MINI-GRIDS
ELECTRICITY FOR ALL

A Centre for Science and Environment report

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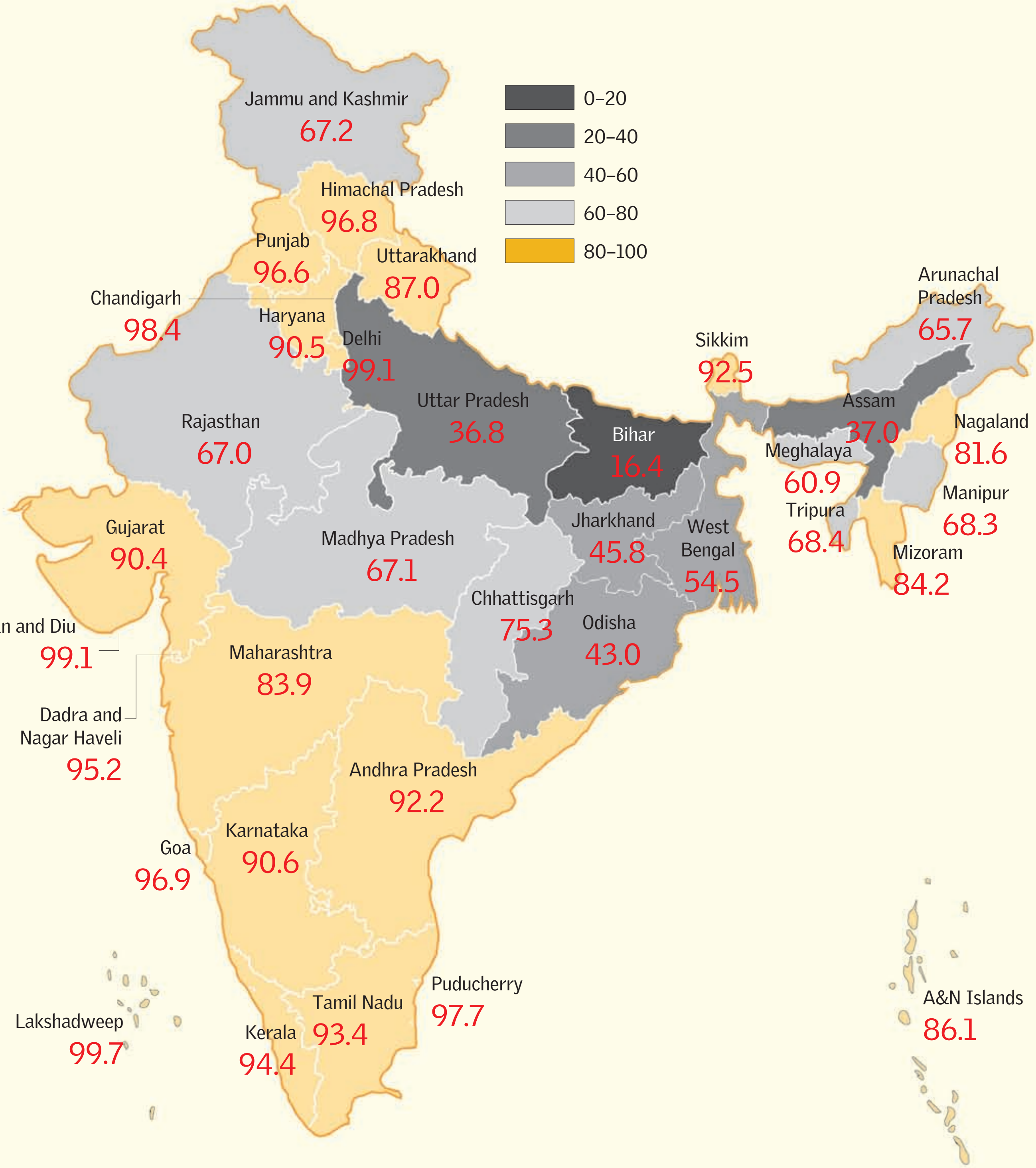
Energy poverty is one of the biggest development challenges India is facing today. This map shows the electrification rate of our states: what percentage of households is electrified in each state.



Source: Census of India 2011

Introduction

Today, in India, we face both an environment as well as a development crisis. On the one hand we are still struggling with the problems of inequality, poverty and improving the human development indicators. On the other hand, environmental pollution and ecological destruction is now a runaway problem. Both these crises are also interacting with and reinforcing each other. This is best reflected in our energy sector.

India suffers from chronic energy poverty. Officially, about 300 million people have no access to electricity. But if we consider the fact that about three-fourths of rural households connected to the grid have erratic and less than six hours of electricity supply, then about 700 million people in the country can be termed electricity-poor. Similarly, about 700 million Indians use biomass such as dung, agricultural waste and firewood as the primary energy resource for cooking. These fuels cause indoor pollution and increase the risk of diseases among women, who predominantly work in the kitchens in India. The estimated economic burden of using traditional fuels, including health costs and lost economic opportunities due to poor education of the girl child, is estimated to be ₹30,000 crore. About two-thirds of Indians, therefore, is still deprived of modern energy services.

India is largely dependent on coal to meet its energy needs. Coal meets more than 50 per cent of the current commercial energy needs and generates more than 70 per cent of our electricity. We are the third largest producer of coal in the world, after China and USA. But the energy from coal comes at huge environmental and health costs.

It is estimated that of the entire industrial sector, 60 per cent of particulate matter (PM) emissions, 45–50 per cent of SO_2 emissions, 30 per cent of NO_x emissions and more than 80 per cent of mercury emissions come from coal-based power plants. Coal-based power plants also account for about 70 per cent of the total freshwater withdrawal by the industrial sector and close to half of our total greenhouse gas emissions. On top of this, most of the coal mining areas have been declared as critically polluted areas. In fact, there exists a fatal overlap of coal reserves, dense forests, tribal populations, high poverty and backwardness. Mining coal, therefore, leads to huge conflicts between the state and mining companies on the one hand and the local communities on the other hand. It also leads to destruction of dense forests and wildlife which may be extremely difficult or impossible to regenerate.

The challenge before India is how to meet its energy requirements without compromising the ecology of the country. In addition, we have to be mindful of the looming danger of climate change. Climate change is already impacting the water and agriculture sector of the country. We cannot afford to let global temperature rise exceed 2°C from the pre-industrial era. Even 2°C would devastate many vulnerable communities and ecosystems. Hence, India must work with other countries to reduce greenhouse gas emissions and to control rising temperatures. In such a situation, we ourselves cannot have a fossil fuel-dominant energy future.

So, how do we move ahead?

Converging energy and environmental security

In the last few years, five trends have become quite clear. The first is that India's dependence on imported fossil fuel is increasing at an alarming rate. We now import close to 40 per cent of our commercial energy and this is only going to go up in the near future. This trend has huge implications for the energy security of the country.

The second trend is the reducing costs of renewable energy, especially solar and wind power. In the last five years, the cost of solar energy has come down by two-thirds. In fact, in a city like Delhi where the distribution companies (discoms) charge about ₹8 per unit from commercial establishments, solar photo-voltaics (PV) can supply electricity at ₹5 per unit during daytime. Though 24x7 solar power is still expensive because of the storage costs, there are large number of applications and areas where it is competitive or even cheaper than coal power. Wind power has already achieved grid parity across the country.

The third trend is the use of electricity for practically all applications. Apart from lighting, cooling and heating, electricity is now being used widely and efficiently for cooking as well. Electric transportation, including cars and buses, are increasing becoming viable. Most industrial applications that currently rely directly on fossil fuels for heating, cooling, transportation etc. can also shift to electricity. A world where most household, commercial, transport and industrial activity is performed by electricity is becoming a reality.

The fourth trend is the urgency of reducing greenhouse gas emissions. There is a growing recognition that we are running out of time. Last year in Paris, a new climate agreement was signed to keep the global temperature rise between 1.5–2°C. About 160 countries have submitted their action plans to mitigate climate change. India has committed to produce 40 per cent of its electricity capacity from non-fossil fuel sources. Most countries have given various renewable targets. So, there is a clear global signal to upscale renewable energy to mitigate climate change.

The fifth trend is the increasing global recognition of supplying clean energy to all. Last year, all countries agreed to a set of Sustainable Development Goals, which includes goals to provide basic energy services to all. The government of India has also committed to provide affordable 24x7 electricity to all households by 2019.

These five converging trends demand that we develop an energy strategy that is based on electricity as a prime mover, and that this electricity is generated from renewable energy resources. This would mean we come out with a new integrated energy policy that charts a roadmap for a renewable electricity future. Our current energy policy of

2006 is primarily focused on developing fossil fuel resources for electricity and direct use of oil and gas for transport, industrial usage and cooking.

But just moving to renewable electricity won't be sufficient. We need a renewable electricity future that is affordable and accessible to all.

The future

The notion of electricity access in India has been centralized generation and grid-based distribution. This idea has failed to supply electricity adequately to two-thirds of our people even after seven decades of independence. In our renewable energy policy also, the idea of centralized generation and grid-based distribution dominates. For instance, Ministry of New and Renewable Energy wants to set up ultra-mega solar power plants of more than 4,000 MW each. State governments are setting up solar parks to install large solar power plants. Will this ensure energy access to all? Are mammoth discoms, centralized grid and large renewable based power plants, compatible with a renewable electricity future?

It is important to understand that 24X7 renewable electricity generation is not going to be cheap. The cost of generating and storing intermittent electricity is an expensive proposition. On top of this, if we have expensive transmission and distribution, which will be the case with centralized grid and big discoms, the cost of 24X7 renewables will not be affordable to a large number of population. Our discoms are in the red and we have a leaking grid (the transmission and distribution losses in the country are in excess of 20 per cent). The idea that we can sustain big discoms with large share of renewable electricity in our electricity mix needs serious examination.

I believe that our renewable electricity future is a decentralized and distributed one. The fact is renewable energy is decentralized—sunlight falls everywhere and wind blows everywhere. Demand for electricity too is decentralized, and most renewable technologies are modular. This makes renewable electricity most suitable for decentralized generation and consumption.

Central to the vision of a decentralized and distributed electricity future is the increased role for small-scale electricity generators who may be households, businesses, and mini-grids. These millions of small generators would meet their own energy requirements and feed excess energy into the grid and draw on the grid when needed. The role of the grid, therefore, would change from being the main supplier of electricity being a platform where surplus electricity would be traded and transported between millions of generators and consumers. In this energy future, there is no role for big discoms. Instead, we will have mini-discoms that would meet the electricity needs of small communities in cities and villages. These mini-discoms would feed excess power to the grid and buy power from other mini-discoms when in deficit. The grid, therefore, would be used to meet a small percentage of total electricity demand. There will be a role for large power plants based on other non-fossil technologies, but this role would be to supplement decentralized generation, which would also reduce over a period of time.

This is not a utopian future. Germany, the leader in renewable energy, has most of its solar PV installed on rooftops. About 1.5 million households in Germany have installed more than 30,000 MW worth of solar PV panels on their rooftops. They are either feeding it to the local grids or consuming it domestically.

What Germany has done, we have to do it at a much grander scale and in a much more decentralized fashion. Also, we will have to dovetail renewable electricity with super-efficient appliances and use them in energy efficient buildings. It doesn't make any sense to use expensive renewable energy in inefficient appliances and buildings. We now have super-efficient appliances that consume one-fourth electricity compared to the appliances currently available in the market. The renewable electricity world, therefore, has to be a world of kilo-Watts and Watts and not mega-Watts and giga-Watts. This is the only way we can make renewable electricity affordable and accessible to all.

If operationalized, this model will revolutionize the way power is produced and consumed in India. Millions of households will produce and consume their own electricity. Thousands of renewable energy-based mini-grids will promote millions of small businesses and social entrepreneurs to create local jobs and build local economies. Living standards in villages will improve, which in turn will ensure women empowerment, better health and education. There cannot be a better development agenda for the country.

In the end, this might be the only way we can avoid large fossil fuel plants. This might be the only route though which we can end the political interference in electricity sector. If there are no discoms, there cannot be a promise of free electricity to the electorate. In one stroke, we can make renewable electricity the main source of energy, solve the challenges related to energy poverty, address climate change, build local economies and move towards a secure energy future for India. This, I think, is the way ahead. Let us develop a blueprint to achieve this future.

