ₹130, ₹310 and ₹415 billions for a total installed capacity of 6,000 MW to 20,000 MW in the three scenarios. According to these assumptions, the total net present value of all the tariffs (annual power purchase agreements [PPAs] signed for a twenty-five-year period) will amount to ₹620, ₹1500 and ₹1800 billion for the three scenarios respectively.

The entire cash outlay towards payment of tariffs is currently expected to come from increase in electricity tariff. Gross generation of electricity (utility and non-utility) for the year 2009–10 for all of India was 862 billion kWh.^a Assuming a 9% GDP growth and a GDP-to-electricity elasticity of 0.9, the generation in 2021–22 could be around 2,200 billion units. The net electricity supplied in 2009–10 was 681 billion units and in 2022 it will be 1,616 billion units.^b

However, to keep the analysis simple, it is assumed that the annual outlay for solar tariff for a particular year is borne by the electricity (grid) consumers of that year. Further, it is assumed that the cost of the tariff is evenly distributed to all customers without differentiating based on consumption levels. In the current year, it is assumed (generously) that 30 MW of solar PV will be installed in all three scenarios. The total electricity generated this year will be a maximum of 53 million kWh.^c The total tariff cost associated with this will be around ₹940 million,^d but when distributed over around 681 billion units of electricity, it works out to be less than a paise per unit. However, by 2022 the installed capacity (PV and CSP) will be significant at 6,000 MW, 14,250 MW and 20,000 MW in the three scenarios respectively. The total generation associated with these installations will be 11 billion kWh, 25 billion kWh and 35 billion kWh respectively. Distributing this over the number of units of electricity supplied, it works out that the additional tariff for each unit

^aGross generation from utilities is 772 billion kWh (Ministry of Power) plus 90 billion kWh of captive generation (estimate).

^bAssumption: 7% auxiliary consumption and 15% T&D losses.

^c Assumption: the capacity utilisation factor (CUF) is 20% or 1,752 MWh of generation per MW of installed capacity.

^d At ₹17.91 per kWh of current tariff this year for solar PV. No CSP-based generation is assumed this year.

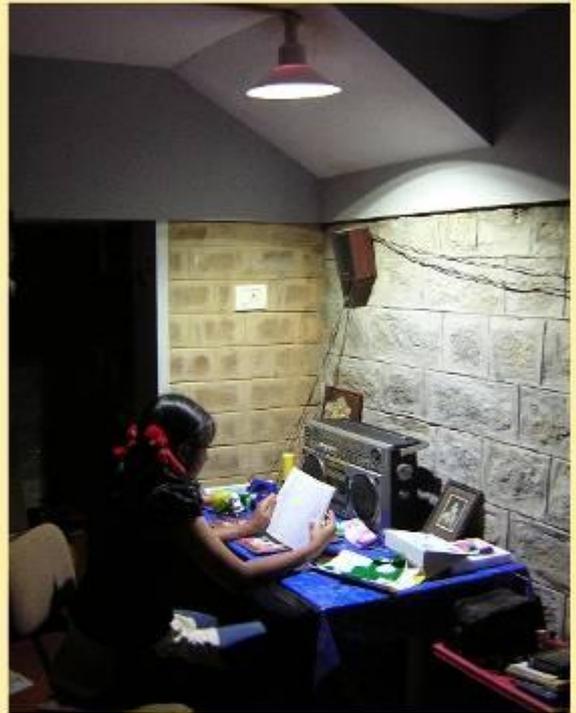
consumed by the customers will gradually increase from under ₹0.01 to ₹0.08, ₹0.19 and ₹0.26 respectively in the three scenarios.

5. Conclusions

Table 8 given below provides a summary of the estimates of generation and costs under the three scenarios considered in this section.

Table 8: Solar Capacity Scenarios for 2022

	2010–11	2012–13	2021–22		
			Pessimistic	Moderate	Optimistic
Installed capacity (MW)	30	500	6,000	14,250	20,000
Solar generation (billion kWh)	0.05	1.06	10.6	25.3	35.7
Total budget outlay for the year (billion ₹)	0.94	2.05	130	310	415
Estimate of electricity supplied by grid (billion kWh)	681	880	1,617	1,617	1,617
Solar Energy as % of total grid supply	0.01%	0.1%	0.5%	1.3%	1.8%
Increase in Tariff per unit supplied (₹)	0.001	0.02	0.08	0.19	0.26



Solar Photovoltaic Applications

Solar Photovoltaic Applications

This chapter presents techno-economic analysis and prevailing policy mechanisms of some applications where solar energy makes most social and environmental sense. Small scale grid-connected and off-grid applications are discussed. Furthermore, in all of these, solar is either economically viable today or will be in the near future. Where relevant, the levelised cost of energy (LCOE) and internal rate of return (IRR) for the developer or investor are calculated to assist in analysis. The discussions here are meant to give the reader a broad picture of the applications and challenges. The applications considered in this chapter are:

- *Solar photovoltaic (PV) options for rural electrification*: Simple effective solutions, including solar lanterns and SHLS are discussed, along with solar-based microgrids. Prevailing financial, policy and institutional mechanisms and barriers to wide-scale adoption are also taken up. The techno-economics of a solar-based microgrid is compared with grid extension. The current capital subsidy is compared with a generation-based tariff structure. Based on the analysis, a generation-based tariff is recommended for rural microgrids solely consisting of solar energy or hybridised with other renewable energy sources in order to ensure sustainable operation.
- *Solar-PV-based irrigation pump sets*: These pumps are found to be competitive at today's cost relative to diesel-based pumps based on cost per unit of electricity or work done. Economic analysis is provided for pumps of two sizes – 1 HP and 2 HP – needed to draw water from up to 230 ft (70.1 m) and up to 530 ft (161.5 m) respectively.
- *Rooftop PV systems for diesel use abatement*: In the case of solar PV systems for diesel consumption abatement, techno-economics is accompanied with a sensitivity analysis that incorporates varying diesel and PV system prices. It is demonstrated that the solar PV system could prove to be viable if diesel prices were to increase or PV systems prices were to come down. The total potential commercial rooftop available and a conservative market size for solar PV for reduction in diesel use is estimated. In addition to the economics, grid-connected rooftop PV systems could face technical challenges given India's transmission and distribution (T&D) woes. Policy recommendations are made at the end of the section.

Solar PV for Telecom Towers

India has more than 250,000 cell phone towers, each equipped with a diesel generator of 3 to 5 kW capacity depending on the number of operators housed on the tower. The towers are energy intensive since they operate non-stop. Given that a substantial number of these towers are in rural areas and any new additions are likely to be there as well, diesel consumption will be inevitable given the grid challenges. Roughly about 2 billion litres of diesel is consumed annually, amounting to around 4.5 million tons of CO₂ emissions. The Ministry of New and Renewable Energy (MNRE) is incentivising the replacement of diesel for telecom towers with solar PV. This report, however, does not evaluate the economics of solar PV for use in telecom towers.

In the case of smaller PV plants, particularly off-grid plants where duration of generation and demand may not match, the energy generated can be stored in batteries. However, batteries increase the overall cost of the system, need replacement every few years, and lower the overall efficiency. Hence, all the analyses given in this section for individual applications have taken into account the cost and efficiency of batteries. In addition, assumptions have been made on the capital cost of the system, hours of annual insolation and discount rate.

1. Solar PV Options for Rural Electrification in India

Almost 16% of India's 600,000 villages are un-electrified.^{1,a} A village is deemed to be electrified if the distribution infrastructure has been set up with minimum community facilities and 10% of the households are electrified. Furthermore, last mile electrification is often a challenge. Households that are un-electrified and use kerosene for lighting make up about 42% of the total number of rural households.² Kerosene is polluting, adversely affects the health of users, and is potentially hazardous. Even the villages and households that are electrified are often subject to blackouts and brownouts.

Policy guidelines surrounding the Jawaharlal Nehru National Solar Mission (JNNSM) should have equal emphasis on off-grid and small solar applications as on utility scale. Social responsibility and energy management must go hand in hand with resource allocation and planning. Providing clean reliable lighting to rural households could have a positive cascading effect. Hence, any recommendation solely based on economics may be limited in value. Health benefits, social equity, job creation, and improved quality of lives and livelihood of beneficiaries have to be carefully evaluated.

Solar PV applications offer good potential in this regard, both as a primary source of power in remote regions where grid extension is difficult, and, perhaps more widely, to augment unreliable power from the grid. Innovative financing schemes have to be conceived so as to ensure that the high per unit cost of generating electricity from solar energy is not passed on to the end-user who is already facing economic hardship. This section studies the following:

- The policy framework under the JNNSM as well as earlier programmes analysed, and the implications for service providers and end-users in three broad categories of solar PV technologies: lanterns, solar home lighting systems (SHLS) and power plants for village-level microgrids.
- Models for dissemination of solar lanterns and home lighting systems from successful programmes in other countries.
- In the case of microgrids, the load required for an average village (based on providing basic support) is evaluated. The results of a detailed techno-economical study of microgrids based on a solar and biomass hybrid power is presented and compared to grid extension. An alternate financial subsidy is recommended based on electricity generation that will better ensure the sustainable operation of the microgrid when compared to the current capital subsidy.

Furthermore, while solar lanterns can be a stopgap measure till electrification, SHLS and microgrids can provide sufficient power to meet residential and community-based requirements, and can easily be integrated if and when the grid does reach these areas. Ideally, based on a region's energy sources and demand, an optimal energy portfolio must be constructed. However, in this section the extent to which solar photovoltaic can meet the electricity needs of rural India is analysed.

^aA total of 95,000 villages are un-electrified, which is 15.8% of the total number of villages.

1.1. Government Initiatives

1.1.1. Electrification Status of Rural India

In 2005, the Government of India launched the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), a massive initiative towards universal electrification. The RGGVY's mandate is to provide grid access to villages and households that are not remote. It targets providing 1 kWh per day (considered to be the lifeline supply) for every household by 2012, and free electricity connection to all below poverty line (BPL) households. The installed capacity needed to provide this minimum electricity to the 69 million households will be just 6,500 MW.^a Of course, it should be noted that the capacity based on solar energy will be about 25,000 MW since the plant load factor (PLF) will be just 20% instead of the 76% assumed in the case of conventional plants. Complementing this is the Remote Village Electrification (RVE) programme of the MNRE, which will provide subsidy only to remote villages and households to use renewable energy to electrify through private sector providers. Table 9 gives the current electrification statistics.

Table 9: Rural Electrification Status of Villages

	Un-electrified as of 2009	Electrification plans for 2009–12	Un-electrified as of March 2012
Villages	118,499	78,256	40,243
Remote villages	18,000	5,000	13,000
Households	69 million	41 million	28 million

Note: Electrification status as of 31 March 2010, RGGVY.

Under the RGGVY, the Indian government will provide 90% of the capital expenditure and the Rural Electrification Corporation (REC) will provide the remaining 10% to the state governments. The REC is the designated nodal agency for the programme. Service providers will be compensated for the first five years for operations and maintenance of the system. The overall budget for capital expenditure for this programme under the Eleventh Plan (2007–12) is ₹280 billion, out of which ₹5.4 billion (2% of total capex) has been designated for decentralised distributed generation (DDG). Furthermore, the MNRE's RVE programme has a budget of ₹0.30 billion in the Eleventh Plan for decentralised solar PV systems such as home lighting systems, street lighting systems and traffic signals.

The MNRE also has schemes like the Solar Photovoltaic Programme and the Solar Lantern Programme, with the express intention of popularising solar-based technologies. There is also an incentive scheme for banks and other financial institutions to provide loans for SHLS and other small solar systems. These two schemes will lapse on the implementation of the guidelines on off-grid applications under the JNNSM.

1.1.2. Guidelines under the JNNSM for Off-grid Solar Applications

The JNNSM envisions to have 200 MW capacity of off-grid solar applications installed by 2013 (end of Phase 1) and overall a 2,000 MW capacity by 2022. The project implementation process has been

^aAssumptions: 7% auxillary power usage, 18% technical losses, 76% PLF and 1.3 capacity utilisation factor (CUF).

decentralised in that banks and other financial institutions can initiate proposals and are channel partners in the disbursement of the funds, in addition to the state nodal agencies (SNAs). Under the scheme, various off-grid PV systems up to a maximum capacity of 100 kW_p will be supported by the ministry. It is expected that systems above 100 kW_p will largely be grid-connected. Some of the salient features of the new guidelines include:

1. The guidelines for off-grid projects involve an upfront capital subsidy of ₹90 per W_p and a soft loan of 5% for 50% of the capital cost. The customer must pay 20% of the cost towards a down payment. The benchmark costs are estimated to be ₹300 per W_p. This sum includes five years of annual maintenance of the system. The loans will be routed through the National Bank for Agricultural and Rural Development (NABARD).³
2. Performance standards have been mandated for the components of the systems. Product specifications for grant of subsidy have not been given, as was the case previously, thereby giving latitude to service providers to innovate and customise their products as per end-user requirements with performance standards. This is a welcome change.
3. For programme administrators like SNAs, who used to be the sole channel previously, 70% of the funds will be disbursed on sanction and the rest on completion of the project, as compared to 50% of each earlier. Release of funds will be back-ended to other entities.
4. Monitoring and evaluation is proposed at two levels. At the first level, all deployment will be given certain parameters for complying with IT-enabled transparency requirements. The projects might be required to provide brief details, photographs and possibly the details of beneficiaries on an online portal of the Indian Renewable Energy Development Agency (IREDA). At the second level, there is a proposal to bring in civil society organisations, eminent persons and corporate houses for the monitoring and verification of the projects.
5. The scheme will be reviewed by an internal review committee at half-yearly and yearly intervals, and modifications therein will be incorporated by the ministry within the framework of boundary conditions.

The implementation process continues to be in project mode,^a as it is argued that this aids in focused deployment in both region and application.⁴ The negatives, however, could be higher transaction costs and delays in approval, which could lead to uncertainty and risks for the project developers. A more rigorous social audit along the lines of the Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA) should be encouraged for evaluation of projects under the JNNSM. Overall, the new guidelines have brought in some welcome enhancements to the previous MNRE policy under the solar PV programme.

1.2. Technology Choices, Economics and Policy

A range of solutions is needed to successfully electrify un-electrified villages, hamlets and individual houses that are in electrified villages but not grid-connected. These solutions should be affordable to the poor as well as economically sustainable. Households in electrified villages that either have no access or unreliable access to electricity can potentially be electrified using solar lanterns or SHLS, provided that they are in regions with moderate to high solar insolation. However, for villages that are un-electrified, grid extension or a microgrid implementation based on a portfolio of renewable sources could be options for successful electrification.

^aThe 'project' has to be initiated by renewable energy service providing companies (RESCOs) or systems integrators. Project report to include details on client and implementation. The bureaucratic hurdles to get the 'project' approved are unclear.

Several studies indicate that it is not the technology or the economics of solar solutions that is stalling large-scale adoption, but institutional mechanisms.^{5,6,7} The issues regarding institutional framework thus merit a closer examination. Some of these are delineated here and will be stressed upon repeatedly in this section:

- **Capital subsidies:** They may be vital to promoting large-scale adoption of solar applications as they currently entail high upfront costs. However, the subsidy structure must be such that issues like those mentioned here do not lead to government subsidies, counteracting the long-term goal of sustainable practices in a sector. See Table 10 for the demerits of capital subsidies.
- **Access to financing:** Down payment requirements and high interest rates have been the major barriers for service providers operating in a commercial mode without government subsidies.
- **Customising the operating models with end-user cash flows and needs:** Two considerations while targeting the rural poor are: the nature of their income flows and the value addition that solar lighting will have on their vocations, livelihoods and lives.
- **Quality of products:** It is of utmost importance to ensure that good quality products are marketed and a reliable servicing follows sales; else villages will end up as 'solar trash yards'.^{8,9}
- **Maintenance:** One of the major advantages of solar applications is the long life span coupled with relatively low maintenance requirements. However, it must be emphasised that the presence of local service centres along with warranty and maintenance contracts are essential for the success of the projects. Also, batteries typically require replacement after three to four years. This underscores the need for service centres.