Chandra Bhushan

CHAPTER 1

Energy and energy access in India

Increasing demand for energy and electricity is a sign of growth and development in any country. But the question is, given the issues of climate change and the changing weather patterns felt across India, is it wise to depend so heavily on fossil fuels to not only fulfill the needs of the ever-growing industries, but also to cater to electricity needs of the expanding population? Renewable energy offers an alternative solution for meeting these needs using decentralized distributed generation. Encouraged by the ambitious targets set by the government, these decentralized distributed systems offer an opportunity to leapfrog almost 240 million people to the electricity source of the future.

- **Energy demand in the India will increase at a rapid pace to keep up with the trajectory of development the country is pursuing. The question is how this need for energy and electricity will be fulfilled given the consequences of climate change the world is facing.**

- **India has only achieved 67.2 per cent electrification even after 69 years of independence. Many of those officially considered electrified receive poor quality electricity for only a few hours a day.**

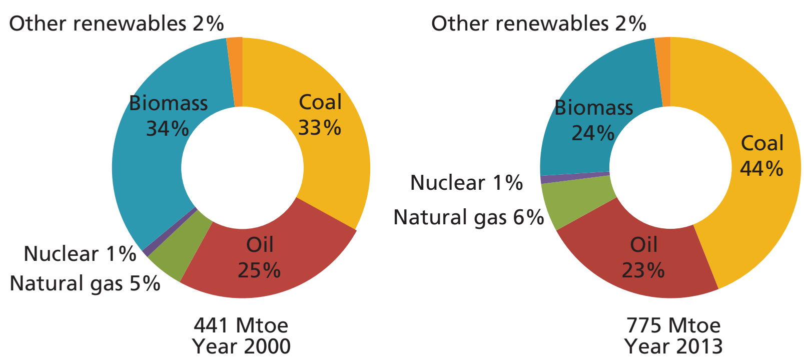
- **One of the reasons for this slow pace of electrification has been the reluctance of distribution companies to supply power to rural India, even though they claim that there isn't any shortage of supply in the country (only 2.1 per cent deficit reported in March 2016).**

- **With reducing costs in the last five years, enhanced ambition by the government and more acceptability among the general population, renewable energy (RE) offers a ray of hope for the growing demand of electricity**

- **In its decentralized distributed form, RE-based mini-grids can manage the local household and commercial electricity demand efficiently by generating power at the source of consumption.**

India is the world's fourth largest consumer of energy, after the US, China and Russia. According to the World Energy Outlook 2015, in 2013, India's primary energy consumption was around 775 million tonnes of oil equivalent (Mtoe), a 75 per cent jump from 441 Mtoe in 2000.[1] India is dependent on fossil fuels to fulfil most of its energy needs—it gets 44 per cent of its primary energy from coal and 23 per cent from oil (see *Figure 1: Primary energy demand in India, by fuel*). RE provides 26 per cent of India's energy but that figure is inflated by the use of biomass—almost 850 million people in India still rely on biomass for cooking purposes.[2]

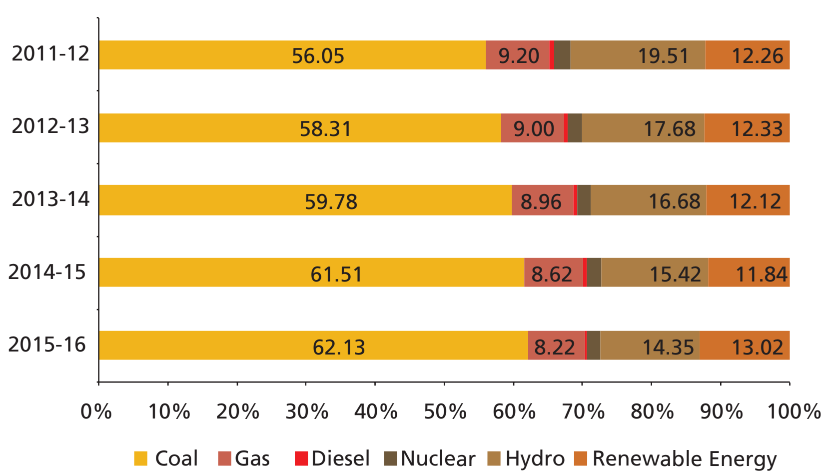
Figure 1: Primary energy demand in India, by fuel



Source: World Energy Outlook 2015

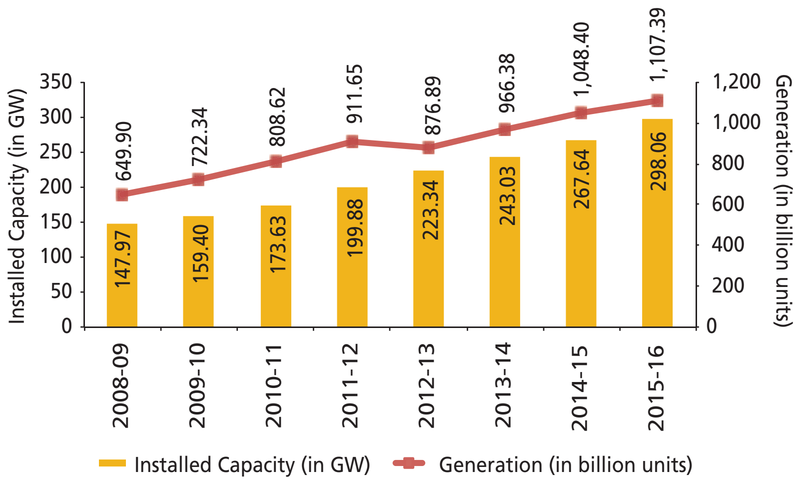
The story is not very different in the electricity sector, which is also dominated by fossil fuels (see *Figure 2: India's electricity sector, by fuel sources of installed capacity*). India continues to invest in building significant coal-based power generation capacity. The share of fossil fuel-based capacity has risen over the last five years. As of 31 March 2016, coal, natural gas and diesel together contributed about 71 per cent of the 298 giga-Watt (GW) of installed generation capacity; coal by itself contributes 62 per cent of installed capacity.[3]

Figure 2: India's electricity sector, by fuel sources of installed capacity



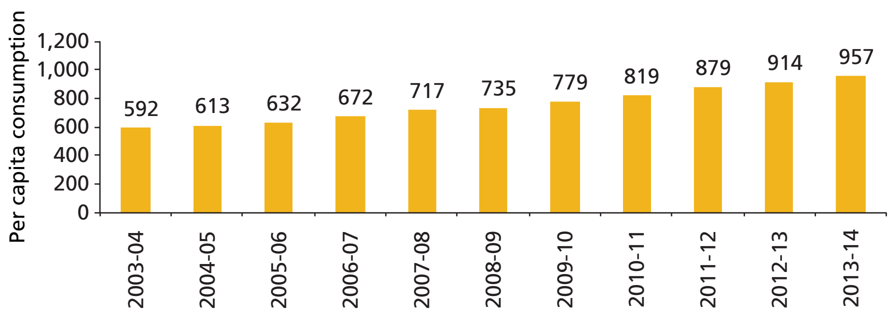
Source: Compiled from executive summary—power sector, CEA reports

Figure 3: Growth of total installed capacity and power generation in India



Source: Compiled from executive summary—power sector, CEA reports

Figure 4: Growth of per capita consumption of electricity in India



Source: Compiled from executive summary—power sector, CEA reports

The installed capacity in the country has increased at a rate of 10.5 per cent annually since 2008–09 and generation has increased at the rate of 7.9 per cent during the same period (see *Figure 3: Growth of total installed capacity and power generation in India*).

Energy poverty in India

Despite the seemingly impressive growth in total generation, India remains energy poor. In 2013–14, the average per capita per annum consumption of electricity was only 957 units, which is estimated to have increased to 1,010 units a year.[4] In the US, annual per capita consumption of electricity is 12,954 units and the world average is around 3,064 units.[5] In the ten years between 2003–04 and 2013–14, the per capita consumption of electricity in the country has increased at a rate of only 4.9 per cent every year, a dismal performance given the growth has come off a low base. (See *Figure 4: Growth of per capita consumption of electricity in India*). India's per capita consumption of electricity compares unfavourably with that of major developing countries.

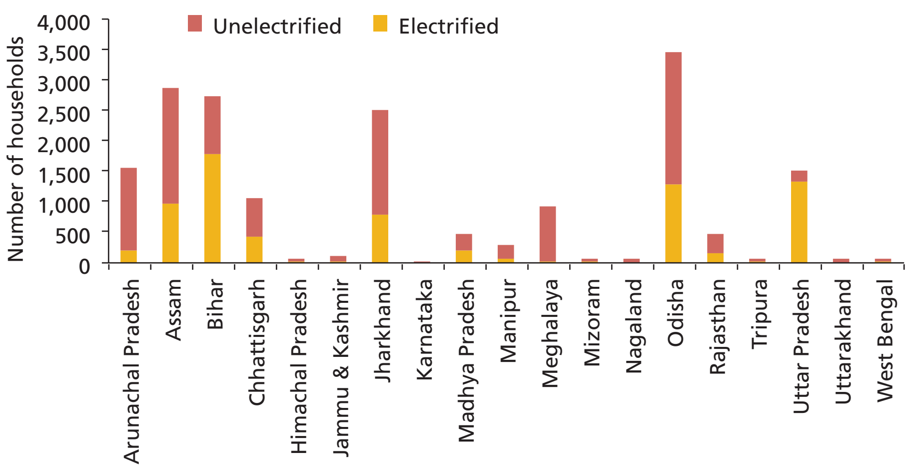
Even this low per capita consumption actually paints a positive picture, with wide disparities in consumption and access. In a country with a population of around 1.3 billion people, almost 240 million people do not have access to electricity[6] (see *Table 1: Electricity access in 2013—regional aggregates*). Currently, 34 per cent of the total population of India is completely dependent on kerosene for its lighting needs.[7] The International Energy Agency projects that India will still have 147 million people without electricity in 2030. The question is, if the rapid growth of the conventional power sector has failed to serve the energy-poor in the country, then why we are planning to opt for the same route in future as well?

Table 1: Electricity access in 2013—regional aggregates

Region	Population without electricity (in millions)	Urban electrification rate (in %)	Rural electrification rate (in %)
North Africa	1.10	100.0	98.6
Sub-Saharan Africa	634.30	59.3	16.8
China	1.20	100.0	99.8
India	237.40	96.0	74.0
Other developing Asia	287.30	96.3	78.0
Latin America	21.60	98.3	84.5
Middle East	16.90	98.4	78.5
Transition economies & OECD	1.00	100.0	100.0

Source: World Energy Outlook 2015—electricity access database

Figure 5: Electrification status across states (as on 13 June 2016)



Source: Rural Electrification Corporation—GARV dashboard

According to Ministry of Power, out of a total of 597,464 villages in India, 587,209 villages have been electrified as on 12 June 2016.[8] This is a misleading picture of energy access and is based on an overly generous definition of village electrification. The government scheme—Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) considers a village electrified if the following criteria is met:

- Basic infrastructure such as distribution transformers and/or distribution lines are available in the inhabited locality
- Public places like schools, panchayat offices, health centres, dispensaries, community centres, etc. can avail power supply on demand
- 10 per cent or more of households are electrified

In addition, there is the issue of number of hours of power supply. Various studies have documented frequent interruptions in power supply across the country, including in major cities. The data shows power outages even in areas where government reports point to minimal "deficits".[9] Rural areas are much worse. There are more power cuts and even outages during the evening hours (5–11 p.m.). Minimum six hours of uninterrupted supply is not very common in rural areas, as reported by Prayas Energy, a Pune-based non-profit organization. Assuming half of the households deemed electrified do not receive guaranteed minimum six hours of electricity, the number of people who do have access to adequate electricity would be only around 650 million.[10]

Why the grid may not provide electricity to poor?

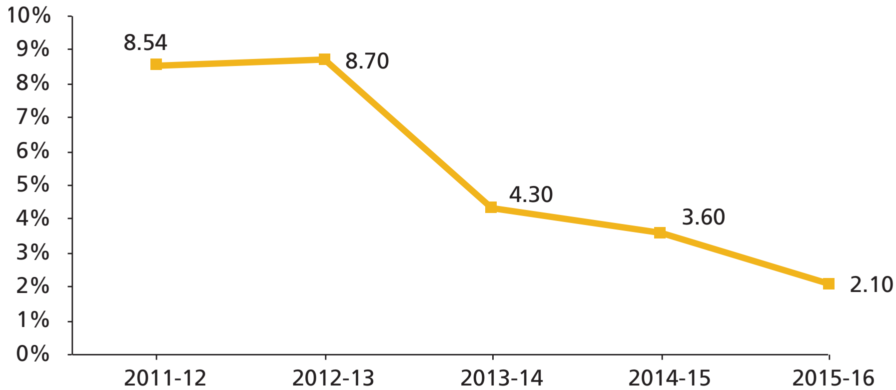
Traditionally, countries have depended on grid expansion as a means to achieve high electrification rates. India, under Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) programme, now DDUGJY, has opted for the same strategy. Under this programme, in the last two years, a total of ₹ 1,123.73 crore have been released, mostly for grid expansion projects. However, there are many reasons why grid expansion has not been able to provide electricity to the poor in the country and may yet fail to do so.

One major issue is ability and **willingness to supply** on the part of the distribution companies (discoms). Most state-owned discoms are suffering huge losses in terms of both revenues and power losses because of inefficiency and mismanagement.[11]

Political interference means small consumers (farmers and poor households) are promised free or heavily subsidized electricity forcing discoms to supply power below cost. For instance, in Haryana, Uttar Haryana Bijli Vitran Nigam supplies power for agricultural use (26 per cent of their total power) at ₹ 0.36 per unit. Further, states don't cover the cost of subsidized electricity. Besides this, the power sector faces huge aggregate technical and commercial losses (over 22.7 per cent in 2013–14).[12] While power theft is a problem, losses also add up due to inefficient supply network and poor bill collection.

Given the problem of low electricity rates in rural areas, power thefts and poor bill collection, the assumption usually is that the situation will get worse when the rural consumer base increases. Discoms are, therefore, reluctant to supply power to rural areas and those who are energy-poor. Discoms are constrained

Figure 6: Reducing power deficits over the years



Source: Compiled from executive summary—power sector, CEA reports

in their ability to purchase power because of their poor financial health so they are most keen to supply to industrial and commercial consumers who pay the highest tariff. With high tariffs, there is also an expectation of regular supply of electricity. Moreover, the higher tariffs that the industrial and commercial consumers pay cross-subsidize the power supplied to residential consumer. This is the reason why, even at the expense of load shedding for residential consumers, industry is given higher priority for supply.

No wonder the existing model of extending the grid and waiting for the infrastructure to be energized has failed to provide electricity to the rural consumers. The fact is that in a country where 34 per cent of the population still uses kerosene for lighting purposes, we need innovative solutions to change the course of development for the rural energy-poor.

A major argument made in favour of grid extension is that there is adequate power supply, and thus extension will solve energy access problems. Official data shows that the power deficit in the country was only 2.1 per cent in the year 2015–16 (see *Figure 6: Reducing power deficits over the years*). But, this deficit only accounts for demand from the discom—this deficit does not even consider many types of consumers, for example rich city residents, who can afford electricity from alternate sources like diesel generators if the discoms that supply them don't provide it. If the electricity demand of the 237 million people in India who do not have access to electricity or those who get intermittent supply is included, deficits would increase manifolds.

The solution: RE-based mini-grids

RE potential

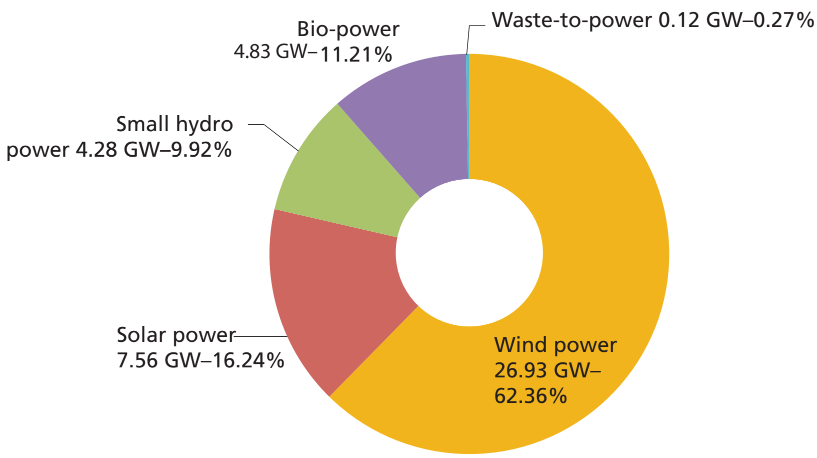
India has huge potential for RE. According to National Institute of Solar Energy, the total potential for solar power alone is estimated to be 748 GW.[13] In comparison, installed capacity of solar power is around seven GW, less than one per cent of the total potential. As of 30 April 2016, solar power is only 16 per cent of the total capacity of renewable energy (43 GW) installed in the country (see *Figure 7: Status of grid-connected renewable energy in India*).[14]

Table 2: Potential for all renewable energy sources

Renewable energy sources	Potential (MW)
Solar power	748,980.00
Wind power	102,772.00
Small hydro power	19,749.41
Biomass power	17,536.41
Bagasse co-generation	5,000.00
Waste-to-energy	2,554.00
Total	896,591.82

Source: Compiled from various Ministry of New And Renewable Energy annual reports and documents

Figure 7: Status of grid-connected renewable energy in India



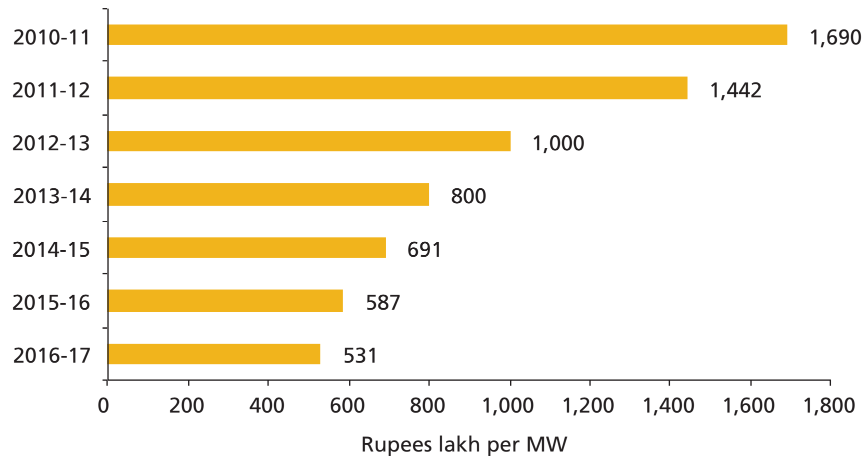
Source: Ministry of New and Renewable Energy

Cost of RE generation

The cost of RE, especially solar energy, has been declining over the years. It has declined by almost 70 per cent since India announced the JNNSM in 2010 (see *Figure 8: Declining capital cost of large-scale solar photo-voltaics power projects*). In the solar project auctions in January 2016, the lowest bid was of ₹ 4.34 per unit, won by Fortum Finnsurya Energy, a Finland-based company operating out of Rajasthan. This proves that solar power is slowly achieving grid parity.[15]

The massive potential and the reducing cost of technology have lead the government to introduce ambitious targets for RE. India wants to install 175 GW of RE by 2022 (see *Table 3: Ambitious RE targets*). In addition, the government has announced the intention of providing "24/7 power to all by 2019".

Figure 8: Declining capital cost of large scale solar photovoltaics power projects



Source: Compiled from various Central Electricity Regulatory Commission tariff orders

Table 3: Ambitious RE targets

Renewable source	Targets (GW)
Solar	100
Wind	60
Biomass	10
Small hydro	5

Source: India's INDCs—Intended Nationally Determined Contributions submitted to United Nations Framework Convention on Climate Change (UNFCCC)

Table 4: Break-up of 100 GW of solar energy in India by 2022

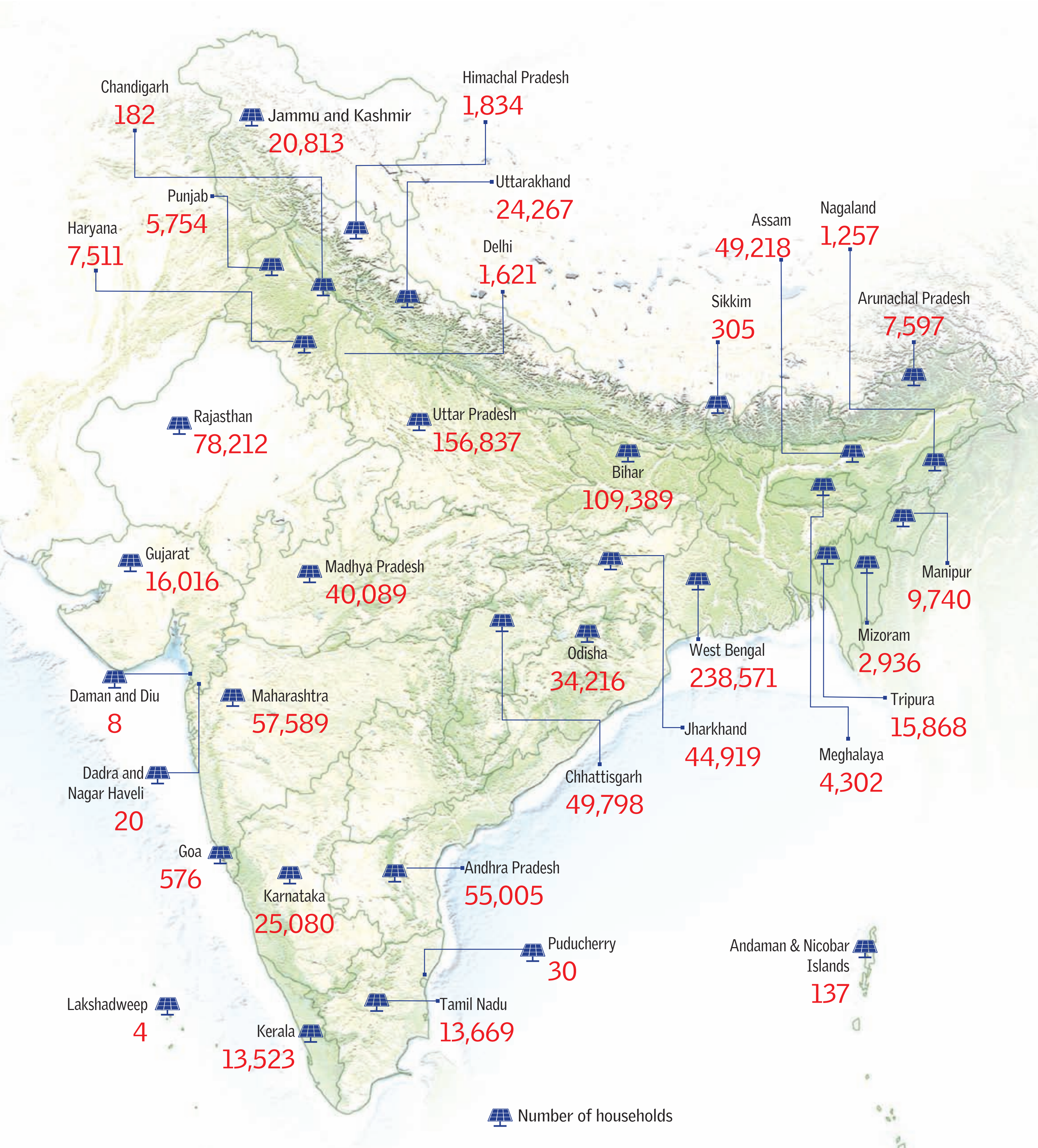
Category	Proposed capacity (GW)
Rooftop solar	40
Scheme for decentralized generation of solar energy projects by unemployed youths and farmers	10
PSUs	10
Large private sector/IPPs	5
SECI	5
Under-state policies	20
Ongoing programmes including past achievements—solar	10
Total solar	100

Source: Ministry of New and Renewable Energy

Growing RE penetration and acceptance

There are more than one million households in the country that are using solar energy for meeting their lighting needs (see *Map 2: States using decentralized solar for lighting*). Rural households account for more than 95 per cent of such installations. Rural India is getting used to using RE, particularly solar power in their houses.