With this background, the extent to which solar technology can contribute to rural energy needs is estimated. In addition, the relevant institutional framework for different options available is examined, and changes that could make the framework more effective are suggested.

Table 10: Demerits of Capital Subsidies

Stifling innovation	If subsidies are tied to specific models, products customised to end-user needs may not be rewarded.
Market distortion	A criticism of some of the World Bank-backed projects, for example, has been the distortion induced by subsidised products tipping the scales against commercially operating service providers.*
Distortion in technology choice	Considering the costs and insolation requirements of solar applications, subsidies under the JNNSM must not unduly favour these vis-à-vis other, perhaps more viable, options such as biomass or micro-hydro.
Lack of sense of ownership	End-users might not appreciate the true value of the product if they do not pay the actual costs. However, this should be balanced with the users' ability to pay.

Note: * NCI/Soluz, Inc., *Innovation in Rural Energy Delivery*, 2006, http://www.soluzusa.com/documents/NCI-Soluz_Innovation_in_Rural_Energy_Delivery.pdf, accessed 2 November 2010.

1.2.1. Solar Lanterns

1.2.1.1. Overview

A solar lantern could be a simple, cost-effective and environmentally friendly means of providing minimum lighting needs for the 28 million households that will remain un-electrified by the end of 2012 in India. Even so, as of March 2010, there are only 790,000 households that have a solar lantern.¹⁰ The Energy Research Institute's (TERI) Lighting a Billion Lives (LaBL) project and the World Bank's Lighting Africa initiative, perhaps the best examples of projects focusing on rapid dissemination of sustainable energy-based off-grid lighting systems, are both centred on solar lanterns. There are inexpensive lanterns on the market and market mechanisms that make solar lanterns affordable to many.

A solar lantern with a 2.5 W LED bulb and battery for four hours costs around ₹1,600.¹¹ The alternate CFL-based lanterns are more popular but also more expensive. If the government were to give a 90% capital subsidy for all 28 million households to purchase a solar lantern, then the total one-time subsidy would be ₹40 billion. This should be compared with the kerosene subsidy of at least ₹166 billion over a period of 15 years.^a

1.2.1.2. Institutional Mechanism and Policy

The newly released JNNSM guidelines for off-grid and decentralised solar applications gives a subsidy of ₹90 per W_p and there are no geographical restrictions.

Thus far the ownership model, wherein end-users own lanterns with a PV module, has been more prevalent compared to the central charging station (CCS) model.¹² In the CCS model, the entrepreneur either rents out lanterns for a fixed number of hours or charges the battery for a fee. This model has several advantages as long as the daily cost is within the end-user's means and is economically viable to the entrepreneur. The CCS model has been adopted for the global LaBL programme.¹³ Chaurey and Kandpal estimate that if users are willing to pay a daily rental of ₹4.0 or a recharging fee of ₹2.98 if they own the lantern, then the CCS model will be economically viable without any capital subsidy as long as the CCS has at least fifty lamps.¹⁴

The CCS model would be well suited for areas with erratic power supply, and could particularly see application in semi-urban and peri-urban areas as well. Pertinent advantages of a CCS model include greater affordability and better maintenance (as it is in the entrepreneur's interests). The model demands a high density of population with regular cash flows in order to be sustainable, and would not be as applicable in rural areas.¹⁵ For instance, whereas an entrepreneur who rents out the lanterns to street hawkers or roadside shops in urban areas could do well, this kind of success may not be replicated in villages. For the CCS model to be sustainable, the lighting should ideally result in a tangible benefit, such as an income generating activity.

In the case of individually owned systems, the solar panel is unlikely to be fixed, and hence may be pulled into the shade unwittingly. Moreover, if the solar panel accumulates dust, its performance will diminish visibly. The margin of error will be large as the size of the panel is very small. Moreover,

^a Assumed consumption of 50 l of kerosene per year for each household and a government subsidy of ₹15.67 per l of kerosene for 2009–10; <http://ppac.org.in/OPM/Subsidy%20to%20Consumer%20-%20%20PDS%20Kero.pdf>, accessed 4 November 2010.

being mobile, solar lanterns are more susceptible to loss. All this points to the advantages of the CCS model where it will be fixed and the entrepreneur can ensure better performance

1.2.2. Solar Home Lighting Systems

1.2.2.1. Overview

SHLS consist of a solar PV panel, battery, charge controller and lighting system (lamps and fan). Depending on the PV panel size this system can power a lighting system ranging from a single lamp to several lamps and a fan or TV. This requires low ongoing maintenance except for a battery change every three to five years. In spite of generous support from the government, so far only 580,000 SHLS have been installed.^a However, it is unclear if this includes those installed by private players without availing a government subsidy. One such example is Tata BP Solar, who have sold 150,000 SHLS to households in the states of Uttar Pradesh, Haryana and Karnataka in the year 2009–10.¹⁶ Still, it all adds up to only a tiny fraction of the total potential. Taking into account solar radiation and economics, about 98 million out of the 137 million rural households can afford and benefit from an SHLS.¹⁷ This system has significant advantage over solar lanterns, particularly in the case of the ownership model: they can take a larger load and fixed panels lead to better performance (difficult to get dragged into shade).

1.2.2.2. Institutional Mechanism and Policy

A critical environment for greater penetration of SHLS is the presence of a well-functioning market of suppliers, maintenance service providers and, of course, competitive pricing. Capital subsidies alone cannot ensure success of the installation. Indeed, experiences under the erstwhile Solar Thermal Programme (solar water heaters) suggest that the gradual elimination of capital subsidy, after 'sufficient dissemination of solar devices, did not hamper their growth or popularity'.¹⁸ Many papers in the literature suggest that capital subsidies have been unsuccessful in the dissemination of PV devices. Besides, there have been examples¹⁹ of commercial models of dissemination of solar systems in countries like China and Kenya, and, closer to home, by service providers like the Solar Electric Light Company (SELCO) and Tata BP Solar. Table 11 describes a few models of dissemination. The latter's customers paid a down payment, and entered into a five-year loan contract without any collateral with rural regional banks. The equal monthly installments (EMI) work out to be between ₹200 and ₹500 for two to four light systems costing ₹13,000 to ₹25,000.²⁰

The normative cost of ₹300 per W_p assumed for the computation of capital subsidy is too low for smaller systems such as SHLS and solar lanterns, where the proportionate costs for balance of systems and installation cost in remote regions will be higher. Hence, this inadvertently disadvantages the poorest customers and supports low quality systems. The 20% down payment requirement might be difficult for the poor. Moreover, the maximum loan amount of 50% of the indicative costs makes purchasing of higher cost (and better quality) systems difficult.

^a Data from respective development authorities of the cities.

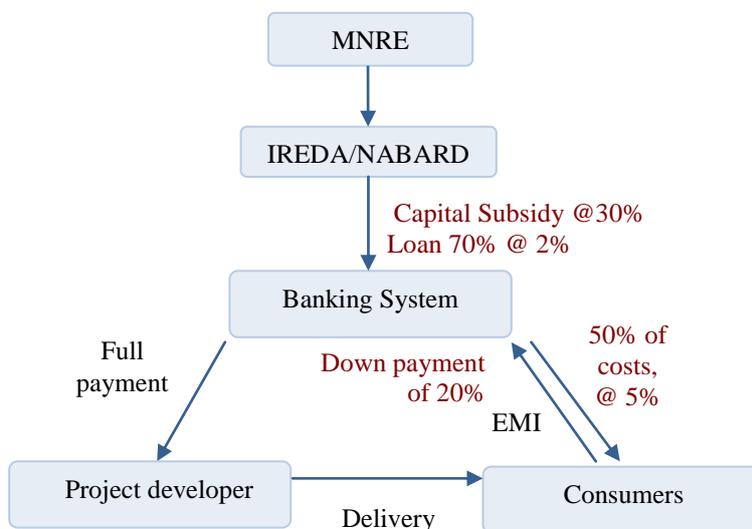
Table 11: Models of Dissemination

	Description	Example	Remarks
Franchisee approach	Franchisees are selected based on a competitive bidding or tendering process and given the responsibility of providing services to designated regions	Argentina, Senegal, Bolivia, Philippines	Competitive; open markets can create pressure in reducing costs; could target remote regions where market models may fail
Leasing/micro-rental approach	Fee-for-service model with service provider installing equipment, but retaining ownership while assuming operation and maintenance (O&M) risks in return of monthly rental	Soluz in Honduras and Nicaragua pioneered the concept for rural areas; also implemented in Laos and African countries like Zambia	Logistically difficult for service providers to collect rent; working capital and risk management are issues for service provider
Dealer/credit line approach	Service providers sell equipment to users in an open market mode; may assist in financing through banks and micro-finance institutes (MFI)	Sri Lanka; India, companies like SELCO	Down payment requirements and interest rates are barriers for end-users; maintenance infrastructure is critical

Other than pricing, the major barriers for PV dissemination in rural areas have been availability of local credit, lack of awareness of end-users, limited outlets of procurement, unavailability of different models catering to the specific needs of consumers, absence of trained manpower for maintenance, and lack of support to entrepreneurs.²¹ The major barriers faced by end-users have been down payment requirements and the higher interest rates that small rural banks or cooperatives charge.

However, as suggested in Figure 8, the capital subsidy of 30% can be given to the lending institution as down payment towards the solar loan, and the rest of the capital can be given as a loan to the end-user. A payment schedule that is convenient to the end-user and acceptable to the bank should be worked out. As an alternative for households that cannot access loans due to lack of creditworthiness, a micro-rental scheme can be looked into. It is estimated that if loans similar to that currently envisaged are provided to the service provider for managing the working capital, this model can be viable and could make the dissemination more inclusive.

Current framework



Suggested framework

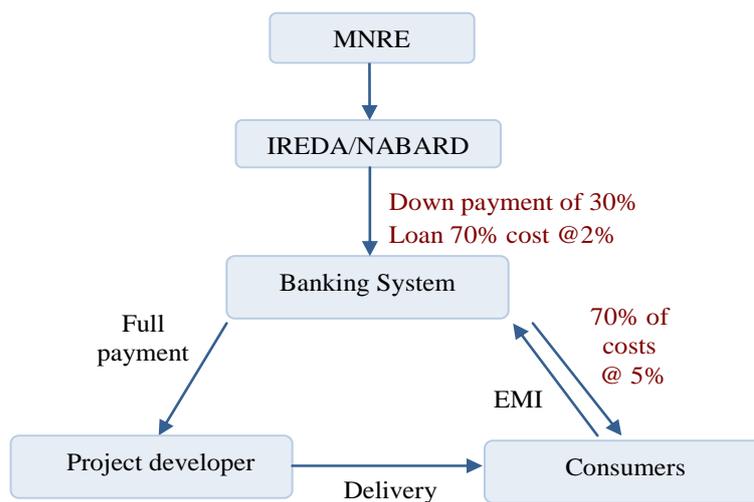


Figure 8: Current and Suggested Support Framework for Off-grid Solar PV

1.2.3. Solar PV Microgrid

1.2.3.1. Overview

The rationale behind a microgrid is that by bringing the generation of electricity closer to the site of consumption, one can avoid the T&D losses of grid extension, especially in remote regions. Additionally, it can alleviate the demand–supply gap and provide more reliable power to rural areas. Given the variability and intermittent nature of solar energy, a microgrid based on a hybrid system of solar and mini-hydro or biomass makes more sense. In this study, a solar–biomass hybrid option is analysed as an illustration since cost data for biomass was more easily available. The optimal allocation of renewable resources will be site-specific, constrained by the availability of resources. Unlike other resources, solar energy is unlimited if the region receives bountiful sunlight. The microgrid is a potential solution for a village or a cluster of villages that have houses in close proximity. The technology is bound to work; the rural poor might be willing to pay for an assured supply of electricity, but even so it has to be borne in mind that sustainable long-term operations of the microgrid is difficult in the absence of solid institutional mechanisms.

Under the current framework, the government provides a subsidy of ₹150 per W_p of installed capacity and a soft loan at 5% for the rest of the amount less the promoter's contribution of at least 20%.²²

1.2.3.2. Techno-economic Analysis

A typical village is assumed to have 150 households with each having an energy requirement of 1 kWh per day. Street lighting, an electrified drinking water pump and community buildings such as health clinics and schools are considered essential needs. At any time, any additional demand can be easily augmented with solar energy. Moreover, if there is demand for a cottage industry or any commercial activity, additional solar panels can be added and the commercial entity can be charged a higher rate. Agriculture will be treated separately in a following section.

Apart from the DDG system, the microgrid will consist of a low voltage (LT) distribution network, individual household connections, meters and a battery bank. Based on these assumptions, the load of such a village is computed to be 35 kW (See Appendix 1: Assumptions in the Section on Rural Electrification). Figure 9 has the economics of a microgrid that is based on 50% solar and 50% biomass, and 25% solar and 75% biomass. This is done solely for the purpose of illustration. The top x-axis is the system cost of solar PV that is likely to go down in the coming years, while the bottom x-axis is the distance to the grid used for the calculation of grid extension costs for the village. The y-axis is the LCOE of both renewable-energy-based generation as well as grid extension.