Map 2: States using decentralized solar for lighting



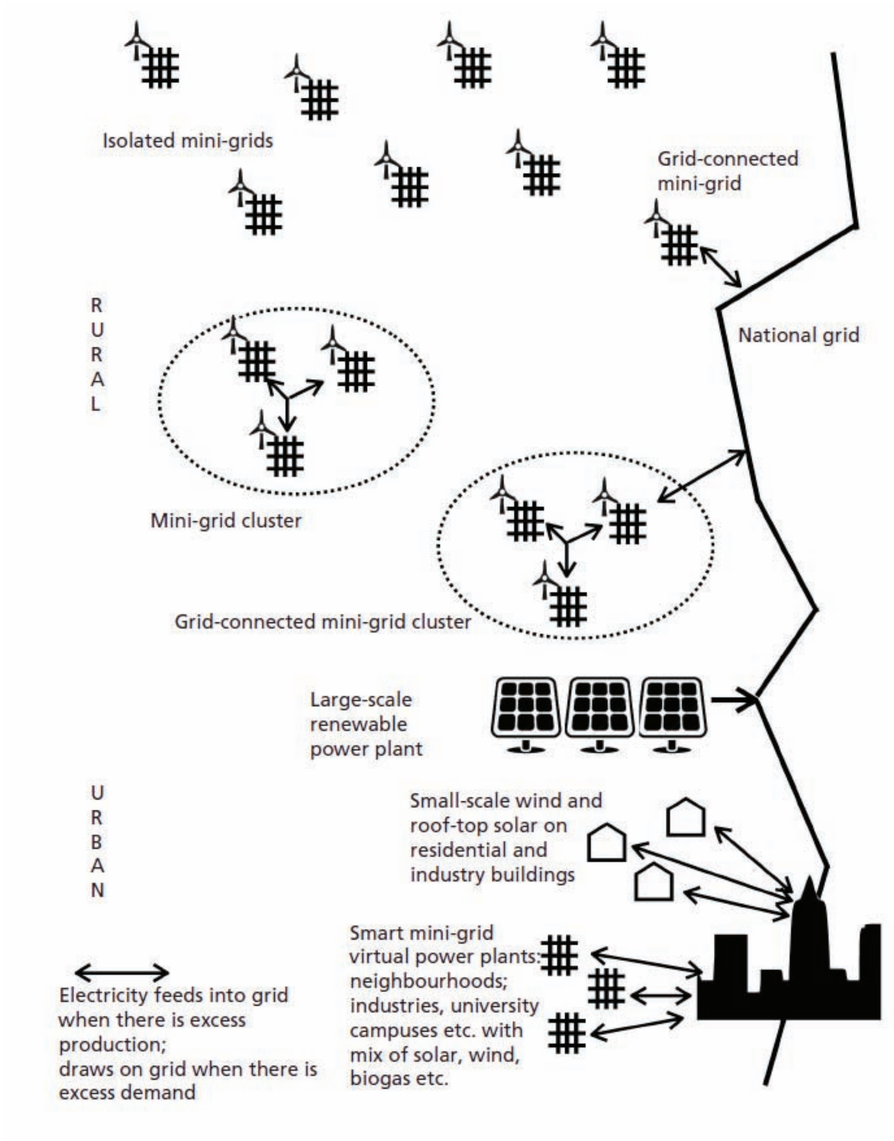
Source: Census of India, 2011

A big section of the population that is not yet served or underserved needs electricity for development. Rural consumers, who don't have regular access to electricity, already spend around ₹ 200-300 a month on kerosene for their lighting needs, so there is a potential paying capacity. It is an untapped market which can use decentralized solutions for generating power using RE and serve around 650 million consumers. It is an opportunity to leapfrog half of the nation from being dependent on fossil fuels to cleaner forms of energy, i.e., RE.

After 69 years of independence, grid extension has failed to provide electricity to almost 20 per cent of the country. The grid and discoms are mired in problems galore—huge financial losses, high transmission and distribution losses etc.—to actually be able to cater to the demand of the millions who do not have access to electricity at the moment. Further, there is a need to shift focus of electrification away from coal-based power because of climate change issues. RE based mini-grids utilize the untapped potential of renewable energy and help manage local household and commercial demand efficiently by generating power at the source of consumption.

We envisage RE-based mini-grids as the basis for the future of electricity where the grid merely acts as an exchange medium for meeting deficits and transferring surplus generation. The future of power is modern, distributed, people-centred and decentralized RE power generation from a large range of sources and developers (see *Figure 9: Future energy systems: Distributed, decentralized renewable electricity*).

Figure 9: Future energy systems: Distributed, decentralized renewable electricity



Source: Programme for Global Renewable Energy and Energy Access Transformation (GREEAT)

CHAPTER 2

Programmes for energy access

The government of India has pursued renewable energy-based decentralized distributed generation route many times in the past, but it has failed to scale up at a pace to match the growing electricity needs of an expanding population. The targets of government schemes have been lost in a labyrinth of sub-targets pushed on by bureaucracy to achieve numbers for rural electrification, even when real electrification was not achieved. Now, things are changing for rural electrification in the country, but issues persist. Massive grid expansion is taking place at an unprecedented rate, but it lacks the quality and reliability that electricity supply should guarantee. Scaling up mini-grids in India is as it should be the new focus for the country, but it is still in the draft stages.

- **Ministry of New and Renewable Energy (MNRE) and Ministry of Power (MoP) have implemented many programmes and schemes in the past to increase the penetration of RE-based mini-grids for electrification in village.**

- **Almost all the schemes have failed to supply adequate power to millions of Indians; but the cause of failure was different in each case. Some schemes failed because of their limited approach (only catering to lighting needs) and some lacked accountability and aspects of ownership in implementation.**

- **MNRE launched a draft national mini-grid policy in June 2016 to mainstream mini- and micro-grids. The policy is a set of guidelines for states to use and draft their own policies. It lays down various options available to states to choose and select the best alternative for themselves.**

- **The policy has considered learning from the past and included options that would help develop a programme that could transition the country s energy future into RE-based decentralized, distributed generation or mini-grids.**

The first RE-based mini-grid in India was installed in 1996 in the Sundarbans in West Bengal.[16] These islands were considered a perfect location for setting up mini-grids because they were isolated and remote, had no grid connectivity and were dependent on diesel generators for power supply.[17] Fifteen solar photovoltaic (PV)-based (total capacity 900 kW), three biomass gasifier-based (1,500 kW) and six wind solar hybrid model-based (24 kW peak) mini-grids were installed to cater to the needs of 50,000 households in 5,000 villages.[18] This project was majorly (almost 70 per cent) funded by grants of the Central, state and local governments. In addition, the project was supported by the local communities. The involvement of the panchayats made the case for these mini-grids stronger and helped in their installation.

Before 2001, there was no programme or scheme encouraging rural electrification and energy access to remote and isolated areas. This changed in the following decade, with the Electricity Act, 2003 which subsequently resulted in National Electricity Policy, 2005, National Tariff Policy, 2006 and Rural Electrification Policy, 2006.

Remote Village Electrification Programme

After Census 2001, Ministry of New and Renewable Energy (MNRE) identified about 18,000 remote villages, mostly in the regions where grid extension was not possible, and launched a scheme called Remote Village Electrification Programme. The aim of the programme was to provide basic lighting services to the villages by 2012, using off-grid renewable technology.[19]

Most of the villages electrified under the programme were provided with solar home lighting systems that included a 37-Watt peak solar module and two 11-Watt compact fluorescent lamps, along with a battery. The scheme was terminated in 2012. The main reason for ending it was that the scheme did not have a long-term vision on electrification; rather these projects were set up as temporary solutions for providing electrical services. Most of the home lighting systems provided became obsolete as a result of lack of ownership, abysmal after-sales services and widespread corruption. In the end, the scheme failed to meet its objective of fulfilling even basic lighting needs.

The Decentralized Distributed Generation scheme

The Rural Electrification Policy (REP) of 2006 set a mandate to provide one unit per day of electricity to all households by 2012.[20] As part of this mandate, the Ministry of Power launched the Decentralized Distributed Generation (DDG) scheme in 2009 under the flagship RGGVY (now DDUGJY) programme to electrify remote villages that cannot be reached by the grid. The DDG scheme was launched with an outlay of ₹ 540 crore and provided 90 per cent capital subsidy in a staggered manner.

RGGVY was heavily criticized for failing to provide even six hours of electricity per household per day in most villages that were deemed 'electrified' by the programme. The DDG scheme was, therefore, modified in April 2013. With the new amendment, the DDG began covering electrified villages that receive less than six hours of electricity per day in addition to non-electrified villages.[21] Given that DDG scheme has been operative for more than seven years; its performance has not been satisfactory. Under the scheme, 474 out of the 4,604 approved projects had been commissioned by 31 May 2016, with the total funds released amounting to ₹ 125 crore.[22]

The DDG programme has been unsuccessful in its reach for a number of reasons. It was not clear who was responsible for monitoring, overseeing and supporting the projects set up under the programme. Several agencies—the developers, Rural Electrification Corporation (REC), state nodal agencies—were involved in the development of projects, so there was lack of accountability and clear responsibility for these projects. The developers were given 90 per cent of capital subsidy for installing these projects and after commissioning no entity was monitoring whether these projects were supplying power and meeting people's electricity demand. In the end, the programme was reduced to another target that was required to be met by REC.

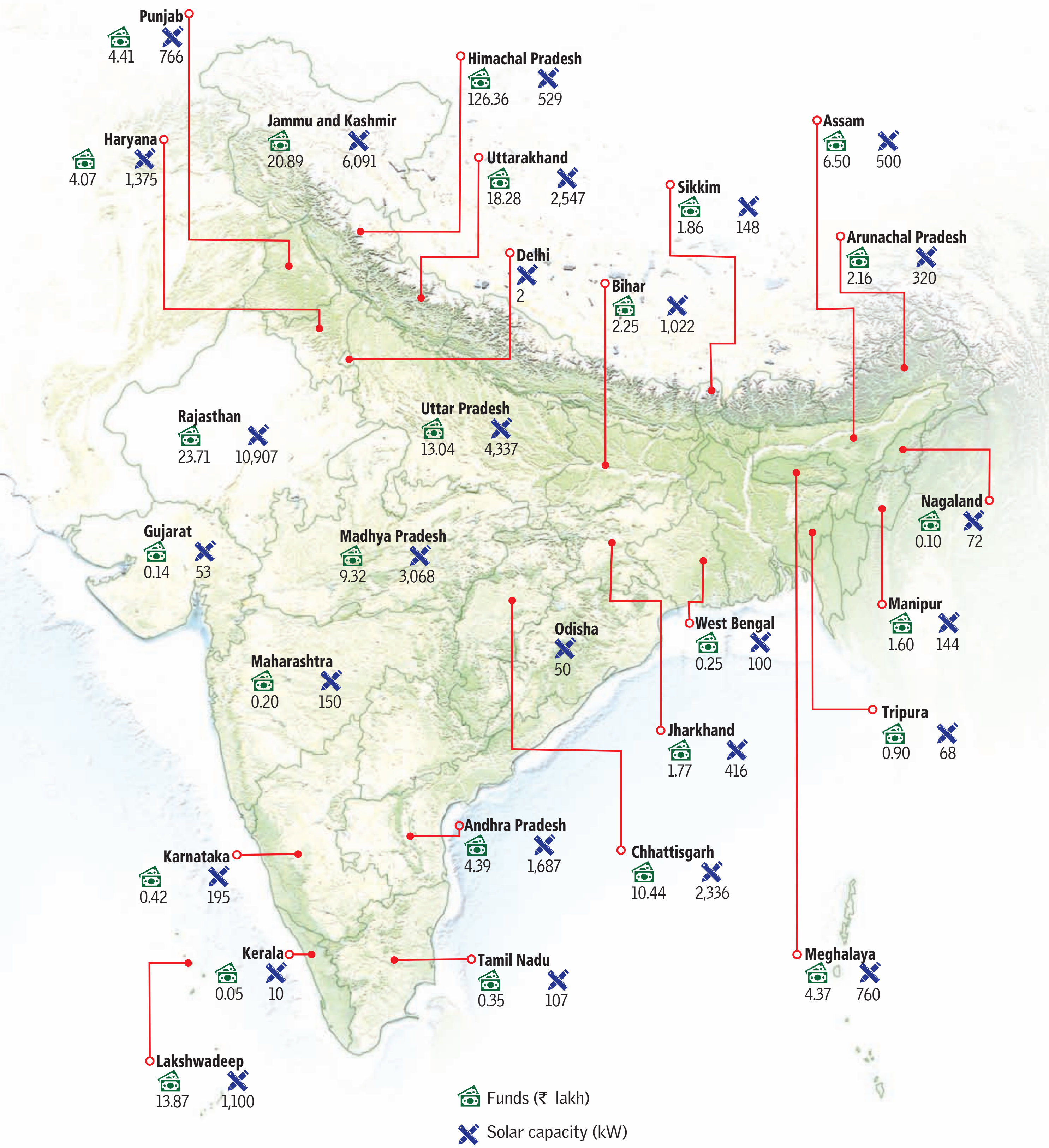
Off-grid solar programme under JNNSM

JNNSM was launched in 2010 to boost solar technology, in both on-grid and off-grid applications. The first phase of the mission, which had an off-grid target of 200 MW, achieved 252 MW by the end of 2013.[23] The scheme offered a capital subsidy of 30 per cent and an interest subsidy of 50 per cent of the project cost.