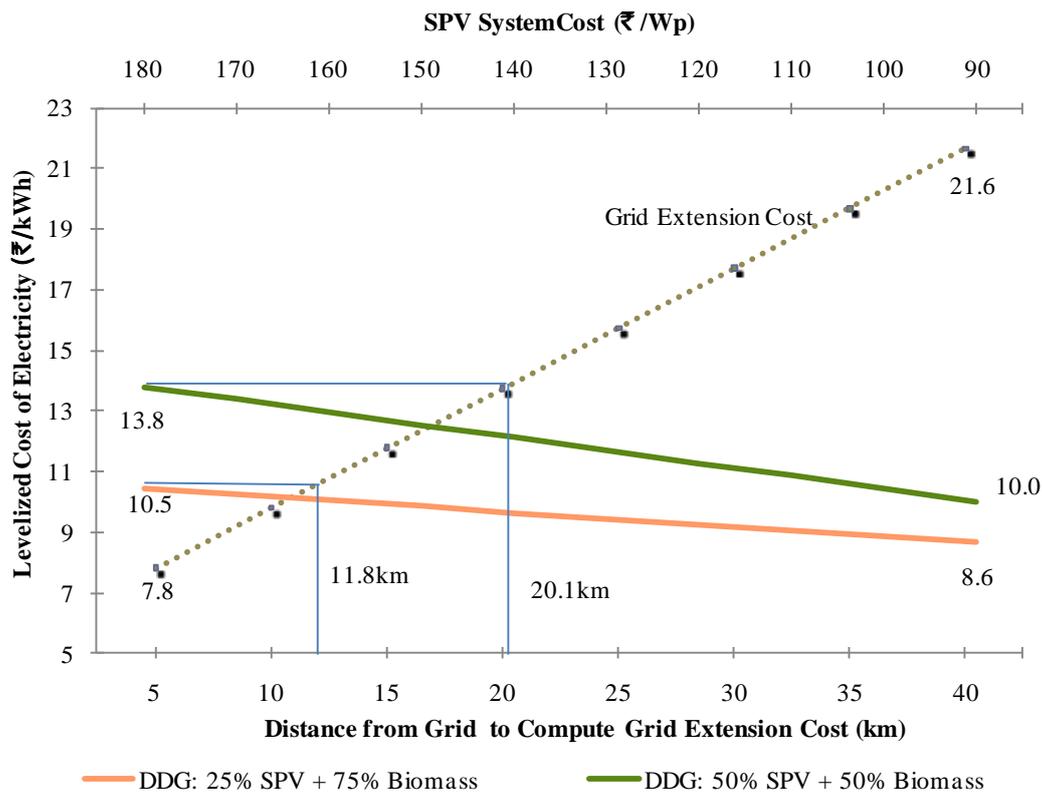


Figure 9: Solar PV System Cost Compared to Grid Extension

Observations from Figure 9 show:

- DDG: 25% solar PV and 75% biomass – solar PV systems cost of ₹180 per W_p (current rates):
 - Capital cost: ₹4.56 million and LCOE ₹10.5 per kWh (at a 10% discount).
 - At today's cost, a DDG with 25% solar PV will be more economical than grid extension beyond 11.8 km.
- DDG: 50% solar PV and 50% biomass:
 - Capital cost: ₹5.76 million and LCOE ₹13.8 per W_p (at a 10% discount).
 - DDG will be economical for grid extensions beyond 20.1 km.
- If the solar PV system price were to drop to ₹140 per W_p .
 - DDG with 25% solar PV will be competitive for grid extensions of over 8.1 km.
 - DDG with 50% solar PV will be more competitive for grid extensions of over 14 km.

It has to be borne in mind that in India the power from the grid is cross-subsidised. Households typically pay ₹2 or less per unit of power for the lowest slab, where most of the rural households this report is targeting will fall under.

1.2.4. Alternate Financial Models

The responsibility of installation and maintenance of the DDG for the life of the plant (twenty-five years) is assumed to be given to either a private contractor or a social entrepreneur as a franchisee. However, it is difficult to ensure sustainable operation of the microgrid and energy distribution. With the current scheme, the advantage is the administrative ease of a one-time payment. However, the disadvantage is that the system may languish without any maintenance after the five years of the annual maintenance contract (AMC).

The section, 'Bouquet of Incentive Instruments' of the guidelines for off-grid applications^a recognises the need for a flexible funding approach for the programme to be effective. A few alternative financial support schemes are suggested in this document. While these are not strictly part of the set of possible incentives, they are related to the arrangements envisaged for successful utility-scale projects.

It can be seen in Figure 10 that the net present value (NPV) of the generation-based incentive (GBI) is within reasonable limits at tariffs of ₹3.50 and ₹4 per unit of electricity generated. However, this may not be economically viable to the developer. For a microgrid based on 25% solar and 75% biomass, Figure 11 shows that if the households were to be charged ₹2 per unit of electricity consumed then the government has to pay at least ₹5.50 of GBI for the IRR to be 10%. However, if the households paid ₹3 per unit, then it suffices for the government to pay ₹4.50 for 10% IRR. Alternate subsidy regimes are discussed in the next section.

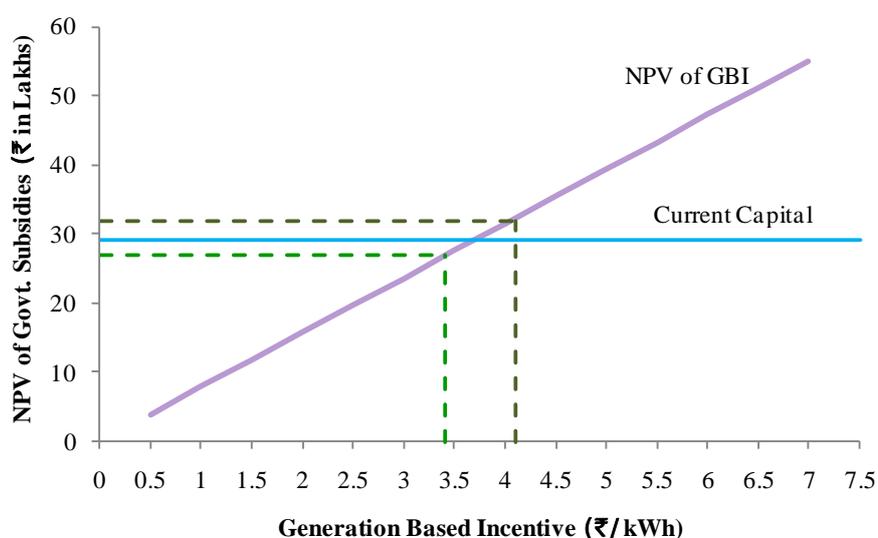


Figure 10: NPV of Generation-based Tariff for Twenty-five Years vs. Today's Subsidy Regime for a System with 50% Solar PV

The IRR for the project developer as a function of government tariff and consumer tariff are plotted in Figure 11.

^a JNNSM guidelines for off-grid and decentralised solar applications, and rooftop and other small solar plants, <http://pib.nic.in/archieve/others/GuidelinesJNNSolarMission.pdf>, accessed 20 November 2010.

How much should the government pay to augment household tariff to make it viable for a developer?

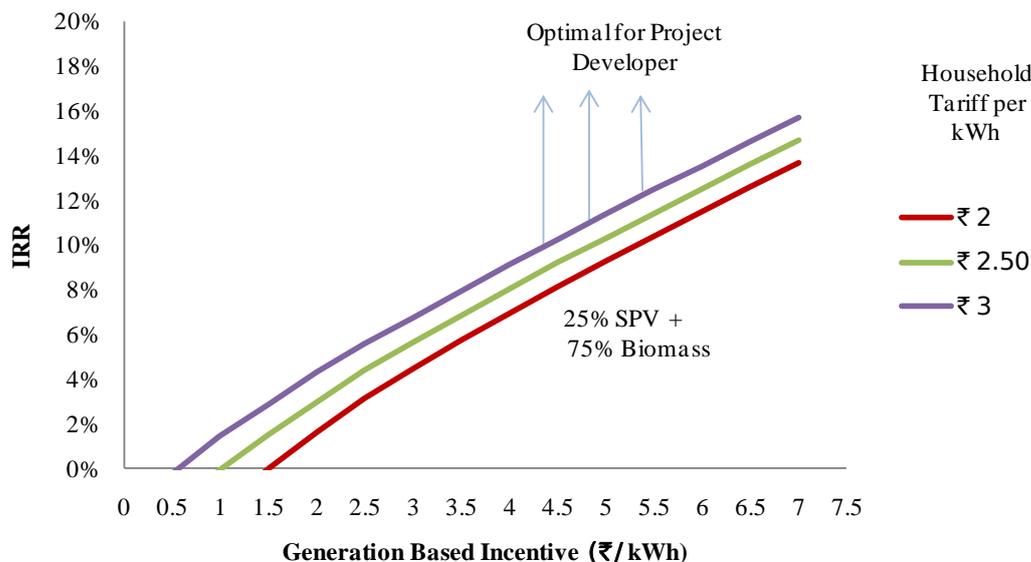


Figure 11: Decision Points: Household Tariffs Plus the Government’s GBI

Alternative I: It is felt that rural end-users should not be charged more than what the urban population is paying for grid-based power. Hence, it is assumed that the end-user is charged between ₹2 and ₹3 per unit of electricity. Here are the additional assumptions made:

- The village panchayat pays a tariff of ₹3.50 per unit of electricity consumed by public utilities.
- The developer gets a soft loan at 5% on 70% of the capital cost.
- Straight line depreciation and the tax rate of the developer is 30%.
- The central government pays a generation-based tariff of:
 - ₹4.5 to ₹5.50 if the solar component of the microgrid is 25%.
 - ₹6.50 to ₹7.50 if the solar component of the microgrid is 50%
- This would result in an IRR of at least 10% to the developer. If a soft loan of 5% is assumed for a loan amount equal to 70% of the capital cost, the IRR will be higher than 10%.

Alternative II: Alternatively, a hybrid option of the current structure and the aforementioned option can be considered – capital subsidy of 10% of the upfront capital cost, with lowered feed-in tariff. A tariff of ₹6 per kW_p for a system with 50% solar PV and ₹4.25 per kWh for a 25% solar PV system results in a 10% IRR for the investor. Here, the end-users and the panchayat pay the same tariff per unit of power as in Alternative I. The issue with this tariff payment remains, but as can be seen in Tables 12 and 13, this option is more attractive for the project developer and also entails less expenditure than generation-based tariffs alone for the government.

Table 12: Capital Cost of Solar-based Microgrids to Electrify a Village with 150 Households

	50% solar PV + 50% biomass	25% solar PV + 75% biomass
Total capital expense (million ₹)	5.76	4.56
LCOE with no subsidy (₹/kWh)	13.8	10.45
Min. (₹18,000/household, capital subsidy @ ₹10/W _e for biomass and ₹150/W _p for solar)	28	15.8

Table 13: Economics of Different Subsidy Mechanisms

	50% solar PV + 50% biomass		25% solar PV + 75% biomass	
	NPV (₹million)	IRR	NPV (₹million)	IRR
Current subsidy (current capital subsidy + 5 years of AMC and soft loan @5%)	3.28	Negative	1.953	Negative
GBI of ₹7 + soft loan @5%	5.51	10.30%	3.94	10.30%
Capital subsidy @10% + GBI of ₹6	5.3	10.10%	3.8	10.20%

1.3. Policy Recommendations

The following recommendations are based on discussions and analysis in this section on rural electrification:

- Solar lighting systems should be given high priority to provide lighting in un-electrified or electrified villages, or in urban areas. Soft loans and capital subsidies should be provided to entrepreneurs, manufacturers and service providers.
- The indicative costs of ₹300 per W_p are too low for small systems where the proportion of costs on balance of systems is higher. This inadvertently disadvantages the poorest customers and supports low quality systems. As the maximum loan amount is 50% of the indicative costs, it makes purchasing higher cost (and better quality) systems difficult.
- A National Bank for Agriculture and Rural Development (NABARD) circular²³ stipulates that the borrowers are required to bring in 20% of the costs. Down payment requirement should be removed for loans towards solar lighting systems, and in its place the capital subsidy should be considered. Furthermore, there could be more flexible loan terms for low-income households. The stipulation for a minimum lock in period of three years seems unnecessary.
- Social entrepreneurs should be favoured by offering them financial incentives to disseminate solar applications to urban and rural poor.
- In the case of solar lighting systems, the framework for supporting local entrepreneurs that set up CCS-based rental services is currently unclear. Governmental recognition of this

model with a mandate on appropriate working capital loans could be effective for greater distribution of lanterns.

- Down payment requirements may continue to be a barrier despite capital subsidy. This requirement could be removed for solar loans. A viable alternative could be the government's capital subsidy of 30% being considered as the down payment from the end-user, with the bank giving a loan covering the remaining costs. Another implication of this is more effective use of capital subsidy, given the concerns mentioned previously. Furthermore, there could be longer loan terms for low-income households and/or further reduced interest rates. This recommendation has been illustrated in Figure 11.
- A generation-based tariff for solar microgrids above a set capacity (say, 10 kW_p) should be considered for implementation. This will ensure sustainable operation of the plant as compared to the one-time capital subsidy currently proposed. In terms of the total subsidy outlay, this will not be very different than the current capital subsidy.
- Methods of monitoring applications and ensuring ongoing operations must be planned and prioritised,
- The mission targets 200 MW of installed solar PV capacity. Given the lack of electrification and access to clean energy sources in villages, coupled with the precedence of solar off-grid projects, the mission's targets for off-grid systems could be more ambitious; off-grid targets should receive more focus and the policy framework for this should have better clarity..
- The Reserve Bank of India should prioritise lending to solar solutions in the case of lanterns and home lighting systems; in the case of microgrids, hybrid solutions based on solar and other renewable energy sources should be targeted for priority lending. Rural regional banks should be extensively involved in channelling these loans.

1.4. Implementation Strategy: An Illustration

- **Priority I:** Solar lanterns and SHLS should be given high priority to provide lighting to those in un-electrified or electrified villages, or in urban areas. Soft loans and capital subsidies should be provided to entrepreneurs, manufacturers and service providers. It has to be noted that this is a stopgap measure till such time that the grid reaches these homes. Even when the grid does reach, solar power can continue to abate pressure on the grid.
 - Since the total investments are very modest at ₹1,600 per lantern and ₹45 billion for 28 million lamps, this issue should be prioritised.
 - Apart from environmental benefits, health and social benefits are unquantifiable yet significant.
- **Priority II:** Priority should also be given to remote village electrification to the extent possible, using solar energy for household and community needs. At a later stage the microgrid can be upgraded by adding more solar modules to accommodate growth and to serve commercial establishments and/or cottage industries.
- **Priority III:** Another strategy could be to augment villages with scarce grid supply with solar-based microgrids or SHLS.

1.4.1. Sample Implementation Plans for Priority I

To give a rough estimate of costs, the 28 million un-electrified households and another 650,000 households (say, fifty households in each of the 13,000 remote villages) totalling 2.87 million un-electrified households are considered. Out of these, if 75% are assumed to be in high insolation regions, the total is 21 million households. Furthermore, assume that 50% of these households (10.5 million) are BPL ones and are provided solar lanterns, and the rest of the 10.5 million households are provided a small SHLS. If 40,243 villages and another 13,000 remote hamlets need

electrification, assuming a solar solution is feasible for 75% of them, the number comes to about 40,000 villages. In Table 14 one can see that a total investment today of ₹114 billion will be enough to meet household- and village-level electrification. This is less than half of the overall budget under the RGGVY and about 6%^a of the overall investments expected in the solar space over the next decade.

Table 14: Total Investment Required to meet basic Solar needs of 40,000 Villages

System	Number	Cost/system (₹)	Total cost (₹billion)
<u>Households</u>			
SHS model	10.5 million	7,177	75.36
Solar lanterns	10.5 million	1,600	16.80
Subtotal for households			92.16
<u>Public works for 40,000 villages</u>			
Solar street lighting (10/village)	400,000	23,100	9.24
Solar drinking water pump (1/village)	40,000	210,000	8.40
Lighting system community buildings (2/village)*	80,000	60,000	4.80
Subtotal for the community			22.44
Total investment for providing basic amenities			114.60

Note: *Assuming 200W per building at ₹300/W for systems with battery.

2. Solar-PV-based Irrigation Pump Sets

Almost 70% of India's population depends on agriculture either directly or indirectly. While 44% of the 140 million sown hectares depend on irrigation, the rest relies on the monsoons.²⁴ Irrigation, therefore, is essential for good crop yield. Most electrical consumption in this sector goes towards operating pump sets for irrigation. In 2006–7, India's agricultural sector accounted for 22% of the total electricity consumption, up from 10% in the 1970s.²⁵ There are about 21 million irrigation pump sets in India, of which about 9 million are run on diesel and the rest are grid-based.²⁶

Grid electricity for agriculture in India is provided at very low tariffs – in most cases, flat rates are charged based on the ratings of the pump.²⁷ This is largely due to logistical difficulties faced with metering and charge collection. But this practice of providing electricity to farmers at highly subsidised rates has led to increasingly high consumption patterns and widespread use of inefficient pumps across the nation. Also, pumps of lower ratings are used to power applications requiring higher power. These factors, among others, have led to an invidious irrigation–energy nexus. Apart from this, limited and unreliable supply of grid electricity has led to farmers' extensive dependence on diesel for water pumping.

^a A total of ₹2,000 billion worth of investments are expected towards the National Solar Mission.

The Pump Predicament

As a result of erratic and limited supply of three-phase power (usually up to six hours a day), many farmers opt for single-phase pumps instead of three-phase ones, thus reducing efficiency and increasing consumption of power. Subsequently the amount of current drawn increases leading to greater susceptibility to sparking and deterioration of windings. Without adequate maintenance of pumps and replacement of windings every three years, pumps further deteriorate and finally burn out. Therefore, farmers have to be trained in proper use and maintenance of the equipment.

In addressing this challenge, the efforts of the Gujarat government are noteworthy. They introduced the Jyotigram Yojana, a programme that seeks to provide a reliable supply of power for agricultural and domestic purposes in rural areas (refer box)^{28,29}.

Jyotigram Yojana

In an attempt to solve the undesirable irrigation–energy nexus in the state, the Gujarat government introduced the Jyotigram Yojana. This constituted the following:

- Feeders supplying agricultural connections were bifurcated from those supplying to commercial and residential connections at substation itself.
- Meters on distribution transformer centres were also installed on both sides of feeders to improve the accuracy of energy accounting.
- Consumers were charged tariffs based on metered usage without deviating from earlier tariff schemes.
- Investments were made in over 500,000 ground water recharge structures.

Impact:

- Growth rate of 9.6% in agricultural output.
- The once-bankrupt Gujarat Electricity Board was revitalised as revenue collection increased from ₹8.5 billion in 2004–5 to ₹12.31 billion in 2007–8 and ₹14.73 billion in 2008–9; the board is profitable now.
- It resulted in an increase in employment opportunities, education of rural women and children, and increased momentum in industrial activities.

The MNRE has a programme for the deployment of various solar PV applications, including water pumping systems.³⁰ However, the deployment has been sparse thus far, with only 7,334 solar PV water pumps having been installed across the country as of March 2010.³¹ Water demand for irrigation is correlated to bright sunny days. Hence, solar-based pumps make sense. Even so, a small buffer storage might be needed to replace diesel satisfactorily.

A solar PV water pumping system consists of a PV array, motor pump and power conditioning equipment, if needed. The power conditioning equipment is used to stabilise the fluctuating

electrical energy output of the array. Depending on the total dynamic head and the required flow rate of water, the pumping system can either be on the surface or submersible^a and the motor can run on either alternating current (AC) or direct current (DC). For AC pumping systems an inverter is required.³² Ratings of pump sets are chosen depending on the water requirements, size of field, total dynamic head, type of irrigation (drip irrigation, use of sprinklers), etc.

Under the current scheme, the MNRE will provide a capital subsidy of 30% of the benchmark cost (₹210 per W_p) and/or^b 5% interest-bearing loans for installation of systems with a maximum capacity of 5 kW_p.³³

2.1. Analysis

Assuming a cost of ₹280 per W_p for solar PV panels, our analysis showed that, when compared to grid-connected systems at current rates, solar PV proved to be costlier. However, as an off-grid application, when compared to diesel generators, it worked out to almost half the cost over a life cycle of twenty-five years even at unsubsidised rates as can be seen in Tables 16 and 17). Other studies have already shown the economic feasibility of solar PV over diesel pumps.^{34,35} Therefore, the former are a viable alternative in economic and environmental terms to diesel pumps in areas where there is no or highly unreliable grid connectivity. Table 15 gives the underlying assumptions of the analysis.

Table 15: Comparative Analysis of Diesel and Solar PV Irrigation Pump Sets: Some Assumptions

Assumptions	
No of operating hours per year (in hours)	1,600
Cost of pump set (₹)	25,000
Cost of solar PV panel per W_p with battery (₹)	270
Assumed flow rate for pump (gallons/minute)	2.6
Life cycle period (in years)	25.0
Cost of grid electricity per unit (₹)	0.5
Discount rate (%)	10
Fuel consumption (litre/kWh)	0.33

^a A submersible pump (or electric submersible pump [ESP]) is a device that has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. Submersible pumps push water to the surface as opposed to jet pumps, which have to pull water. Submersibles are more efficient than jet pumps.

^b Non-commercial entities: capital subsidy *and* interest subsidy; industrial/commercial entities: capital subsidy *or* interest subsidy.

Table 16: Cost Comparison between Diesel and Solar PV Pump of 1 HP Rating (₹)*

	Capital cost	Operating cost /year	Net present cost	Cost per kWh
Solar PV	259,702	1,500	293,793	8.6
Grid electricity	30,000	2,181	79,559	2.3
Diesel at ₹42	25,000	20,557	405,578	11.9
Diesel at ₹50	25,000	24,187	471,575	13.9
Diesel at ₹60	25,000	28,724	554,072	16.3

Note: * Motor rating = 1 HP (230 ft [70.1 m] depth), subject to variations with type of pump used, number of stages, flow rate, etc.

Table 17: Cost Comparison between Diesel and Solar PV Pump of 2 HP Rating (₹)*

	Capital cost	Operating cost /year	Net present cost	Cost per kWh
Solar PV	559,314	1,600	595,677	7.6
Grid electricity	30,000	3,168	102,008	1.3
Diesel at ₹42	25,000	45,513	859,790	11.0
Diesel at ₹50	25,000	53,778	1,011,871	12.9
Diesel at ₹60	25,000	64,233	1,201,972	15.3

Note: * Motor rating = 2 HP (530 ft [161.5 m] depth), subject to variations with type of pump used, number of stages in case of a submersible pump, flow rate, etc.

The key barrier to the large-scale dissemination of solar PV water pumps is the high capital cost incurred by farmers compared to the much lower capital cost of conventional pumps. Solar PV is a competitive option in the face of diesel, its adoption being contingent on the ease of access to subsidies. Another factor to be considered is the space requirement for the installation of a solar PV pump set. For every kW_p installed, a space of 10 m² is necessary. For example, in order to install a 10 HP pump, 74.6 m² of land would be necessary. This factor limits adoption by small-scale farmers to whom land availability is a major concern.

If it is assumed that a moderate 50% of the total diesel pumps in India (of the 9 million pump sets) are replaced by solar PV, the total potential for savings in diesel fuel will be approximately 185 billion kg per year (Table 18). In terms of carbon dioxide, approximately 470 billion kg could be abated annually.

Table 18: Estimation of Potential for Diesel Use Abatement Using Solar PV Irrigation Pumps

Assumptions	
No. of diesel pumps	9,000,000
Operating hours per annum	1,600
Diesel pumps replaced by solar PV (%)	50
Average rating of pump (kW)	3.73
Efficiency of average diesel pump	0.40
Total units consumed (million kWh)	671,400
Fuel consumption (l/ kWh)	0.33
Fuel saved(million l)	223,800
Density of diesel (kg/l)	0.83
Fuel saved (billion kg)	185.75
Carbon dioxide saved (kg/kWh)	0.70
Total CO ₂ saved (billion kg)	469.98

2.2. Conclusion

The government must undertake or sponsor techno-economic studies that provide a comprehensive understanding of the losses incurred in using the flat-rate scheme and in providing grid electricity to farmers for irrigation. Such a study must take into account the losses incurred in the use of inefficient pumps, T&D losses in grid extension, theft of power, etc. A comparison of this expenditure with the economic and technical dynamics of use of solar PV will provide insights into better resource allocation for the government.

As our analysis demonstrates, the life cycle cost of diesel-driven irrigation systems is much greater than that of solar PV irrigation systems. A large contributor to the successful dissemination of solar technology is the awareness among farmers of this very fact. Awareness and dissemination programmes must be undertaken to urge farmers to use this technology. Furthermore, though there is a tab on the number of irrigation pumps in use, there is no data to indicate their ratings. Studies must be carried out to determine these as well to enable more informed policy choices.

3. Rooftop PV Systems for diesel use abatement

Sustaining India's burgeoning urbanisation is a formidable challenge faced today. The urban rooftop area was estimated to be 1 million m² in 2006^a (including all major cities) and growing every day. Most buildings in urban cities are highly electricity intensive; they consume large amounts of power for lighting and air-conditioning applications.

^a TramellCrowMeghraj quarterly reports for mid-2006.

In India, the application of solar PV has particular significance given the condition of its transmission and distribution infrastructure – high losses, poor power quality and frequent load shedding. Most buildings, public, private and commercial (for example, malls, hotels, hospitals and nursing homes), have diesel generators for back-up in case of load shedding by the utility. Given environmental considerations, the use of diesel should be minimised. There is abundant opportunity to use rooftop or building-mounted solar PV systems to generate electricity and thereby reduce the consumption of diesel. However, due to the intermittent supply of solar power and grid outages, diesel-solar PV hybrid models could be potential solutions.

Generous subsidies have been offered by the government (both central and state). Despite this, widespread installation of solar PV systems to generate electricity on urban rooftops does not seem like a reality that will take shape in the near future. The fact remains, as our analysis will demonstrate, that solar PV systems with battery storage are too expensive, and systems without battery cannot serve to completely replace diesel-generated power. With respect to the grid integration, the current urban grid infrastructure does not have the capacity at low tension level to accommodate distributed generation. The other constraint could be finding adequate and appropriate space (not covered by shade) on the roof to mount solar modules.

This report details the policy frameworks and economic feasibility of rooftop projects based on current MNRE guidelines. While the techno-economics are discussed, the technical challenges and establishments of standards for grid integration in urban rooftops are given in Appendix 2: Grid Integration in Urban India.

3.1. Current Policy

As we are aware, the JNNSM's target for all off-grid solar applications is 200 MW for the first phase, and 2,000 MW by 2022. Furthermore, another 100 MW is targeted for small ground-mounted solar plants as well as rooftop PV systems. In June 2010, the MNRE came out with guidelines that specify the financial support available, and standards and technical requirements for the equipment to be used in these systems.³⁶

Small-scale solar PV systems can be classified into two categories:

1. *Off-grid systems*: Where the electricity generated is consumed locally and not fed back to the grid. In some cases a battery may be provided for storage of electricity. This application includes rooftop PV as well as decentralised distributed generation.
2. *Grid-connected systems*: Where the electricity generated is either fed into the grid or consumed when the grid is not live (therefore reducing diesel consumption). The inverter needs to synchronise with the grid and additional protection features should be included in the inverter to prevent islanding.

3.1.1. Off-grid Solar PV Systems

The JNNSM specifications for off-grid solar systems are as follows:

- Installation up to a maximum capacity of 100 kW_p for urban areas.
- One of the motivating factors being to encourage replacement of diesel.
- MNRE financial support: combination of 30% subsidy and /or 5% interest loans.
 - Non-commercial entities: capital subsidy *and* interest subsidy.
 - Industrial/commercial entities: capital subsidy *or* interest subsidy.

The benchmark cost and subsidy for 2010–11 is outlined in Table 19. The capital subsidy for special category states, namely, the North-East, Sikkim, Jammu and Kashmir, Himachal Pradesh and Uttarakhand, is set at 90%.

Table 19: Benchmark Cost and Subsidy, 2010–11 (₹/W_p)

Configuration	Benchmark cost	Capital subsidy
Solar PV with battery	300	90
Solar PV without battery	210	70

3.1.2. Grid-connected Solar PV Systems

The JNNSM also supports small-scale grid-connected systems under the Rooftop PV & Small Scale Power Generation Programme (RPSSGP). The features of this scheme are provided in Table 20.

Table 20: The Features of the RPSSGP

Category	Grid connection	Size	Target
Category 1	Connected to high voltage (HT) distribution network (i.e., below 33 kV)	100 kW _p to 2 MW _p	90 MW*
Category 2**	Connected to low voltage (LT) distribution network (i.e., 400 V for three phase, and 230 V for one phase)	Below 100 kW _p	10 MW

Notes: *Target for Phase 1 of the JNNSM (2010–13).

** Category 2 guidelines will be issued later. Currently guidelines released are applicable to Category 1 only.

The local distribution utility will sign a Power Purchase Agreement (PPA) with the project proponent, at the tariff determined by the appropriate State Electricity Regulatory Commission (SERC).

The distribution utility will be paid a GBI for the solar power. This shall be equal to the difference between the tariff determined by the Central Electricity Regulatory Commission (CERC) and the base rate. The base rate is to be set at ₹5.50 per kWh for the financial year 2010–11, and it shall be increased by 3% every year.

3.2. Techno-economic Analysis

This section analyses each configuration as categorised and prescribed by the JNNSM guidelines in terms of its technical and economic merits and limitations. In this study, the LCOE was used to compare the cost of energy generated by rooftop PV (RTPV), a renewable resource, with the cost of a standard fossil fuel generating unit (diesel generator set). The techno-economic analyses of three types of rooftop solar systems are considered here:

1. Grid-connected systems
2. Off-grid systems with batteries
3. Off-grid systems without batteries

Average cost of electricity (ACOE) is the cost incurred by a customer (generally a commercial or industrial establishment) in purchasing or producing every unit of electricity consumed. With a grid rate of ₹5.5 per unit and a diesel rate of roughly ₹15 per unit, this cost depends heavily on the extent of time grid power is available: the lower the availability, the greater the consumption of diesel and, consequently, the greater the ACOE.

For a project to make commercial sense, it may be noted that the LCOE of solar-PV-generated power must be less than the ACOE incurred. The parameters considered in evaluating LCOE and IRR for RTPV and the corresponding value in the base case have been listed in Table 21. Feed-in-tariff in the table has been assumed to be equal to nominal generation-based tariff offered to utility-scale establishments.

Table 21: Important Parameters and Base Values: Some Assumptions

Parameters	Base value
Capital cost without battery (₹/W _p)	180
Capital cost with battery (₹/W _p)	270*
Operation and maintenance (O&M) cost (1%) (₹/W)	1.8
O&M escalation rate (%)	5
Capacity utilisation factor (%)	21
Lifetime (years)	25
Feed-in-tariff (₹/kWh)	17.9
Efficiency (without battery) (%)**	80
Efficiency (with battery) (%)**	70
Discount rate (%)	10

Notes: * The MNRE's normative cost for such a system is ₹300. However, it is felt that the given number is closer to the real price of such a system.

**This is conversion efficiency excluding the efficiency of the solar panel.

Figure 12 shows the bearing of various components on the life cycle costs (measured in terms of LCOE) and IRR of a typical solar PV system with battery storage.