An analysis during the first phase of implementation showed that only 27.5 per cent of JNNSM's achieved targets were for the benefit of rural households. 40.6 per cent of the projects were directed to educational and social institutions and the remainder was allocated for projects located in urban and semi-urban areas. The benefits of the off-grid component of JNNSM's first phase have not gone to states that suffer acute energy poverty.[24] Energy-poor states, such as Bihar, Uttar Pradesh and Assam, received the least amounts of off-grid subsidy; interestingly, Himachal Pradesh, which received the highest subsidy, did not install many projects. (See *Map 3: Central financial assistance and solar capacity addition under off-grid solar scheme of JNNSM*.)

The actual performance and allocation of funds raises serious questions about the intent of the scheme. It seems that, as with the DDG programme, the motivation for off-grid JNNSM scheme was meeting targets without actually ensuring that installations takes place for providing access to electricity to people who need it.

Map 3: Central financial assistance and solar capacity addition under off-grid solar scheme of JNNSM



Source: http://greencleanguide.com/states-wise-cfa-and-capacity-of-off-grid-solar-installations-under-the-jnnsm-2010-11/

Uttar Pradesh leading the way in mini-grid development

Uttar Pradesh (UP) became the first state in the country to announce a mini-grid policy in February 2016. Under the policy, the state government will facilitate private players to set up solar plants to power rural households and recover tariff from users. The policy has limited the size of mini-grids to a maximum of 500 kW. There is no lower limit of installation.

The policy offers developers the option to apply for state government subsidy (currently undetermined) apart from the already existing 30 per cent capital subsidy offered by MNRE. However, the state government's subsidy is only available to developers that meet the following criteria:

- **Developers need to procure their own land for the projects.**
- **The project should guarantee minimum eight hours of electricity supply—three hours in the morning and five hours in the evening—to all households willing to pay in the chosen area.**
- **Supply for manufacturing and commercial needs for minimum of six hours.**

In case developers want to avail state government subsidy in addition to Central financial assistance, the policy specifies the amount consumers can be charged. It states, a "developer will charge ₹60 per month for a load of 30 Watt and ₹120 per month for load up to 100 Watt for eight hours of daily electricity supply; and for a load more than 100 Watt tariff will be on mutual consent between consumers and the developer." Essentially, if a consumer avails the ₹60 per month option, they would be paying ₹8.33 per unit and consumers with ₹100 per month option would be paying ₹5 per unit. It can be argued that these rates are comparable to electricity prices in urban areas.

However, there is no indication on how these tariff rates were designed or calculated. Speaking at an event in Lucknow, the secretary, Uttar Pradesh New and Renewable Energy Development Agency, Partha Sarathi Sen Sharma, acknowledged the fact that most developers would not opt for the state subsidy specifically because of the tariff restrictions. He said, "We understand that most developers would not select the option of state government subsidy. But the plan for the state right now is to increase the number of mini-grid plants in the state and expansion of rural electrification thereby." The major criticism of the mini-grid

Draft national mini-grid policy, 2016

The MNRE released a draft 'National Policy for Renewable Energy based Micro and Mini-Grids' in June 2016. The policy intends to mainstream RE-based micro- and mini-grids for enhancing affordable energy services and improving local economy. It targets to set up at least 10,000 projects with a minimum capacity of 500 MW in the next five years (by 2021). It lays out all the options that are available for developers and the support Central government can offer for the development of this sector. The draft policy in itself is a set of guidelines for states to use and draft their own policies. It lays down various options available to the states to choose from and select the one best suited for the conditions in a particular state.

The draft policy, for the first time, talks about RE-based mini-grids providing energy services beyond lighting.[25] It introduces the concept of utilizing mini-grids for commercial purposes and in the manufacturing sector. It also emphasizes the importance of a diversified customer base for developers and the use of varied tariff for different kinds of electrical loads. It discusses how mini-grids should be planned—whether there should be an open market for developers, on the lines of how they have been working in the past few years. This option allows developers to set up projects in any area they deem fit. The other option is the state nodal agency specifying the area where mini-grids

sector is that developers have been allowed to charge whatever rate they want for electricity—the draft policy not only allows the maintenance of this status quo, it actually expects it.

Schemes like DDG were established by the Ministry of Power to encourage mini-grids in areas where extending the grid is either physically or financially unviable. The UP policy addresses one of the most important concerns of the mini-grid developers—uncertainty about the future of a plant once conventional grid arrives in the village. The state has, therefore, laid out two exit policies for the developers:

i. **The energy generated by the mini-grid will be supplied to the grid and the discom will pay the tariff decided by Uttar Pradesh Electricity Regulatory Commission (UPERC)/ tariff decided by mutual consent. Project developers will be given priority for authorization as a franchisee by the discom, or**
ii. **Based on the cost–benefit analysis of the installed project, the project will be transferred to the discom at the cost determined by mutual consent between the discom and developer by the estimation of cost/ profit or loss of the project installed by the developer.**

UPERC simultaneously released regulations for supply and generation of power from RE-based mini-grids. The regulations outlined technical standards and safety measures for new and existing projects and explained various operational models to co-exist with the grid.

UP has one of the lowest rates of electrification in the country—only around 36.8 per cent of people have access to electricity. Mini-grids provide an opportunity to redefine the electricity sector in the state and the new mini-grid policy is a good start. The idea of regulated tariff has been introduced, albeit unintentionally, and it is a step in the right direction. It is important that the poorest and the electricity-deprived of the country are not charged enormous amounts for the same electricity that urban India enjoys at much cheaper rates.

should be set up. Obviously, the role of state nodal agencies becomes crucial in the second scenario. They are expected to be accountable for the development of mini-grids in the state, including the creation of 'contingency fund' for supporting the operation and maintenance of stranded assets.

Additionally, taking ideas from the UP mini-grid policy (see *Box: Uttar Pradesh leading the way in mini-grid development*), the draft policy defines exit conditions for mini-grids operating under two scenarios:

a) When a mini-grid is installed in an area where the grid was already supplying power, or
b) When the grid is extended and starts supplying power to an area where a mini-grid was already operating.

The policy proposes three exit options to developers:

1. Continue supplying to consumers and exist in parallel with the national grid,
2. Continue to supply to consumers and sell excess or unsold electricity to the national grid at the interconnection point and draw power from the grid if required, or
3. Supply all electricity generated to the national grid at the interconnection point.

Again, since these are options available to states, the tariff for any interaction with the grid and the role of developer from that point onwards would be defined after an agreement with the State Electricity Regulatory Commission (SERC).

One of the important innovations of the draft is the creation and maintenance of a project information system (PIS). Till date, there is no database or record of how many micro- and mini-grids are operating on the ground and what is their current status of operation. The PIS would be a databank of this information and would help keep an account of the number of working and under-construction projects under various categories, as follows:

- Less than 10kW—Category A
- From 10 kW to 100 kW—Category B
- From 100 kW to 250 kW—Category C
- From 250 kW and above—Category D

The ministry discourages construction of isolated category A projects or micro-grids and recommends that such projects be set up only in clusters, preferably interconnected, in adjacent villages.

There are many challenges for the development of mini-grids in the country. The draft policy is a good first step in encouraging more installations while simultaneously aiming at providing affordable and reliable electricity for the unserved and underserved population of the country.

CHAPTER 3

Mini-grid for rural electrification

CSE's proposal of incorporating feed-in tariff and generation-based incentives into the mini-grid model tries to address the challenges that the sector has been facing for years mostly related to finance. All calculations have been done on the assumption that every household has to be provided at least one unit of electricity daily. With this target in mind, the financial burden on the government would last only for the next 12 years. Deen Dayal Upadhyaya Gram Jyoti Yojana, Clean Environment Fund, diversion of kerosene subsidy, Green Climate Fund and the new carbon market that the Paris agreement of 2015 would develop can all easily fund the transformation of electricity for millions of people in India.

- **CSE proposes a model based on feed-in tariff (FiT) and subsidy for setting up distribution infrastructure that meets the grid codes and standards, to ensure every household receives one unit of electricity a day.**

- **There are no policy impediments that prevent RE-based DDG systems from generating and distributing power in both remote villages and in grid-connected areas. The model envisages a monitoring and verifying authority that would guarantee the number of units being distributed to different types of consumers and the amount of incentives to be provided to developers.**

- **Under the model, bringing mini-grids under regulation and support projects through FiT will increase bankability of projects. It would also help in ensuring sustainability of projects because they would have to continuously supply electricity to receive the incentive.**

- **The model emphasizes on the need for a thorough demand analysis to be a part of the detailed project report (DPR), before allocation of a project. This would help fulfil the aspirational needs of the poor using the most efficient equipments and appliances.**

- **The draft national policy states various exit options that are available, but the model focuses on the developer becoming a distribution franchisee, supplying power to residential households and feeding excess generation into the grid.**

- **Monitoring and verification authority (MVA) will be an autonomous body working in areas of verification, monitoring and rating of mini-grid developers. After the project is commissioned, MVA will monitor the performance of the mini-grid periodically.**

Since the Electricity Act (EA) was passed in 2003, numerous policies have been introduced which facilitate the developnment of mini-grids as a viable solution for rural electrification. The EA was a landmark bill in the power sector in India. It triggered electricity reform throughout the country, with private sector participation.[26] Sections 3, 4 and 5 of the Act introduced the ideas of a National Electricity Policy (NEP), National Tariff Policy (NTP) and Rural Electrification Policy (REP), which were notified in 2005, January 2006 and August 2006 respectively. Between the EA and the three policies, all the questions regarding the development of DDG are answered.

Sections 4 and 5 of the EA permits operation of stand-alone generation and distribution system in rural areas based on renewable and other non-conventional sources of energy. These systems can generate and buy power from the grid and distribute it or, they can generate and feed it into the grid.

Section 5.1.2 of the NEP, 2005 provides for DDG to operate both in remote areas and in grid-connected areas.[27] Section 1.7 uses the EA and calls for the development of RE by introducing renewable purchase obligation (RPO) and preferential tariffs. However, there is a need for clarity on whether the RPO and the feed-in tariffs extend to the RE-based DDG as well, when connected to the grid. The draft Renewable Energy Act released in July 2015 introduces the notion that DDG would be included to fulfil the RPO requirements of the state discoms. However, the act is yet to be officially notified.

Section 6.3 of NTP, 2006 allows captive power plants to export surplus power to the grid for a tariff rate fixed by the SERCs.[28] Although grid interaction is allowed by the EA, NTP does not explicitly state that the export of excess generation is allowed for DDG systems.

REP, 2006 is an amalgamation of Section 4 (provision for stand-alone power-generating systems, including those based on renewable energy, for rural electrification) and Section 5 (bulk power purchase and distribution in rural areas by panchayat institutions, users associations, co-operative societies, Non-govermental organizations or franchisees) of the Electricity Act, 2003.[29] The policy brings together the Rural Electricity Distribution Backbone, Village Electrification Infrastructure and DDG as an integrated whole to provide access to electricity to households as well as to supply electricity to meet varied demands (irrigation pump sets, small and medium industries, khadi and village industries, cold chains, healthcare, education and Information Technology) to facilitate overall rural development, employment generation and poverty alleviation. It also asks the Central Electricity Regulatory Commission to lay down guidelines on how the subsidies would be passed on to consumers as opposed to tariff determination on a case-to-case basis. The commission also has the right to intervene by scrutinizing tariff if these guidelines are not implemented in any particular case.