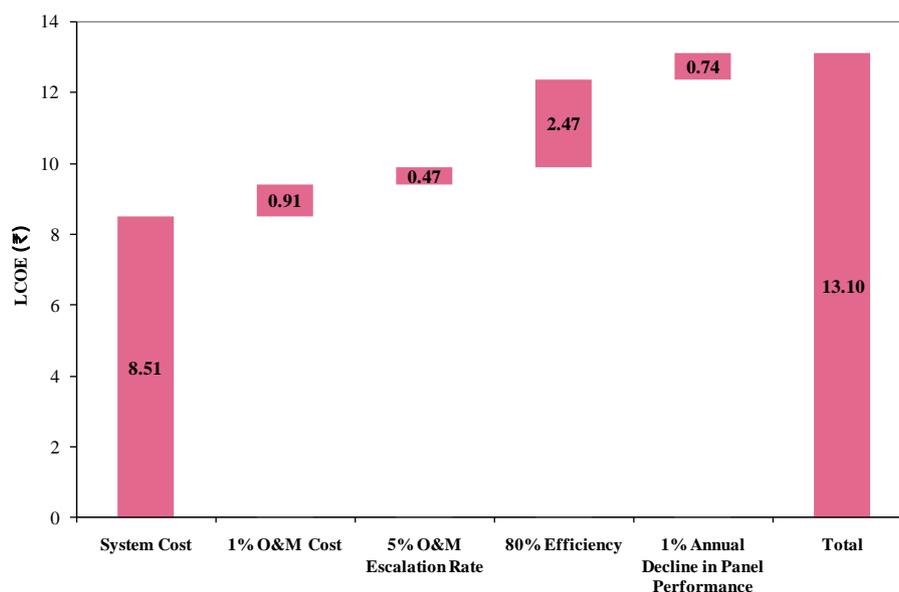


Figure 12: Components of LCOE of a Typical Solar PV System

The diesel price per unit of electricity generated has been calculated assuming that every litre of diesel produces three units of electricity, excluding O&M costs. Thus, for every unit of electricity produced, the operating cost of diesel works out to be one-third the current cost of diesel (₹42 per l), plus ₹1 to account for O&M. Today the cost of running a diesel generator is anywhere from ₹13 to ₹15 per kWh, and it can be seen from Figure 12 that it is not significantly different from that of solar PV. The government decontrolled petrol prices in July 2010 and has announced that it will do the same for diesel prices as well. As a result, prices will soon be determined by the international crude oil market. Therefore, it is safe to say that costs of diesel can only be expected to increase. Logically, the economics of solar PV systems will become more attractive as diesel prices increase.

3.2.1. Grid-connected Systems

Generally, all commercial establishments run on diesel-generated power in the absence of grid power due to load shedding and other outages. In this section, solar PV systems that are grid-connected are analysed. When the grid is live, the end-user consumes electricity from it (as it is cheaper) and feeds solar energy generated back to the grid. When the grid is down, the user could opt to consume the solar energy, thus reducing diesel consumption.

A sensitivity analysis of the major parameters for the RTPV LCOE model is shown in Figure 13. It illustrates the sensitivity of project IRR to various parameters. Note that the IRR is most sensitive to diesel price and capital expenditure (system cost per W_p). If the system costs decrease or diesel prices increase, there would be a substantial increase in profitability.

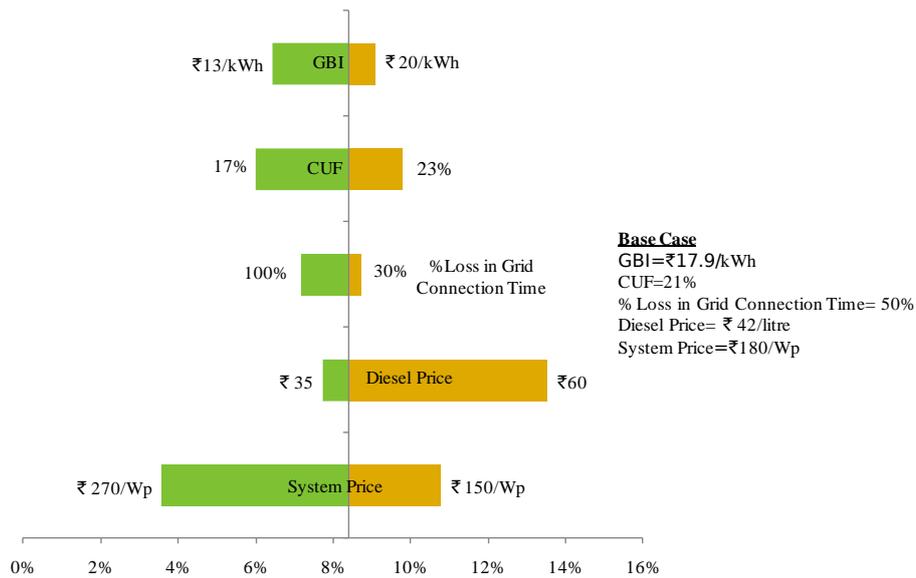


Figure 13: Sensitivity of IRR in a Grid-connected Project

Another aspect of grid-tied systems that needs prime consideration is the loss of connection time due to load shedding. For medium voltage systems in which there is a dedicated line to the nearest substation, this may not be an issue as uninterrupted supply to the grid is possible. But for situations where this is not the case, the investor needs to consider the percentage of time when the grid is not available owing to load shedding. In Figure 14 notice the fall in IRR with loss in grid connection time; this is expected, as the revenue earned by feeding the grid (₹17.9 per kWh) is greater than the savings accrued as a result of abating diesel consumption (₹15 per kWh).

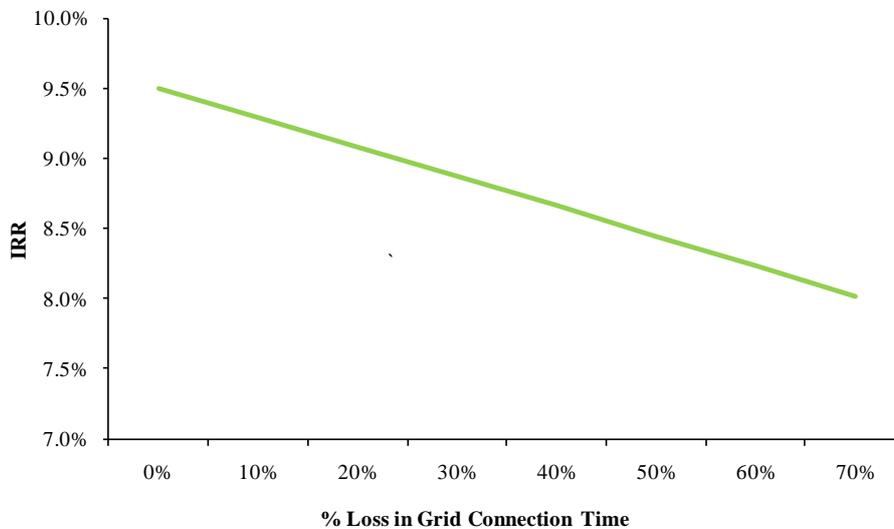


Figure 14: Variation of IRR against Loss in Connection Time in a Grid-connected System

3.2.1.1. Conclusions

Although economically viable at feed-in tariffs of ₹17.9 per kWh (the same amount as GBI offered in case of utility scale), it is unclear if the current urban grid infrastructure has the capacity to accommodate distributed generation at the low tension level. Technological challenges have to be addressed, and standards for grid integration must be established (refer to Appendix 2). Moreover, given that even at today's diesel cost, the cost of generation from solar PV is comparable, going forward with the expected increase in diesel price, solar PV will get competitive. Hence a large tariff is unnecessary here.

3.2.2. Off-grid Systems with Battery

The solar electricity generated using a PV system with a battery will abate the use of either grid electricity or diesel, whichever is live during that time. The economics of the PV system become more attractive when it reduces diesel use. Typically, this system is used where there is no grid power and to run a dedicated load on 100% solar power. Thus, the presence of a battery allows for the complete replacement of diesel-generated power, even during nights and on cloudy days when insolation is low.

The analysis featured in Figure 15 shows the sensitivity of IRR to major parameters for an off-grid system with battery.

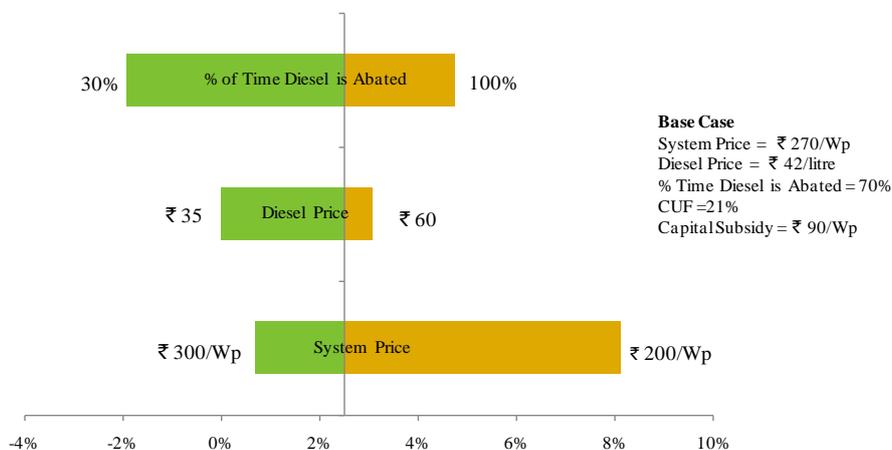


Figure 15: Sensitivity Analysis for Off-grid System with Battery

Capital expenditure plays an essential role in determining the viability of a project. For systems with a battery, current pricing dictates much higher initial costs (subject to battery capacity); and even with the generous capital subsidy offered by the government, profitability is not certain. The average cost of abated electricity works out to be ₹12.15 per kWh, while the LCOE of generation using solar PV systems is much higher at ₹23.29. This clearly demonstrates the unviable nature of such an investment.

3.2.2.1. Conclusions

On account of high capital costs and lower efficiencies of systems with battery storage, solar PV is not a viable replacement for DG unless:

- The system costs falls below ₹190 per W_p.
- Diesel price increases to over ₹80 per litre.

3.2.3. Off-grid Systems without Battery

A PV system without a battery is also a feasible form of technology. This system is used to cut down diesel use and, hence, is mainly applicable when 100% power is derived from DG sets. Note that the system can only save diesel; it cannot replace DG since there is no provision for storing solar energy. Again, the solar-electricity generated will abate the use of either grid electricity or diesel – whichever is live during that time.

Not installing battery storage poses three major implications:

- The system price decreases considerably.
- The efficiency of the system increases.
- The system can be used effectively only in the presence of sunlight.

These implications allow for a better base case, making the proposition more attractive as seen in the sensitivity analysis in Figure 16.

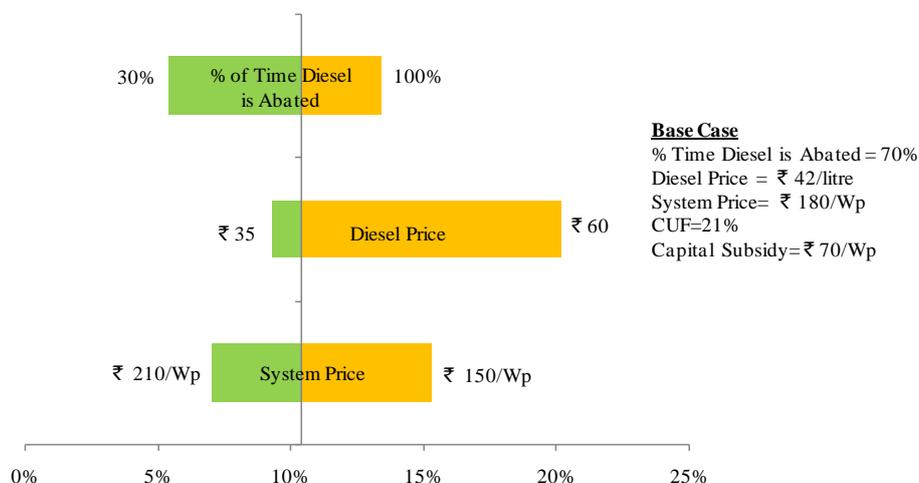


Figure 16: Sensitivity Analysis of IRR in a Typical Off-grid System without Battery

The ACOE abated at current tariffs of grid power and diesel fuel remains ₹12.15 per kWh, while the LCOE of solar PV generation is a comparable ₹12.98.

3.2.3.1. Conclusions

Given the base case, systems without a battery present more attractive economics when compared to systems with a battery. The only shortcoming is the system's complete dependence on availability of solar energy; it is not possible to conserve diesel during the night or on cloudy days. A possible solution would be to implement a hybrid system where diesel-generated power replaces solar power during periods of low insolation, thus allowing only for a nominal use of diesel and for avoiding complete dependence on the sun.

3.3. Policy Debate

From an investor's perspective, the subsidy regime poses a difficult choice. If an investor has to setup an RTPV system connected to LT transmission, then the alternatives are:

- Opt for a grid-connected system and claim tariff-based incentive.
- Opt for an off-grid system and claim capital subsidy.

The curves in Figure 17 clearly indicate that the choice of technology is heavily dependent on the duration of time for which one is connected to the grid. As long as the loss in grid connection remains less, it would make more sense to opt for the grid-connected system and avail of a GBI. As loss in grid connection increases, the off-grid system with capital subsidy proves to be more attractive. However, an off-grid system with battery storage remains unattractive in spite of variations in grid connection time. The difficulty in the choice is represented in Figure 17.

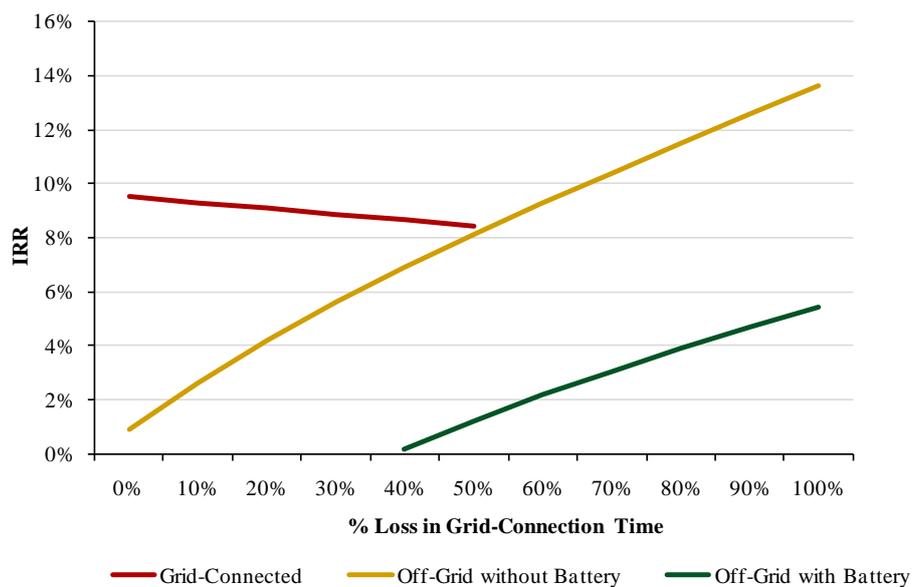


Figure 17: Comparison Curves: Grid-connected, Off-grid with Battery and Off-Grid without Battery

Note: The grid-connected system is assumed to receive a GBI of ₹17.91 and the off-grid systems a capex subsidy.

Given that generation from solar PV can be close to demand centres thus avoiding T&D losses, the target of 10 MW for Category 2 seems very low. A mere 100 installations of 100 kW_p each will meet the target. Just the captive generation based on diesel in industries and commercial establishments runs into thousands of megawatts.

3.3.1. Policy Recommendations

- Without low tension (LT) level power evacuation, abatement of large-scale diesel use will be difficult. The MNRE should fund pilot plants to study the transmission difficulties. Furthermore, a detailed life cycle cost analysis should be done and the information be made available.
- RTPV systems with batteries are economically viable only with a feed-in tariff. However, off-grid systems without battery are more attractive economically with the current capital

subsidy if the loss of grid connection is fairly high. This system should be promoted to reduce diesel usage in buildings and regions where the grid is highly unreliable.

- Given the frequent power outages, a solar rooftop PV solution needs to be carefully considered and incentivised for households. A token financial incentive such as a discount in the monthly utility bill might suffice to encourage citizens to install solar PV to meet a minimum household load.
- Clear and easy regulations should be implemented for individual customers to avail of the tariff.