These policies provide a basis for RE-based DDG systems to generate and distribute power in remote villages as well as in grid-connected areas. They can act as a franchisee of the distribution company, collect revenues from consumers, manage the system and undertake routine operation and maintenance of distribution infrastructure. What is lacking is a clear definition of how these policies would be implemented, monitored and verified. It is important to know how many units of electricity are being supplied to rural consumers—the agricultural sector; whether the mini-grid developers are building installations capable of connecting to the grid; and if they have the necessary clearances etc. Also, clarifications are required on how the subsidies, whether generation-based incentives, feed-in tariffs or capital subsidies, would be paid for. The REP, 2006 states, "The Ministry of Power will put in place a coordination mechanism between the agencies or ministries implementing various schemes to ensure that the villages are selected for coverage in different schemes in a manner so as to ensure the attainment of the objectives of this policy."

The new mini-grid draft policy, introduced in June 2016, has resolved the impediments in development of the sector, nevertheless challenges persist.

Challenges

High capital and operating expenditures

Since solar PV is not impacted much from site-specific issues, most of the mini-grids in India are based on solar PV technology. But high upfront capital expenses and subsequent operation and maintenance (O&M) expenses incurred on battery replacement add to long and uncertain returns on the investment. Mini-grid customers are generally poor and revenue collections from them are inconsistent. All solar mini-grids that have been developed so far are either based on corporate social responsibility (CSR) funds, multilateral grants or government subsidies. Financial institutions do not consider mini-grids economically viable. The biggest challenge for their developers is the absence of a credible and reliable source of finance to meet upfront capital costs.

Mini-grids based on biomass face problem of reliable fuel supply and ever increasing cost of biomass. Small hydropower (SHP)-based mini-grids are location specific and usually situated in remote areas where the cost of accessing them and transporting equipment increases manifold.

Despite these pitfalls, many mini-grids (including solar mini-grids) have managed to survive by recovering O&M expenses through the sale of power to consumers. However, this power comes at high costs for the consumers. O&M expenses of solar mini-grids with storage facilities are much higher than those of mini-grids based on biomass or SHP. But biomass and SHP mini-grids are site-specific and can be commissioned only where these resources are abundant (see *Table 5: Cost of power generation based on different technologies*).

Taking advantage of lack of monitoring, some mini-grid developers charge outrageously high tariffs of ₹ 120 per unit of electricity—on the grounds of high cost of power generation. The challenge is to make electricity from mini-grids as affordable as grid power and still be able to recover the capital and operating expenditures in a reasonable time frame for sustainable operations.

Table 5: Cost of power generation based on different technologies

Technology	Location	Implemented by	Capacity of plant	Overall project cost (in Rs)	Annual operating cost (in Rs)	Cost of generation per unit (in Rs/unit)
Solar	Darewada, Maharashtra	Gram Oorja#	9.36 kW	3,200,000	120,000	28.85
Solar	Rawan, Chhattisgarh	CREDA	7 kW	NA	70,500	NA
Solar	Neechli, Rajasthan	Gram Power*	5.5 kW	2,200,000	NA	28.00
	Bhabhan, Rajasthan					
Micro-hydel	Putsil, Odisha	IRDWSI	14 kW	1,697,611	10,000–12,000	5.50
Biomass	Sahebganj, Bihar	Husk Power	32 kW	1,800,000	>2,00,000	6.90

Notes:
Cost of generation does not consider the cost of finance and return on equity as the project is based on CSR funds
* Cost of generation does not consider the cost of finance and return on equity as the project is based on foreign grant
CREDA—Chhattisgarh Renewable Energy Development Agency
IRDWSI—Integrated Rural Development of Weaker Section of India

Source: CSE survey and analysis

Demand in rural areas

Existing mini-grids have to operate at low plant load factor/ capacity utilization factor due to lack of demand in the early stage of a project. This is a catch-22 situation—high tariff is required to meet the O&M expenses, but it leads to low demand and hence low plant load factor. Banks want developers to predict cash flows, which is a big challenge considering the uncertainty of the growth in demand. Therefore, new mini-grids are being set up with an anchor load or a productive load to ensure baseline demand for the system.

Mini-grids have typically been unable to fulfil the aspirational needs of the poor. Once the energy-poor get access to power, they want to use more appliances and, therefore, more power. They also want access to power for longer periods, not just six hours. But mini-grid developers build systems based on current demand, or modest growth in demand. Demand analysis and increasing the capacity to accommodate growing demand is one of the challenges of deploying mini-grid systems.

Irregular tariff collection

Incomes in villages are irregular and dependant on agricultural output. A villager's capacity to pay electricity tariff on a regular basis, therefore, is a challenge. A mini-grid developer either has to be lenient about tariff collection, which affects cash flow, or disconnect supply to defaulters, which affects plant load factor. The challenge in mini-grid development is that it cannot be built solely on technical considerations, but has to take into consideration the social and economic characteristics of the rural economy. This is a big dilemma for most mini-grids as most of them currently run solely on revenue collected from villagers.

Bureaucratic delays

Mini-grid developers complain that bureaucratic delays in getting subsidies from financial institutions like National Bank for Agriculture and Rural Development, Indian Renewable Energy Development Agency Limited, REC or Small Industries Development Bank of India derail many projects. The developers are generally new-generation social entrepreneurs with little financial resources. Delays in getting government subsidies has a huge impact on their cash flows and, ultimately, on the project's survival. To counter these delays, MNRE introduced the empanelment of mini-grid developers as Rural Energy Service Providers (RESPs). These RESPs are entitled to receive Central financial assistance without much hassle. However, the rating process of this empanelment proved unfavourable to social entrepreneurs who have a sizable presence in this sector. Social entrepreneurs find the process unfair since the rating process is heavily dependent on the financial strength of the company rather than focusing on the performance record. This process is now being re-thought.

Social challenges

To set up mini-grids, the project developer has to engage with the community to understand village demography and socio-cultural equations. The developer also has to engage with the community for ease of daily operations and maintenance of the system. Human resource training at the local level is essential to take care of basic maintenance issues and day-to-day operations. This ensures community ownership, which in turn helps address social issues like theft, vandalism etc.

Technological and operational challenges

All renewable energy technologies except solar PV systems have a minimum economically viable size below which generation of power is not cost-effective. Due to low demand in villages, solar-based mini-grids are the preferred option. These are currently tiny in size, mostly less than 10 kW. Upsizing a solar PV-based mini-grid simply requires additional panels to be interconnected in series or parallel combinations.

But as an increasing number of renewable energy-based mini-grids are connected to the grid or interconnected in a cluster (this scenario being more and more plausible given that the grid is rapidly expanding with the DDUGVY programme), the stability of the grid will be much more complex because of issues like voltage and frequency fluctuations, back feeding, reactive power, harmonics and sudden ramp-up or ramp-down of power from mini-grids. Mini-grids and the main grid have to be sophisticated enough to handle these issues effectively. This calls for investment in main grid. It also discourages the building of smaller mini-grids which so far have been the predominant form of electrification in India.

Maintaining a separate inventory and human power for O&M for several small mini-grids is another challenge. These issues can be effectively handled by making the mini-grid a sizable one. The size of the mini-grid should not be a constraint for choosing the right technology. One mini-grid can cater to a cluster of villages with one or multiple renewable generators.

Large players versus small

Governments and some proponents of mini-grids want large private players with strong financial standing to enter the market. However, this is considered a major threat by the social entrepreneurs and small enterprises who dominate this sector. But our analysis indicates that there is a space for both. Most major players would not prefer to go to remote villages and set up small mini-grids. These areas can only be served by social entrepreneurs.

Competitive environment

The biggest fear in the minds of mini-grid developers is what will happen to their business when cheaper grid power reaches villages they are operating in. It has been observed that households want to shift to conventional grid power as and when the grid reaches the villages—this is because this grid power comes at a much cheaper price and presumably offers a regular supply of power (supply is not limited to few hours). Since the levelized cost of renewable-based generation is not competitive to coal-based grid power, these developers need policy support and protection under the regulatory framework to co-exist with the main grid. However, this threat is premature. It has been observed that several mini-grids were still able to hold their own due to the unreliability and poor quality of grid power.

Now, since new policies and regulations have been introduced addressing this issue, it is important to understand that the national grid and mini-grids would be complementary to each other. Grid interaction is very important for the development of the mini-grid sector. In the future, the main national grid can act as a medium of exchange for filling the gaps of deficits and transfer the excess supply.

How to overcome the challenges CSE's Model

To address challenges and impediments and foster development in the mini-grid sector, CSE has developed a policy and business model. This model would help operationalize the draft mini-grid policy and ensure at least eight hours of supply and one unit of electricity per day per household.

The first issue we address in our model is how to support mini-grids. It is quite clear that on simple logic of market economics, mini-grids are not viable currently. Like most RE projects, they need financial support. The big question is what kind of financial support. Capital subsidy regime has been pursued for mini-grids both by MNRE and Ministry of Power, but current schemes, which offer up to 90 per cent subsidy, have failed to scale up and provide millions of people access to electricity. The government wants to give capital subsidy in a staggered manner based on project development and performance to ensure that the subsidy is utilized appropriately. Mini-grid developers want the entire subsidy upfront as they cannot withstand bureaucratic delays. Upfront capital subsidy also raises the issue of ownership of mini-grids. Transfer of ownership to communities has not been sustainable in the past.

Many other suggestions have been put forth to secure finance for mini-grids, including:

- Bringing mini-grids under regulation and support projects through feed-in tariff (FiT)/ generation based incentive (GBI). This will increase bankability of projects.
- Including mini-grids in the Reserve Bank of India's priority-sector lending list. Currently, the RBI supports off-grid solar home lighting systems for individual households.
- Long-term finance at subsidized rates (three–four per cent) provided from leading national and private sector banks as mini-grids are rural infrastructure development projects with long gestation periods.
- Encouraging private investment in mini-grids by incorporating accelerated depreciation.

We suggest that mini-grid projects be divided into two parts:

1. A power generation plant with electricity storage along with O&M and selling of power and recovery of tariff.
2. Transmission and distribution infrastructure including connectivity and interaction with the main grid.

It is important to recognize that government is already funding the extension of the main grid and discoms are providing household connections. For BPL families, no charges is levied for giving connection, for others, certain amount is charged which varies from state to state.

We suggest that capital subsidy be provided, if necessary, for the development of the transmission and distribution infrastructure of these mini-grids. This would not only ensure that the infrastructure that is being set up for these projects meets the performance and safety standards and codes of the national grid, it would also ease the process of grid interaction for these projects and

What can be achieved with one kWh per day per household?

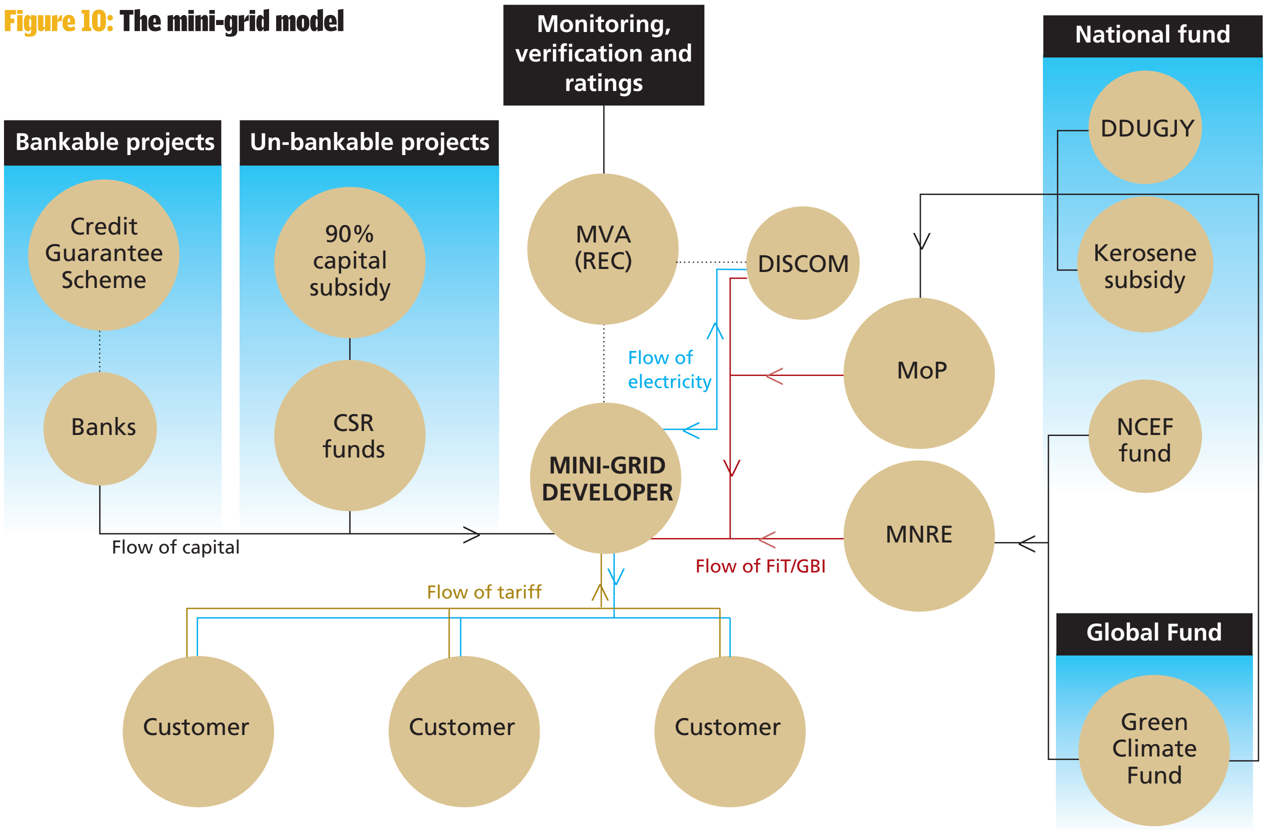
On an average, one unit a day can provide enough electricity for several LED lights, fans and mobile charging. It is essential that the electricity demand should be complemented with most energy-efficient appliances. This provides an immense opportunity to help people make the transition to super-efficient appliances and modern forms of energy.

Table 6: What can be consumed in a day with one unit of electricity?

Appliance	Load (W)	Quantity (no.)	Hours of consumption	Consumption per day (Wh)
LED lamps	9	2	6	108
LED lamps	7	1	6	42
Ceiling fans/ table fan	25	2	15	750
Mobile charging	8	4	3	96
Total	49	9	30	996

Source: CSE analysis

Figure 10: The mini-grid model



Source: CSE analysis

lessen the burden of capital costs of the project as well. For the first part—power plant, O&M etc.—we adopt an FiT/GBI model. A combination of capital subsidy and FiT/GBI would make most projects bankable.

There could still be some mini-grids which are not bankable but are important from the energy access point of view. For example, mini-grids set up in very remote areas. These could be financed by either of the following means:

- Encouraging companies to use CSR funds to set up mini-grids.
- 90 per cent capital subsidy by the government to support mini-grids.

CSE mini-grid model

Implementing agencies

MNRE will implement the programme. It would be the policy and funding agency. REC will be the monitoring and verifying authority (MVA) and the programme will be implemented by state nodal agencies (SNAs). SNAs will formulate the plan to achieve target set by MNRE in the national mini-grid policy. REC will work with SNAs to identify villages where such mini-grids can be installed. The criteria for selection of villages would be:

a. Grid-connected villages: The grid has been extended but a household in the village receives less than one unit or less than eight hours of electricity a day.

b. Remote villages: The grid will not reach the village in the foreseeable future or in a simple cost–benefit analysis, a mini-grid will be economically advantageous over the grid.

Selection of the project developer

The project developer (PD) will undertake a detailed study on project feasibility and resource availability before preparing a detailed project report (DPR). The DPR will include demand growth and how the mini-grid plans to meet the increased demand in future. Expansion plans, if any, have to be included, with a set time-frame, in the DPR. This will be a major step in the development of mini-grids since DPR would be the basis of deciding the right kind of PD suitable for development of a project in an area. The DPR will have to be produced by the bidder rather than being filed by a third-party consultant appointed by the Central or state government. This will ensure that the bidder is actually taking into consideration needs of the households including future demand growth while preparing the DPR. The size and capacity of the required plant along with future expansion will have to be decided at this stage. The tender document will have to specify the size of the cluster based on site specificity—number of households etc.

SERCs will declare the benchmark tariffs for various technologies. PD will have the choice to select a combination of technologies/ renewable energy sources to provide the services at the least cost. PD will submit the DPR along with the bid to REC. The technical and financial bids will be submitted separately. The DPR will be a part of the technical bid.

Mini-grid developers should be selected through a bidding process, which should be handled by the MNRE. The technical bid will be opened first for evaluation. REC will verify the documents and assess the feasibility of the mini-grid project, prepare a list of successful bidders in order of preference, and submit the list to MNRE.

Since mini-grids are proposed to have preferential tariffs like FiT, a reverse bidding mechanism can be instituted to discover the cost of generation. However, utmost care should be taken to ensure performance of the mini-grid over its life cycle. Commercial bids of successful PDs will be opened by SNAs. Reverse bidding will decide the winner.

O&M and capacity building

A project need not simply be allocated to the lowest bidder. The O&M strategy is an important aspect to be scrutinized carefully before awarding the contract. This should cover the employment and training of locals. The bidding document should have plans for capacity building like skill and micro-enterprise development etc.

A smaller capacity project usually cannot sustain itself because the O&M costs become too big a share of the expenses for operating such a set-up. Therefore, as the draft national policy recommends, small projects are recommended to be set up in clusters either connected to each other or closely related. This will distribute O&M expenses over the connected mini-grids. The clustering approach is also encouraged with larger installations. This would support exchange of electricity between surplus- and deficit-facing mini-grids.

Financing the project

Successful PDs will apply to banks that have arrangements for financing mini-grid projects and obtain their approval. If the bank approves financing, the PD can commission the project. In grid-connected villages, the government will provide 90 per cent subsidy to develop distribution infrastructure in the villages based on work progress. It should be ensured that the distribution systems meet the standards of the main grid to ensure connectivity in the future. Subsidies received by developers should be used in ensuring grid safety and meeting technical standards. REC will monitor the progress and ensure that payments are made as per schedule.

If the bank rejects financing, the PD will look for CSR funding and submit a report to the corporate houses of its choice, along with a copy of the rejection letter from the bank. The CSR funding team will evaluate the project based on the technical evaluation report of the REC and take a decision on funding.

What is the optimal size of a mini-grid?

The average population of a village in India is around 1,400. Assuming that the average size of a household of is five and transmission, storage and commercial losses are about 20 per cent, ensuring that all households have at least one unit of electricity every day, a mini-grid system should be able to generate 122,640 units in a year.

If we consider a capacity utilization factor (CUF) of 19 per cent, the minimum capacity of a solar mini-grid should be 74 kW. A biomass mini-grid should have a capacity 22 kW and SHP mini-grid capacity should be of 40 kW assuming CUF of 65 and 35 per cent respectively.

Table 7: Average population in six least electrified states

States	Rural population	No. of villages	Average size of village
Assam	26,807,034	25,372	1,057
Bihar	92,341,436	39,073	2,363
Uttar Pradesh	155,317,278	97,814	1,588
West Bengal	62,183,113	37,469	1,660
Jharkhand	25,055,073	29,492	850
Odisha	34,970,562	47,675	734
Total	396,674,496	276,895	1,433
India	833,748,852	597,608	1,395

Source: CSE analysis

Grid interactivity

In grid-connected villages, PD will sign a memorandum of understanding with discoms for acting as a franchisee. GBI/ FiT will be paid by REC. In remote villages, capital subsidy will be paid by REC.

PDs will generate electricity, supply it to customers and receive tariff as paid by customers at a rate decided by the SERC. PDs will receive the differential amount (bid tariff minus tariff paid by the customer) as GBI for the number of units of electricity supplied to the customer. It should be noted that GBI would be paid only for electricity supplied to residential consumers, whose tariff would be decided by the SERC. PDs are free to charge other consumers at any mutually agreed rate.

Excess power produced by the mini-grid is fed back into the grid. For excess power, PDs receive FiT from the discom, as decided by the SERC. In case of deficit, PDs will buy power from the main grid at a mutually agreed rate with the discoms. However, excess power generated in case of remote village will be a loss to the nation. If excess power is generated, beyond a certain percentage, a penalty would be levied on PDs. PDs, therefore, will be obliged to develop programmes for productive load in their area of operation.

Role of monitoring and verifying authority (REC)

REC will be an autonomous body working in areas of verification, monitoring and rating of mini-grid developers. After a project is commissioned, REC will monitor the performance of the mini-grid periodically. Monitoring parameters will include, but will not be limited to, the measurement of the number of units for FiT/ GBI, system up-time, O&M measures, demand growth, skill development, local employment, micro-enterprise development and customer feedback. Based on their performance, mini-grid developers will receive annual ratings from REC. Capital subsidy for distribution network will be administered by REC through SNAs.

REC will take a fee for administrating the programme.

Costs of the model

Going by Census 2001 and 2011 data, the growth rate of the number of rural households in the country stood at 1.96 per cent while the rate of electrification in rural areas stood at 1.18 per cent per year. On the basis of these rates, we find that there are 167.83 million rural households of which 92.81 million were electrified as per Census 2011. This means that 75.02 million households are still to receive access to electricity. We also assume that 75 per cent of those electrified villages currently do not have minimum guarantee of one unit of electricity per day. The total number of households that did not receive even one unit of electricity in day was 144.62 million. With a growth rate of 1.96 per cent, in 2016, the number is 158.79 million.

Table 8: Growth of rural households in India

Description	Unit	Reference year	
Census year	Year	2001	2011
Census data on rural households (in millions)	No.	138.27	167.883
Cumulative average growth rate in the number of household	%	1.96	

Source: Census of India, 2011

We have made the following additional assumptions to calculate the capital expenditure required till 2025:

- In the current DDG scheme under the larger DDUGJY programme, mini-grid developers are eligible for 90 per cent capital subsidy for setting up mini-grids in the country. This subsidy includes development of distribution infrastructure also. It is assumed that per kilowatt cost of developing distribution infrastructure in a village would be ₹ 30,000 and government will continue to provide 90 per cent capital subsidy for setting up distribution infrastructure in the villages with an escalation of three per cent per annum—which means a subsidy of ₹ 27,000 per kilowatt for setting up distribution infrastructure, with an escalation of three per cent per annum
- We assume that 10 per cent of the un-electrified households are to be electrified per year starting from 2016 to achieve 100 per cent energy access by 2025.
- We assume that the share of solar mini-grids in the total will increase from 50 per cent in 2016 to 90 per cent in 2025 due to overall reduction in the cost of generation. The share of biomass-based mini-grids will decrease from 30 per cent in 2014 to 10 per cent in 2025 because of an increase in the cost of generation and saturation of biomass resources. Similarly, share of small hydropower-based mini-grids will also decrease from a 20 per cent level to nil progressively for similar reasons.
- CUF for solar-based mini-grids is taken as 19 per cent in 2016 even though it can be presumed that CUF will increase over the years because of improvements in cell and module efficiency. CUF for biomass and small hydropower-based mini-grids are considered consistent at 65 per cent and 35 per cent respectively as these technologies are highly matured.
- The report *Policy and Regulatory Interventions to Support Community Level Off-Grid Projects* by ABPS Infra to the Forum of Regulators calculated the capital expenditure for solar, biomass and SHP as ₹ 1,50,000 per kW, ₹ 50,000 per kW and ₹ 1,00,000 per kW respectively in 2012. We assume a 7 per cent reduction on capital expenditure for solar and a 4 per cent increase of the same for biomass and small hydropower every year.

Considering the above assumptions, we find that a total of ₹ 2,47,230.88 crore of investment will be required till 2025 to build 28,837 MW capacity of mini-grids and provide a minimum of one unit per day per household for the entire population of the country.

Table 9: Costs of providing one unit of electricity to un-served and underserved population

Type of finance	Share	Total (in ₹ crore)
Equity	19.24%	47,569.62
Debt	38.48%	95,139.25
Subsidy for distribution	42.28%	1,04,522.01
Total	100.00%	2,47,231.88

Source: CSE analysis

It is clear from *Table 9: Costs of providing one unit of electricity to un-served and underserved population* that the capital requirement is quite huge and cannot be met by upfront capital subsidy. This kind of investment can be secured only through the participation of private players in the sector.