With the objective of disincentivising the usage of diesel and promoting solar PV and distributed generation, policy makers must scrutinise the possibility of tax imposition based on capacity of generation from diesel in commercial buildings. The current subsidy scheme for off-grid applications, although generous, cannot aid investors proposing installation of systems with battery. And, as mentioned earlier, systems without battery may not serve the purpose satisfactorily. Moreover, in this application, as electricity is supplied from three sources – solar PV, diesel and grid – monitoring and metering will be a challenge.

3.4. Estimation of Potential for RTPV Systems

An attempt to estimate the potential of cutting down on diesel use in commercial establishments using RTPV was made for Bangalore, one of India's major cities. Table 22 calculates the percentage of abatement possible using the total commercial space available and office electrical intensity in the respective cities. Owing to abundant commercial space in Bangalore, lower office electrical intensity and lower diesel consumption, potential for diesel use reduction is only 60.6 million units annually.

Extrapolating this to all major cities in India, the total potential of RTPV systems was determined (see Appendix 3: Estimation of Commercial Floor Space Available, 2006) for individual cities (Table 23). It was found that a capacity of about 140 MW_p of solar PV systems could be installed in India; a figure that more than meets the government's official target of 100 MW_p for all small grid-connected systems.

Table 22: Estimation of Potential for RTPV Systems in Bangalore

Total commercial space in Bangalore (Grade A & B only) (million m ²)	7.265
FSI* considered****	5
Total rooftop available (total commercial space/FSI) (million m ²)	1.453
Rooftop available for solar PV (%)	25
Total RTPV area (million m ²)	0.363
Office electrical intensity (kWh/m ²)**	130
Total electricity consumption (million kWh)	944
Diesel consumption (%)	6.4
Units of diesel power (million kWh)	60.6
RTPV unit area required (m ² /kW _p)	10
Total installed capacity feasible for Bangalore (MW _p)	36.3
Capacity utilisation factor for RTPV (%)	21
Annual electricity generation from PV (million kWh)	67
Diesel use abatement possible (%)	110

Notes: * The floor area ratio (FAR) or floor space index (FSI) is the ratio of the total floor area of buildings on a certain location to the size of the land of that location, or the limit imposed on such a ratio.

** Average EPI as specified in BEE bandwidth document

*** Data from Bangalore Development Authority.

Table 23: Total PV Potential across All Major Cities in India Extrapolated to 2009*

Total commercial floor space (million m ²)**	102.67
Assumed FSI	5
Area free for RTPV (%)	25%
Total rooftop available for PV installations (million m ²)	5.13
RTPV unit area required (m ² /kW _p)	10
Total PV potential (MW_ps)	513.33

Notes: * Delhi, Mumbai, Kolkata, Bangalore, Chennai, Pune and Hyderabad.

** TrammellCrowMeghraj quarterly reports, mid-2006.



Solar Thermal Applications

Solar Thermal Applications

1. Introduction

Solar thermal technology harnesses solar energy into thermal energy for non-electrical applications, and is already a mature and economically viable option. The solar thermal collector capacity in operation worldwide equalled 151.7 GW_{th}, corresponding to 217 million m², by the end of the year 2008, with the main markets in China (87.5 GW_{th}) and Europe (28.5 GW_{th}).¹ The majority of the solar thermal technologies operating today provide hot water to households for both sanitary purposes and space heating.²

While solar water heating is well established, it is crucial that the potential of solar thermal technology in other applications in the residential and industrial sectors are analysed as well. In the residential sector, solar cooking has the potential to reduce the use of traditional firewood and biomass. In the industrial sector, process heat is used in multiple industries, such as, food (for cleaning, drying and pasteurisation), machinery and textile (for cleaning and drying). Approximately 30% of the heat energy used in industry is below 100°C and 57% is below 400°C.^{3,4} Working temperatures for some of the thermal applications are shown in Figure 18. Given the demand for heat at low to medium temperatures, the potential use of solar energy is enormous. It is estimated that solar energy could provide 3.8% of the total energy consumed by industry in the European Union (EU 25).⁵

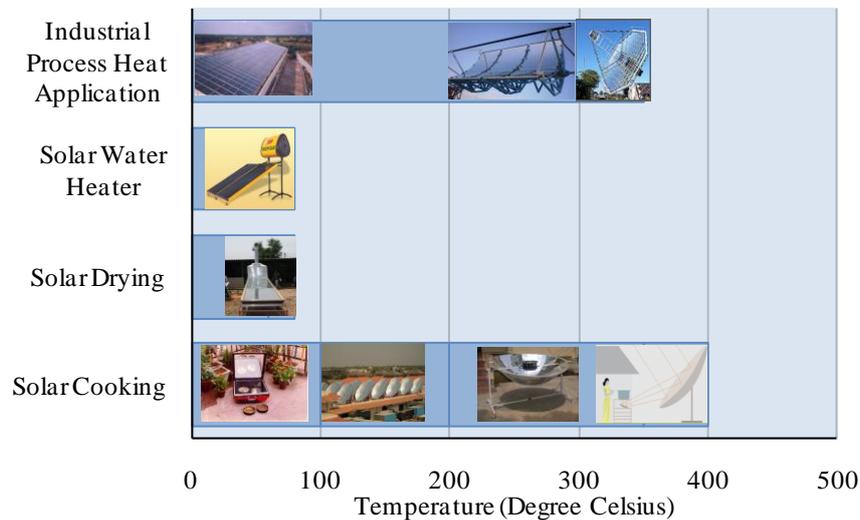


Figure 18: Thermal Applications and Working Temperatures
(Source: CSTEP)

For low temperature applications of up to 100°C, such as for solar drying, water heating and industrial heat processing, flat plate collectors (FPC) and evacuated tube collectors (ETC) are prevalent. An FPC is the most common type of non-concentrating solar collector. It consists of a dark flat plate that absorbs the solar energy and is backed by an insulated fluid tube with a glass or polycarbonate cover. ETCs have multiple glass tubes that heat up solar absorbers, which ultimately heat the solar working fluid. For high temperature applications (greater than 100°C), for example, cooking and process heat, concentrated solar thermal technologies such as the parabolic trough can be used.

Solar thermal technologies have a natural advantage in India due to the fact that the average radiation is 4.5 to 6 kWh/m²/day, with an average of 300 clear days in a year.⁶ India targets harnessing 20 million m² of solar thermal collector area by 2022.⁷ However, the gross potential just for solar water heaters is estimated to be 140 million m².⁸ The Jawaharlal Nehru National Solar Mission (JNNSM) targets for solar thermal collector area are outlined in Table 24. The JNNSM has mostly focused on concentrated solar technologies and utility scale, but it is essential that the advantages of solar thermal technology not be ignored. The capital subsidies provided for its use are sufficient, but concerted efforts must be made by the Ministry of New and Renewable Energy (MNRE) to increase awareness and ensure that strong institutional mechanisms are in place for sustainable operations. The applications for solar thermal technology include drying, large scale cooking, water heating and industrial heat processing, and these have the potential to yield enormous savings over conventional fuels. This chapter focuses on medium and high temperature collectors, and discusses the potential of solar thermal technology in each of these areas, as well as energy and cost implications.

Table 24: JNNSM Solar Thermal Targets

Application segment	Current status as of 30.6.2010*	JNNSM targets		
		Phase 1 (2010–13)	Phase 2 (2013–17)	Phase 3 (2017–22)
Solar thermal collectors (million m ²)	3.53	7	15	20

*This is entirely solar water heaters

1.1. Current Policy

The MNRE provides a capital subsidy of 30% of the normative capital cost. This is specified per square metre of collector area for solar thermal collectors. The normative capital cost and the subsidy are reviewed and revised annually. The capital subsidies for various collectors are:

- For FPC with air as the working fluid, ₹2,400/m²; and with water as the working fluid, ₹3,300/m².
- For ETC, ₹3,000/m².
- Solar concentrator with a single-axis tracking system, ₹5,400/m²; and double-axis tracking system, ₹6,000/m².
- Solar concentrator with manual tracking system, ₹2,100/m² of collector area; and for solar collector system for direct heating applications, ₹3,600/m².

Soft loans are also available at a 5% interest rate,⁹ which may be used towards the balance of the system that comprises of installation, civil work for large systems and for accessories.

To meet the unmet demand for thermal energy or for electricity generation in un-electrified rural areas, solar thermal power plants and local distribution networks are provided capital subsidies of 60% and soft loans at 5%. These may be in either standalone, or in co- or poly-generation mode.

2. Solar Drying

Annually in India, about 35% of all agricultural produce worth roughly ₹500,000 million goes to waste during the post-harvest period.¹⁰ The loss is anywhere from 10% for durables (cereals and pulses) to about 40% for perishables (fruits and vegetables).¹¹ Proper drying techniques for grains, cereals and pulses can ensure effective storage and reduce losses. Grains are traditionally dried in the open under the sun, but may be susceptible to moisture in case of a flash rain. Quality may also be compromised since there is no control over temperature and external pollutants. Strengthening the centralised food storage systems that currently suffers from poor quality control would be ideal. However, food storage at the farm level will help increase the farmer's income and security, as food prices flatten out at the end of the crop season.

Fossil-fuel-fired dryers (commonly used in the food processing industry) can also be used to dry large quantities of produce in a short period of time. However, this entails a significant initial investment and ongoing fuel costs, as well as considerable damage to the environment. Solar agricultural drying has received increased attention in recent years as it is more economical than fossil-fuel-based drying and the equipment can be easily assembled with low-cost materials.

The Ministry of Food Processing Industries has framed a vision for the year 2015 to increase the processing of perishables from 6 to 20%.¹² This can be viewed as an opportunity for solar dryers or air heating systems to penetrate the food processing industry. Hence, the twin objectives of solar agricultural drying are to reduce agricultural wastage through remote independent solar drying (with innovative financial mechanisms and institutional structure) and to reduce the energy consumption through solar air heating systems.

2.1. Types of Solar Dryers

One of the more common dryers uses an FPC-based solar air heating system to absorb solar energy. The temperature achieved through solar air heating/drying ranges from 50°C to 80°C. This technology can act as a Partial Energy Delivery (PED) or a Full Energy Delivery (FED) unit. The PED unit requires a back-up energy system and is used when the temperature requirement is high, while an FED system can be used when the temperature is lower. A hybrid system of biomass and solar energy can also be considered. Depending on the drying process, required temperature, microclimate and site conditions, solar drying technology has the potential of saving considerable amounts of conventional energy in a variety of industrial establishments.

Drying or process heat is crucial in any food processing industry. For example, solar dried tomatoes, bananas, peaches and mango pulp have great potential in a global market. As solar drying is fairly new in this segment, energy savings figures as compared to the use of fossil fuels are not readily available. However, there are several installations of solar driers in industries such as fish drying, leather tanneries, spice drying, drying of fruit pulp and paint shops (automobiles, motorcycles or bicycles). Figure 19 depicts two such installations in India.



Figure 19: Solar Dryer Installation at Sakthi Masala, Erode (left), and Leather Drier with Hot Air Ducts at M.A. Khizar Hussain & Sons, Chennai (right)

(Source: http://www.assochem.org/3rdasia/presentations/p25-04-8/TECHNICAL_SESSION_2/DR_C_PALANIPPAN.pdf)

2.2. Applications

The **fishing industry** employs 14.66 million people in all. India's 8,041 km of coastline and inland waterways together annually contribute about 5,600 million kilograms of fish. Since fish is perishable and spoils quickly, it must be chilled or dried in order to extend its shelf life. Currently in India only 6% of fish is dried and cured.¹³ Conservatively assuming that all of this is dried using solar FPCs, this would imply that 336 million kg of fish could be dried hygienically, while also improving its marketability. Also, 50.4 million m² of FPC area or, alternatively, 80.64 million kg of firewood, would be required to dry this quantity of fish.

Fishing can be carried on for about ten months a year barring spawning season. The coastline receives bountiful solar energy except for the monsoon months; hence, solar drying is possible for most of the year. Small-scale drying of fish is generally done in the open under the sun, while large-scale commercial drying uses firewood as fuel. The state government of Kerala has set up community-based fish drying units that are a hybrid of FPCs and firewood. Fisher people are charged a nominal fee based on the weight of fish. Furthermore, subsidised hygienic plastic bags are also provided to market the dried fish.

Given the large domestic and international market for dried fish, this is an application that should be incentivised.

In the **tea industry**, the manufacturing process involves withering, processing (rolling/Cut-Tear-Curl), fermentation, drying, sifting and packing. The three different forms of energy used in tea manufacturing are electrical, thermal and human. More than 80% of the energy required is thermal in order to remove moisture from the tea during withering and drying.¹⁴ Normally, 1 kg of coal is used to process 1 kg of tea.^{15,16} With solar air heating, the potential savings are about 0.15 kg of coal per kg of processed tea.^{17,18} The Tea Board of India estimates total production to be 979 million kg as of December 2009, with 75% coming from north India where solar energy is limited. If solar air heating is assumed for 30% of the tea production in north India and 50% in south India,^a a savings of about 51.3 million kg of domestic coal is possible. The total energy saved will be about 225 million kWh (with an equivalent CO₂ emission reduction of 225 million kg).^b Thus, solar air heating systems could play a considerable role in reducing the amounts of coal and firewood used. Table 25 gives an overview of costs for solar heating installation in the tea industry.

^a Tea estates in the north-eastern state of Assam do not have as many sunny days as the south Indian estates.

^b Assuming CO₂ due to coal = 1 kg/kwh.

Table 25: Installation Costs for Solar Air Heating System for the Tea Industry and Government

Kg of coal saved/kg of processed tea	Energy produced/m ² of solar collector/ year	Total collector area required (million m ²)	Cost to the industry (without subsidy) (million ₹)	Cost to the government (subsidy) (million ₹)
0.15	750 kWh*	0.3	₹2407	₹722**

Notes: *Considering 50% thermal efficiency of solar collectors and 1500 hours/year of operation.

**Based on MNRE capital subsidy of ₹2,400/ m² of FPC using air as the working fluid.

3. Solar Cooking

Over 80% of rural households use biofuels and animal dung for cooking. A vast majority of such homes burn firewood in traditional cook stoves (*chulhas*). This emits smoke and also has adverse environmental and health effects. Additionally, the process of collecting firewood is often an exhausting and time-consuming task. While small-scale solar cooking will benefit individual families in terms of health, large-scale solar cooking has the potential to save considerable fossil fuel. Solar cooking has several advantages since it requires very little maintenance, and saves cooking time and fuel cost. The focus of this case study is on large-scale solar cooking applications with the solar steam cooker. There are many large installations of solar cookers in India where several thousand meals are prepared daily.

3.1. Solar Cookers

There are four major types of solar cookers: box cooker, dish cooker, Scheffler cooker and solar steam cooker. A total of around 639,000 box solar cookers and 10,200 dish solar cookers have been deployed so far in India.¹⁹ The box cooker seen in Figure 20 is possibly the most widespread, and is useful for cooking at moderate to high temperatures for a single family. The cost of a box cooker varies from ₹1,800 to ₹3,000 depending on its size and features.²⁰ Indian culinary and cultural habits make it difficult for most to replace the use of firewood with solar cookers completely, but box cookers can supplement firewood. This will be of immense help to rural families in the reduction of indoor air pollution, in reducing deforestation, and helping reduce the drudgery of collecting wood for rural poor women.

For community-based cooking for up to fifteen people, the dish cooker seen in Figure 21 is a carbon-free solution. The temperature here can reach up to 300°C, which is sufficient for roasting, frying and boiling.



Figure 20: The Box Cooker
(Source: <http://mnre.gov.in/solar-boxcooker.htm>)



Figure 21: The Dish Cooker
(Source: Trans Solar Technologies)

The community (Scheffler) solar cooker seen in Figure 22 uses parabolic reflector dishes to concentrate solar energy on a cooking vessel that allows cooking to take place in a conventional kitchen. The dish is able to track the sun throughout the day to ensure continuous cooking, similar to the dish cooker. Temperatures up to 400°C can be achieved, and it can cater to forty to fifty people.

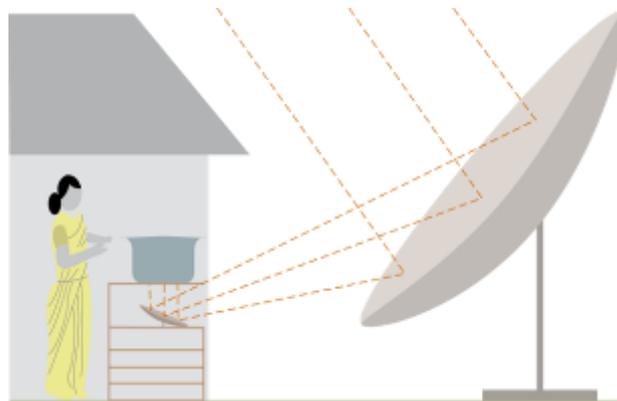


Figure 22: The Community Solar Cooker
(Source: CSTEP)

3.2. Concentrated Paraboloid Solar Cooking (CPSC)

For cooking in large establishments where hundreds or thousands of people are served, the use of an indirect method for cooking is preferable. Indirect cookers separate the solar energy collection element from the cooking area using a heat transport medium to bring the collected energy into the cooking area. The preferred heat transport medium is water (steam). In the solar steam cooking system, a number of parabolic solar concentrators are deployed to heat water and form steam, which can be effectively used for large-scale cooking in community kitchens.²¹ There is an automatic tracking system for the concentrators to track the sun. The CPSC system (Figure 23) is a partial energy delivery system; it cannot act as a standalone system. Diesel or LPG may be used as back-up to generate the steam. Hence, there is no need for a separate cooking arrangement.

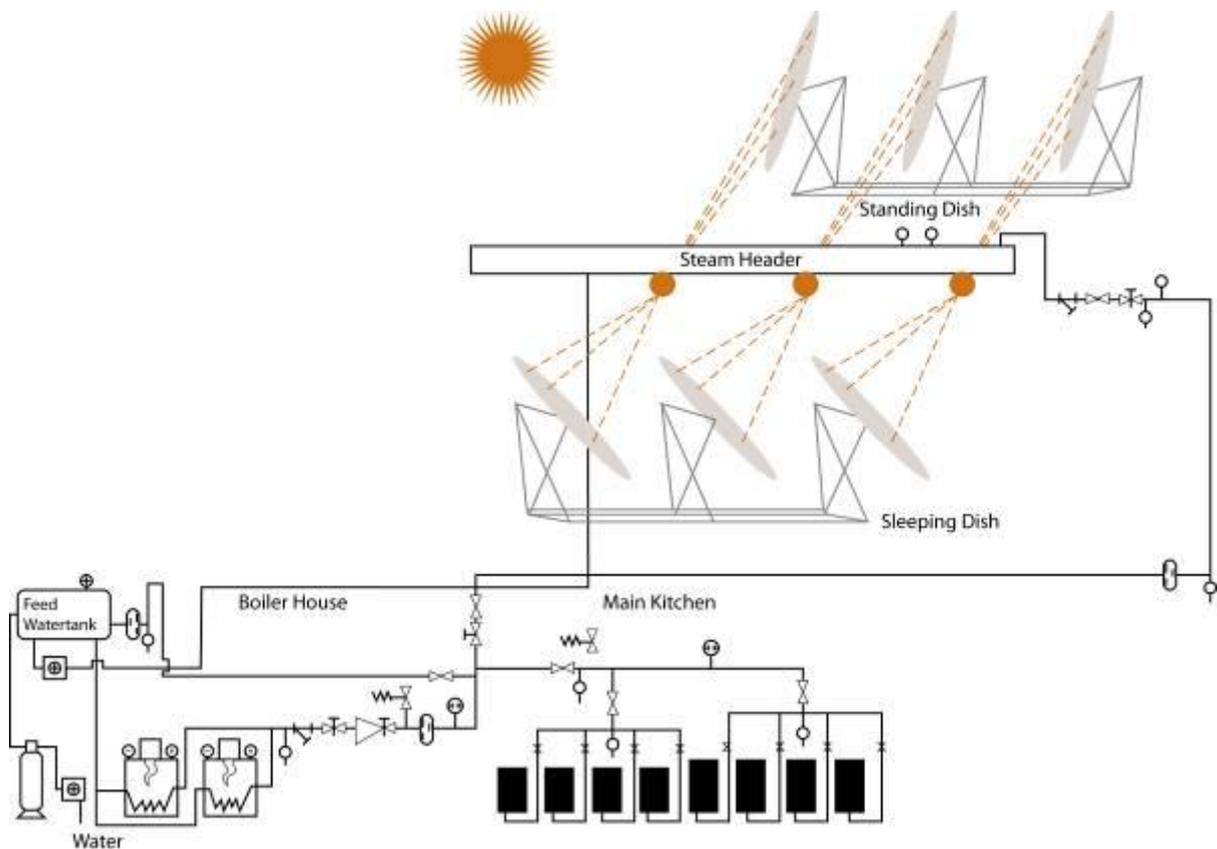


Figure 23: Schematic of the CPSC
(Source: CSTEP)

Economic Analysis of the CPSC

In this analysis, assumptions are based on data available from multiple existing installations in India. The MNRE uses a normative cost of ₹18,000/m² of collector area. The cost of the solar cooking system (including the concentrators, steam pipes and tracking system) is considered to be around ₹10,000/m² of collector area, based upon the various existing CPSC installations in India, which is substantially lower than the normative cost assumed by the government.^{a,22}

A system that provides 600 meals a day in order to feed 300 people twice a day is considered (Table 26). This requires 300 kg of steam to be produced,²³ and 1 m² of concentrator area can usually produce 3.5 kg of steam. If a standard collector size of 7.2 m² is used, twelve concentrators (six pairs) are required, which would give a total concentrator area of 86.4 m². Thus, the system cost is approximately ₹864,000 without subsidy.

^aAn approximate average of seven CPSC installations in India (<http://www.teda.gov.in/page/Solar-Ann1.htm>).

Table 26: Cost Calculation for a 600 Meals/day System

Cost/m ² collector area (₹)	10,000
Capital cost (₹)	864,000
MNRE subsidy for single-axis tracking (₹)	467,000
O&M cost (%)	2
Inflation O&M (%)	5
Life of CPSC (years)	20
No of concentrators required to produce 300 kg of steam	12
Area of each concentrator (m ²)	7.2
Collector area (m ²)	86.4
Number of receivers	6
Alternate fuel used	Diesel
Number of days of usage of system per year	320

Table 27 outlines the energy and cost savings from this system, and it is apparent that even without subsidy there is a short payback period.

Table 27: Potential Energy and Cost Savings for a 600 Meals/day system*

Annual diesel saved (l)	Annual energy saved (kWh)	Annual cost savings (₹)	Payback period (w/o subsidy)** (years)	Annual CO ₂ emissions savings (kg)***
9,600	98,223	384,000	2–3	25,728

Notes: * Assuming CPSC is used 320 days/year and a diesel price of ₹40/l.

** Assuming annual O&M expenses of 2% of the capital cost, and an inflation rate of 5%.

*** Assuming CO₂ emissions of 2.68kg/l of diesel.

Potential Use of the CPSC

Solar steam cooking systems can cook for several thousand people at a time in residential schools, institutions, hotels, hostels, hospitals, industrial canteens, etc. The potential benefit in installing CPSC countrywide is analysed. Tables 28 and 29 show cost and energy implications respectively when considering the installation of CPSC in 5,000 hostels in India, assuming a 300 kg steam producing system in each of the institutions.

Table 28: Cost Implications of Installation of CPSC in 5,000 Hostels

No. of installations	Cost/m ² (₹)	Collector area required (million m ²)	Cost to the government (million ₹)	Cost to the investors (million ₹)
5,000	10,000	0.432	2,333*	1,987

Note: * Assuming all installations have a single-axis tracking system and a capital subsidy of ₹5,400/m².

Table 29: Energy and Cost Savings for Installation of CPSC in 5,000 Hostels

Annual diesel saved (million l)	Annual CO ₂ emissions savings (million kg)	Annual cost savings (million ₹)	Annual energy saved (million kWh)
48	129	1920	491

It is clear that the CPSC is economically viable and can reduce the usage of fossil fuel. The solar steam cooking system provides an eco-friendly solution to meet the energy demands of cooking in community kitchens.

4. Solar Heat for Industrial Applications

The current application of solar energy for industrial process heat is negligible around the world. However, the potential for this is large, both worldwide and in India. Industries account for about 40% of the total primary energy consumption. As of 2008, there were only ninety solar thermal plants for process heat operating in the world.²⁴ There are currently just a few of these in India. Moreover, each unit is customised for a specific application and location. Hence, there is less data on the economics and energy savings from the use of solar thermal technology in industrial applications.

Solar thermal solutions can abate the use of fossil fuel in low to medium temperature applications. Since both FPCs and ETCs can only produce temperatures up to 85°C,²⁵ Scheffler or CPSC systems can be used to produce higher temperatures required for industrial process heat. IIT Mumbai, in collaboration with Clique Development, has successfully developed solar concentrators based on the Fresnel paraboloid technology under the trademark ARUN™.²⁶ Some of these installations are used in the dairy industry (Latur and Bhilvadi in Maharashtra) and to generate steam for different processes at the Heavy Water Board. Solar thermal technologies can be used in chemical processing plants, textile industry and in paint shops for drying.

4.1. Application

The [Latur Dairy Plant](#) pasteurises 25,000 litres of milk per day. In the milk industry, thermal energy is used for pasteurisation (60–85°C) and sterilisation (130–150°C) processes. Drying of milk powder, with high constant energy required, is another important demand. During production, milk and whey are spray-dried in huge towers with air that is heated from 60°C to 180°C.

The use of solar heat processing saves the plant about 75 kg of furnace oil a day. The energy saved daily is about 840 kWh.²⁷ Even if only 1,000 milk cooperatives in India were to use solar energy to offset some of their fossil fuel consumption in pasteurisation, about 269 million kWh of energy consumption could be abated and 177 million kg of CO₂ could be abated annually for the lifetime of the plant.

5. Solar Water Heating Systems

Solar water heating systems (SWHS) are generally composed of solar thermal collectors, a water storage tank, interconnecting pipes and a fluid system to move the heat from the collector to the tank. Globally, solar water heating is commercially viable, and is competing directly with conventional water heating systems. China is undoubtedly the world leader in this – their annual production in 2007 reached 40 million m², accounting for two-thirds of global output that year.²⁸ Furthermore, China has the largest installed base of SWHS in the world with over 125 million m² and one in ten families having adopted the technology.

In India, the current SWHS collector area stands at a more modest 3.53 million m²,²⁹ with 0.62 million m² of collector area added in 2009–10. Earlier, only FPCs were used in India, but ETCs have been introduced in the market in the last few years.³⁰ The realisable techno-economic potential at this stage has been estimated at 40 million m².³¹ Greentech estimated that the SWH market potential

for the residential and commercial sectors combined for all of India will be 18.7 million m² by 2022.³²

Bangalore has been particularly successful in getting SWHS implemented throughout the city. The policies the city has implemented include making SWHS made mandatory for buildings having 200 m² of floor area or 400 m² of site area. Residential buildings (apartment complexes) with more than five apartments need to install a 500 litres per day (LPD) solar water heater. The Bangalore Electricity Supply Company (BESCOM) denies access to the electricity grid otherwise.³³ Also, a rebate of ₹0.50 per unit with a maximum limit of ₹50 per installation is provided by BESCOM to all who have installed an SWH.³⁴ According to BESCOM, widespread installation of SWHS has brought down the morning peak load.

5.1. SWH Techno-economic Feasibility Study

There are three main parameters that would affect the payback period for an SWHS with respect to a conventional electric geyser – usage, capital expenditure and electricity costs. A model was formulated for calculating the payback period of a household SWHS as a replacement for the conventional electric geyser. The payback time for the FPC and ETC systems have been calculated depending upon the number of months in a year the SWH is used. Table 30 gives a rough idea of cost comparisons of the different systems.

Table 30: Comparison of Costs for Each System

	FPC (125 l)	ETC (100 l)	Conventional storage geyser
Initial cost (₹)	25,000	13,500	6,000
Installation cost (₹)	3,000	3,000	500
One-time maintenance cost (₹)	1,000	1,000	700
Operational expenditure/year (₹)	0	0	1,080*

Note: *Assuming 4 kWh usage for nine months.

In calculating the payback period, it is assumed that the conventional geyser of 2 kW capacity is used for two hours a day and the unit cost of electricity is ₹4. From Figure 24, one can see that the payback period for an ETC system used for nine months a year is approximately two and a half years (here the annual abatement of electricity is 1,080 kWh), and three and a half years when used for six months. At present, an FPC system costs approximately twice that of an ETC system, and so the payback period will be significantly higher.

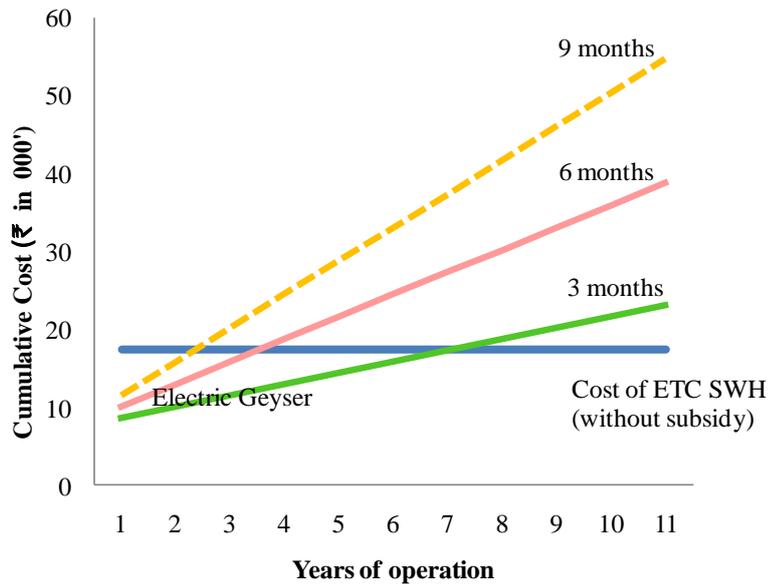


Figure 24: Solar Water Heater (ETC) Payback Period

Thus, solar water heating should be considered as a serious alternative to conventional water heating systems.

6. Conclusion

The adoption of solar thermal technology is very low in the country, in spite of generous capital subsidy offered by MNRE. The use of solar thermal technology can substantially reduce fossil fuel consumption in the domestic and industrial sectors, which would result in a considerable reduction in annual CO₂ emissions. There are only a limited number of solar thermal installations in India in spite of simple and inexpensive manufacturing and short payback periods. Most of the data available at present is based on anecdotal experience of a few. Hence, there is a severe dearth of statistics on the techno-economics of solar thermal applications. Dissemination of data specific to the technology, workings and economics of solar thermal systems would provide impetus in increasing the adoption of these technologies. The parabolic trough or Fresnel-based concentrated solar thermal technologies that are used to generate temperatures higher than those for FPC or ETC are even less common, and not much is known about the technical challenges and economic viability of these.

The MNRE should fund a few large-scale demonstration plants and incentivise the industries that are manufacturing and utilising solar thermal technologies. Furthermore, the MNRE should sponsor several case studies of working plants and hold workshops to widely disseminate the information.

The JNNSM target of 20 million m² of solar thermal collector area for all applications is clearly not ambitious given that the potential for solar water heaters alone in the country is as high as 18.7 million m².³⁵

Due to lack of availability of data and time constraints, it was not feasible to estimate the total potential for each of the applications. Table 31 provides an idea of energy savings for the number of installations assumed by the authors. This was done only for the applications presented in this chapter. The estimate for tea is based on case studies. The estimate for solar water heaters is from the Greentech report. However, the number of installations assumed by the authors for cooking, fish drying and pasteurising are ballpark figures; this can easily be several orders of magnitude larger.

It is difficult to estimate the potential for industrial applications, as there are several to be considered here. However, taking into account India's solar potential and going by the estimates provided by the International Energy Agency (IEA) for Europe, the potential energy savings can be substantial. It is felt that evaluating potential energy savings from the use of solar thermal technology merits a study of its own.

Table 31: Conservative Estimates of Solar Thermal Applications

Industry	Conservative estimate (million m ²)	Total investment (million ₹)	Annual energy saved (million kWh)	Fuel saved	CO ₂ mitigated (million kg)*
Tea	0.3	2400	225 (thermal energy)	51.3 million kg coal	225
Fish drying	50.4**	403,200	37,800 (thermal energy)	40.3 million kg of firewood	+
Box cookers	3,195,000 units	9590	-	Firewood saved	-
Large-scale cooking***	8.6	86,400	9,820 (thermal energy)	960 million l of diesel	2,570
Solar water heating	18.7****	126,230	10,098 (electrical energy)	Abating grid	8,078
Dairy industry *****	3.5	-	2,690	240 million kg of furnace oil	1,770

Notes: * Assumptions on CO₂ emission: CO₂ due to coal = 1kg/kWh; CO₂ abatement in SWH is 0.8 kg/kWh; CO₂ due to diesel = 2.68 kg/l of diesel; CO₂ due to furnace oil = 0.66kg/kWh

** 6% of annual total fish potential of India. Solar dryer is used 50% of the drying time.

*** CPSC single-axis tracking system installed in 100,000 large establishments in India (hostels, places of worship, industrial canteens, hospitals and hotels).

**** Greentech SWH market assessment report: realistic estimate of SWH that includes residential, commercial and industrial sectors.

***** Solar heat processing to pasteurise 25,000 l of milk/day in 10,000 dairy plants in India.

+ Wood is carbon neutral as it releases carbon that it captured. However, the use of firewood has other negative effects, such as deforestation.

6.1. Policy Recommendations

- Case studies on the experience of solar thermal installations in India should be carried out and the results disseminated to the public. This is an extremely important first step to increase the awareness and interest in solar thermal investments.
- MNRE-supported demonstration solar plants in each potential industrial sector along with industrial partners should be prioritised. The industrial partners who are willing to invest in such pilot plants can be offered tax benefits and/or soft loans in addition to the capital subsidy. The MNRE is already involved in this effort, but it could be scaled up and given very high priority considering the fossil fuel savings and accompanying health benefits.
- As manufacturers of solar thermal systems are limited in India, special incentives should be provided to encourage companies to set up manufacturing facilities.

- Strategies to improve the quality of equipment and installations through the use of technical standards and quality labels should be created (like the Keymark voluntary certification scheme in Europe).
- Social entrepreneurs should be encouraged with special loans and training programmes through regional rural banks and government institutions.
- Though the current subsidy provided is sufficient, to ensure sustained operation of the system in the future, sound institutional mechanisms should be in place. Servicing and maintenance contracts for the life of the plant should be planned before large outlays of capital subsidies are given.
- The Ministry of Food Processing Industries should undertake a study of fruits and vegetables that can be easily dried and have a market. The study can also help identify regions where the cropping pattern is such that solar drying makes most sense. This will help reduce wastage of perishables, thus increasing the income of the farmer.
- The use of a solar dryer is more economically viable for a multiple crop system since it can be used only for a few weeks after the harvest for any particular crop. Hence, suitable business models need to be created for dissemination of solar dryers to individual (or groups of) farmers.
- The family sized solar box cooker should be propagated as a means of reducing the time spent time by women in collecting wood towards cooking in *chulhas*. Urban and rural populations should be educated on the advantages of solar cookers over the use of kerosene or biomass for community cooking. Campaigns to overcome inhibitions to solar cooking should be organised.
- Solar cookers for small to large communities, where feasible, should be advocated for use in schools, community halls and institutions.
- Integrating solar cooking with the midday meal preparation in schools could save fuel as well as create awareness among students.
- Mandatory regulations requiring new or renovated buildings to be equipped with appropriate solar thermal systems should be implemented and accompanied by financial incentives (for example, a discount on monthly electricity bills).

Appendix - 1

Assumptions in the Section on Rural Electrification

Table 32: Basic Household Energy Requirements

Household	Lights	Fans	TV/appliances	Total
Number of items	2	1	1	
Wattage	11	60	120	202
Hours of use/day	6	8	3	
Total energy/year (kWh)	48.2	175.2	131.4	355

Table 33: Electricity Needs of the Model Village

	Streetlights	Community building	Drinking water pump (3 HP)
Number of items	15	2	1
Wattage	40	150	2,238
Hours of use/day	8	6	2
Total energy/day (kWh)	3.2	1.8	4.5
Total energy/year (kWh)	1,168	657	1,634

Assuming distribution losses of 5%, load demand factor of 0.9, and allowing for load growth of up to 10%, an installed capacity of about 35 kW is sufficient to meet the assumed basic electricity demand of the village.

Table 34: Economics of a Biomass and Solar (50:50) Hybridised Microgrid

Per unit capital costs		Village installation		Capital costs	
Solar PV ($\text{₹}/W_p$)	180	Demand (kW)	35	Solar PV cost (million ₹)	3.15
Low voltage (LT) line (million ₹/km)	0.12	LT length (km)	3	Battery (million ₹)	0.49
Household connection (1 ₹/node)	1800	No. of households	150	LT line (million ₹)	0.36
Biomass gasifier (million ₹/kW)	0.078			Household connection (million ₹)	0.27
		Inverter efficiency	0.95		
		Battery efficiency	0.8	Decentralised distributed generation (million ₹)	5.64
		Solar PV size (kW_p)	17.5		
		Biomass gasifier size (kW)	17.5		

Table 35: Assumptions in Computing LCOE of Grid Extension

High voltage (HT) line (million ₹/km)	0.16	Tariff for households (₹/kWh)	2.50
Transformer 66 kVA (million ₹)	0.2	Inflation (%)	5
LT line (million ₹/km)	0.12	Number of households	150
Household connection cost (million ₹/home)	1800	Total capital cost for 15 km extension (million ₹)	3.23
Distribution losses (%)	10		

Appendix - 2

Grid Integration in Urban India: Establishment of Standards and Technical Challenges

Insufficient generation of power in India has led to widespread load shedding. Consequently, establishments turn to economically and environmentally expensive diesel generators to meet their needs. Distributed generation provides a very attractive solution. This could also save millions of kilowatts of power lost in transmission in the Indian grid system. However, there is insufficient clarity on the technical standards for proposed projects of grid-connected systems rated for less than 100 kW at low voltage/tension (LT) level (400 V for three phases and 230 V for single phase).

Some major issues to be considered are:

1. Power quality issues: The quality of power provided by a photovoltaic (PV) system for onsite alternating current (AC) loads and for delivery to the utility distribution grid should be within a certain range with regards to voltage, flicker, frequency and distortion.
 - a. Voltage: The voltage operating window should be selected in a manner that minimises nuisance tripping. Based on International Electro technical Commission (IEC) Standard 61727:2004, the operating range can be 85 to 110% of the nominal voltage. Thus, for India, the operating range based on a voltage of 230 V would be 195.5 to 253 V.
 - b. Flicker: As per IEC 61727, operation of the PV system should not cause voltage flicker in excess of the limits stated in the relevant sections of IEC 61000-3-3 for systems less than 16 A or IEC 61000-3-5 for systems with current of 16 A and above.
 - c. Frequency: When the utility grid frequency deviates outside specified conditions, the PV system should cease to energise the utility line. IEC 61727 specifies the frequency limits to be ± 1 Hz, which is when the system should stop energising the utility line within 0.2 s.
 - d. Distortion:¹ The current experience of several European utility-scale producers shows that harmonics are not currently a concern at the LT distribution level, and that penetration from 33 to 50% of distribution transformer/line capacity is considered safe.² European distribution grids are much more robust than their Indian counterparts; hence, studies will be required to establish standard practices in the Indian case.
 - e. Direct current (DC) injection: According to IEC 61727, the PV system should not inject DC power greater than 1% of the rated inverter output current into the utility distribution grid under any operating condition.
 - f. Power factor: The PV system should operate at a lagging power factor greater than 0.9 when output is greater than 50% of rated inverter output power.
2. Safety and protection issues: The following protection issues need to be kept in mind while designing PV systems:
 - a. Islanding protection: In the event of loss of grid supply, utilities require that the PV system should stop feeding power to the grid. This can be achieved either by an in-built protection in the inverter/Power Control Unit (PCU), or, if this is not supplied or is insufficient to satisfy the utility, it can be provided by external relays.
 - b. Grounding.
 - c. Lightning surge protection.
 - d. Ground earth/fault detection: When the size of the PV array becomes large enough to cause

a fire, or if there are other energy sources or storage connected, then there is a need for ground fault detection.

- e. Overload and overheat: The inverter should include a feature for auto-shutdown when there is an overload condition or it gets overheated. It should also incorporate an auto-restart feature when normal conditions are restored.
 - f. Utility grid interface disconnect switch: A manual, lockable, load-break disconnect switch should be available that provides clear indication of the switch position and is both visible and accessible to utility workers. There should be a visual verification of the switch contact position when it is in the open position.
3. Impact of high penetration of PV on distribution networks: The small (kW level) rooftop PV systems will typically be connected to the existing LT distribution networks. The power production from PV will occur mostly in the late mornings and early afternoons. Whereas, in the case of residential lighting load in particular, the peak consumption will be in the evening. Thus, the instantaneous power production from PV will often exceed the instantaneous power consumption in residential areas with a high concentration of PV systems. This mismatch in power can create a net reverse power flow through the distribution transformers. The question, therefore, arises as to what the maximum PV power that can be injected into the utility's distribution system could be without damaging the system. The PV power installed is limited by:
- a. Nominal rated power of distribution transformer.
 - b. Capacity of distribution line and/or feeder.
 - c. Voltage rise.
 - d. Power quality issues such as harmonics.
 - e. Unintentional islanding.

Appendix - 3

Estimation of Commercial Floor Space Available

Table 36: City-based Estimation of Commercial Floor Space Available, 2006 (sq. feet)

City	Type included	Total inventory	Under construction	Total
Mumbai	Grade A	33,807,000	5,589,000	39,396,000
Delhi	Grade A, excluding 100% owner occupied	15,456,000	4,429,700	19,885,700
Kolkata	Grade A, excluding 100% owner occupied	19,424,000	14,303,000	33,727,000
Chennai	Grade A, excluding 100% owner occupied and above 25000 sq.ft	45,768,000	34,002,000	79,770,000
Bangalore	Grade A & B, excluding 100% owner occupied	50,358,100	9,300,000	59,658,100
Hyderabad	Grade A&B, excluding 100% owner occupied	14,431,400	4,927,000	19,358,400
Pune	Grade A&B, excluding 100% owner occupied	31,030,400	15,456,000	46,486,400

*Source: Trammell Crow Meghraj reports quarterly reports MID 2006

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Annexure 4 - List of Acronyms

AC	alternating current
ACOE	average cost of electricity
AM	air mass
AMC	annual maintenance contract
a-Si	amorphous silicon
BEE	Bureau of Energy Efficiency
BESCOM	Bangalore Electricity Supply Company
BOS	balance of system
BPL	below poverty line
CCS	central charging station
CERC	Central Electricity Regulatory Commission
CFL	compact fluorescent lamp
CIGS	copper-indium-gallium-diselenide
CIS	copper-indium-diselenide
CPSC	concentrated paraboloid solar cooking
CPV	concentrator photovoltaic (technologies)
c-Si	crystalline silicon
CSP	concentrated solar thermal power
CUF	capacity utilisation factor
DC	direct current
DDG	decentralised distributed generation
DG	diesel generator
DISCOM	distribution company
DNI	direct normal irradiance
EMI	equal monthly installments
EPI	Energy Performance Index
EPIA	European Photovoltaic Industry Association
ESP	electric submersible pump
ETC	evacuated tube collectors
FAR	floor area ratio
FED	full energy delivery
FIT	feed-in tariff
FPC	flat plate collectors
FSI	floor space index
GBI	generation-based-incentive
GEDA	Gujarat Energy Development Authority
GHG	greenhouse gas emissions
GW _{th}	gigawatt thermal
HAREDA	Haryana Renewable Energy Development Agency
HIT	heterojunction with intrinsic thin layer
HRD	human resources development
HP	horse power
HT	high voltage
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IREDA	Indian Renewable Energy Development Agency
IRR	internal rate of return
JNNSM	Jawaharlal Nehru National Solar Mission
kW _p	kilowatt peak

LaBL	Lighting a Billion Lives
LCOE	levelised cost of electricity
LED	light-emitting diode
LPD	litres per day
LPG	liquid petroleum gas
LT	low tension/voltage
MFI	micro-finance institutes
MNP	Minimum Needs Programme
MNRE	Ministry of New and Renewable Energy
MNREGA	Mahathma Gandhi National Rural Employment Guarantee Act
MW _p	megawatt peak
NABARD	National Bank for Agriculture and Rural Development
NAPCC	National Action Plan on Climate Change
NPV	net present value
NSM	National Solar Mission (abbreviated JNNSM)
NTPC	National Thermal Power Corporation
NVVN	NTPC Vidyut Vyapar Nigam
O&M	operation and maintenance
PED	partial energy delivery
PEN	Planters Energy Network
PLF	plant load factor
PPA	power purchase agreement
PV	photovoltaic
R&D	research and development
REC	Renewable Energy Certificate
REC	Rural Electrification Corporation
RESCOS	renewable energy service providing companies
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
RPO	renewable energy purchase obligation
RPSSGP	Rooftop PV & Small Scale Power Generation Programme
RTPV	rooftop photovoltaic
RVE	Remote Village Electrification
SELCO	Solar Electric Light Company
SELF	Solar and Electric Light Fund
SERC	State Electricity Regulatory Commissions
SEZ	Special Economic Zone
SHLS	solar home lighting system
SNA	state nodal agency
SPD	solar project developers
STC	standard test conditions
STU	State Transmission Unit
SWHS	solar water heating system
T&D	transmission and distribution
TERI	The Energy and Resources Institute
W _e	watt electric
W _p	watt peak
μc-Si	microcrystalline silicon

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