About the question of the quantum of preferential tariff (FiT or GBI) required, on an average, to provide one unit a day to every un-served and underserved household, we need a supply of 35.12 billion units.

On the basis of the following assumptions, the graph depicts the amount of preferential tariff which would be paid partly by the consumers and partly by the government to support mini-grid development.

- India will be able to address its energy access issues adequately by 2025 (in the next 10 years).
- We assumed a seven per cent reduction in capital expenditure for solar and a four per cent hike in capital expenditure in case of biomass and small hydropower to calculate the levelized cost of generation to determine the feed-in-tariff.
- The average spending of villagers on lighting has been seen to be ₹ 150–300 per month per household for various residential and commercial activities. Therefore, the weighted average tariff for rural customers is considered as ₹ 5 per unit as the base tariff for 2016. It is also assumed that the tariff will increase at the rate of 10 per cent every fourth year.
- The cost of generation from solar, biomass and SHP is ₹ 10.46, ₹ 3.70 and ₹ 3.91 per unit respectively. Cost of electricity generated using biomass and SHP is lower than the cost of electricity paid by consumer, these mini-grids do not meet the criteria for a government support for feed-in tariff.

Funds for preferential tariff and their sources

The requirement for FiT/ GBI can be arranged from following sources:

DDUGJY: The programme received an allocated sum of ₹ 35,447 crore for the 12th Five Year Plan. Out of this, only ₹ 900 crore has been allocated to the DDG scheme.

How much CO_2 saved, money from carbon market?

The renewable energy-based mini-grids are not just the answer to leapfrogging millions of individuals to a decentralized distributed renewable energy future that the world should be aiming at, it is also an opportunity to cut carbon dioxide emissions by millions of tonnes. If we don't install RE-based mini-grids, this demand would undoubtedly be filled by adding thermal power plants in the electricity mix.

Ideally, to generate 35.12 billion units in a year, we need to install a thermal power plant of 5,700 MW capacity.[30]

A sub-critical power plant uses 0.74 kg of coal to produce one unit of electricity.

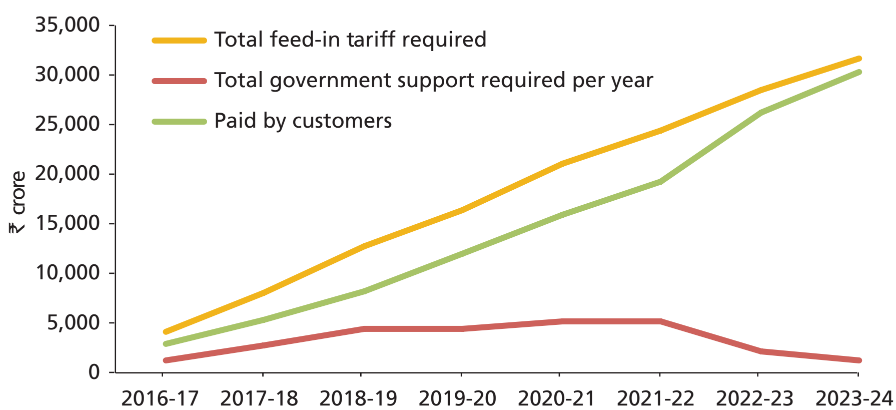
The Paris agreement has introduced back a carbon trading system. At the peak of the trade, one tonne of CO_2 was worth around $30. Assuming the same rate, the renewable energy-based mini-grids provide an opportunity to earn $1.62 billion or ₹10,530 crore in a year. Although small when compared to the total investment, it is an additional income that be generated with minimal expenses for developers.

Table 10: Savings from CO_2 emissions

Value		Units
Average units in a year	35.12	In kWh millions
Coal consumed to produce one unit	0.74	kg
Total coal consumption in a year	28.65	Million short tonne
Emission factor	1,885.00	kg CO_2 per short ton
Emissions from thermal generation	54	Million tonne of CO_2
Price of CO_2	30.00	$ per tonne of CO_2
Total cost of CO_2	1,620.13	$ millions
Total cost of CO_2	10,530.87	₹ crore

Source: CSE analysis

Figure 11: Yearly tariff and support required by mini-grids



Source: CSE analysis

National Clean Energy Fund (now called Clean Environment Fund): National Clean Energy Fund was created in 2010–11 by introducing a carbon tax termed coal cess on the sale of every tonne of lignite or coal. In 2015–16, the coal cess was increased from ₹ 100 per tonne to ₹ 200 per tonne. In this financial year, the cess has been doubled again to ₹ 400 per tonne with a change in name. Now, the fund is called the Clean Environment Fund. For the year 2016–17, the fund has been distributed to Ministry of Environment, Forest and Climate Change; Ministry of Water Resources, River Development and Ganga Rejuvenation; and MNRE. MNRE has been allocated a total of ₹ 4,947 crore. About 50 per cent of this money should go to provide preferential tariffs for renewable energy-based mini-grids.

Diversion of kerosene subsidy: The government has spent ₹ 20,415 crore on kerosene subsidy in the financial year 2014–15. In reality, according to the Economic Survey of 2014–15, 41 per cent of kerosene allocation through public distribution systems is lost as leakage, and only 46 per cent of the remainder reaches poor households. This issue is being resolved using the Jan Dhan Aadhar Mobile agenda, under which subsidy is directly credited to the consumer's bank account. As per Census 2011, around 73.5 million villagers are dependent on kerosene for lighting. This subsidy must be diverted progressively towards the development of mini-grids.

Green Climate Fund (GCF): The UNFCCC has developed a Green Climate Fund (GCF) in order to support programmes, policies and other activities of participating developing nations. Energy access is a development priority for the United Nations. As the development of mini-grids is an attractive proposition to leapfrog 1.2 billion energy-poor people from dirty fossil fuel directly to clean energy, a sizable portion of the GCF should be used to support mini-grids through FiT/ GBI in developing nations. The idea of global feed-in tariff (GFiT) must be advocated strongly by all participating developing nations in all UNFCCC conferences till a consensus is reached. GCF only has commitments of $10 billion as of date and even fewer projects' applications. A model of this sort being developed for even one nation is a project that meets all the criteria set up by the committee.

Case studies

Centre for Science and Environment visited mini-grid sites across the country and studied the various mini-grid models. They varied in size, type of renewable source used, funding methods, operating models and ownership structures.

We saw mini-grids as small as 1.5 KW, based on solar photovoltaic technology, as well as those as large as 32 KW, based on biomass technology. The advantage of a solar mini-grid is its scalability because of which it can be as small as a few kilowatts or as large as megawatt-sized. However, most of the solar based mini-grids commissioned in India so far are smaller and cater only to basic lighting needs of customers.

Most mini-grids are funded through grants from the government, multilateral funding agencies or corporate houses, under their CSR initiative. The operating models vary based on who owns and operates them. Mini-grids owned and operated by the government charge a minuscule amount for energy consumption, which is insufficient to meet operational expenses, but those operated by a trust charge significantly higher amounts to cover all the operational expenses plus a corpus for future developments. There are some mini-grids funded by private investors with a profit motive. Powers from these mini-grids are even more expensive.

Table 1: Micro- and mini-grids in India, 2013 provides details of mini-grids commissioned in India, capturing these variants:

Table 1: Micro- and mini-grids in India, 2013

Most renewable energy based mini-grids in India are based on solar PV.

Mini-grid developer	Techno-logy used	Mini-grids commissioned (no.)	Households benefited (no.)	Funding method	Average plant size (kW)	User charge (in ₹)	Load per household	Average supply (hours/day)
Husk Power System, Bihar	Biomass	300	400/plant	Investment, subsidy	32 kW	100/ month	30 W	6-7
Kuvam Energy, Bihar	Solar PV	4	387	Equity, subsidy	0.96 to 3.12 KWp	200/ month	2 LED lights and mobile charging unit	4
Saran Energy, Bihar	Biomass	1	325	Investment, loan	128 KW	7.5/kWh	Variable	10
Mera Gao Power, Uttar PradesH	Solar PV	500 +	13,000	External funding, seed capital	240 W	100/ month	2 LED lights and mobile charging unit	7
Scatec Solar, Uttar Pradesh	Solar PV	14	70	Equity	NA	Different slabs, 4.5-6.5/ Kwh	2 CFL lights, and mobile charging unit	6
Sun Edison, Madhya Pradesh	Solar PV	1	70	Corporate social responsibility	14 kWp	20/month	2 LED lights and mobile charging unit	6
Gram Power, Rajasthan	Solar Pv	4	250	External funding, subsidy,	5 kW	28 – 30/ Kwh	Two 8 W CFL lights	Unlimited
Gram Oorja, Maharashtra	Solar Pv	1	36	Corporate social responsibility	9.36 kW	20/kWh	Two LED lights, mobile charging unit, television	Unlimited
Desi Techno Solutions, Odisha	Micro Hydel	10 +	NA	External funding, loan, subsidy	3-40 kW	40 in 1st 6 months; 20 in 2nd 6 months	70 W (3 * 20-W CFL lights; rest for other appliances	9
Minda NexGen Tech Ltd, Uttar Pradesh	Solar Pv	1	13	Equity	240 W	150/ month	Two 1.5 W LEDs, Mobile charging point (5.5 - 6 V)	6
Uttarakhand Renewable Energy Development Agency	Solar Pv	47	NA	Central and state subsidies	1.5 kW	150/ month	Two 1.5 W LEDs	6
Chhattisgarh Renewable Energy Development Agency	Solar Pv	1,476	58,000	Central and state subsidies	4 kW	5/month	2 CFL lights, and mobile charging unit	4-6

Source: CSE Field Survey

CASE STUDY

Gram Power—Rajasthan

Four villages in Rajasthan, using a prepaid metre that detects theft, get micro-grid solar power

Women in the village Neechli Babhan gather under a tree to cool down. Judicious with electricity consumption, they use fans only in the evenings.

It looks like a regular electricity metre, but the innovative version is changing the way people use electricity and pay for it. Neechli Babhan, a small village in Rajasthan's Pali district, has a smart metre installed in 80 of its 150 houses. The smart metre forces people to use electricity judiciously.

The device is an innovation by Gram Power, a company started by engineering graduates Yashraj Khaitan and Jacob Dickinson. Mohan Singh, a daily wager, says that it gives real-time information about credit left, just as prepaid mobile phones do. It also shows the number of hours an appliance can be used. 'We have only ₹30 left,' pitches in Mohan Singh's 10-year-old daughter. 'Please get it recharged before we run out of credit,' she tells him, proudly showing off that she can read the metre. Mohan phones Udai Singh, who recharges smart metres in the villages and hamlets.

Within 10 minutes, Udai Singh is in Mohan's house, with an instrument, called a dongle, the size of a mobile phone. He enters 100 on it for the ₹100 that Mohan pays him, takes it close to the smart metre and presses a button. The meter makes a clicking sound and shows ₹130 as balance. The ₹100 recharge can help Mohan light an 8-watt CFL for 400 hours.

The electricity comes from a 5.5 kW solar micro-grid set up on the roof of a school.

Table 1: Project synopsis

Location	Neechli Babhan, Rajasthan
Size of power plant	5.5 kW
Number of households	80 connections
Overall cost of project	₹25,00,000
Tariff	₹31.25 per unit (prepaid meter)
LCOE	₹27.00
Implemented by	Gram Power
Funded by	MNRE Subsidy, Foreign Funds
Energy services for	Lighting, Television
Grid interconnectivity	Grid ready
Grid presence	No

Neechli Babhan is off the main grid because of its rocky terrain. The power generated through solar panels is stored in batteries, which make electricity available 24 hours a day. The plant has generated about 4,600 units until September 2013. A capacity utilization factor of 16 per cent can be observed from the plant's generation.

The micro-grid installed is also power theft-proof. All smart metres in the village are connected wirelessly and can be controlled online. A wire hooked on a distribution line can be detected by the metres and the line is shut down immediately.

Idea for change

In 2008, Khaitan and Dickinson, still in their twenties, met while studying engineering at the University of California, USA. Khaitan belongs to Jaipur. He was aware that back home, villages without power were underdeveloped. Besides, power distribution companies in the state were facing two major problems—theft and bill payment default.

Khaitan spoke to Dickinson and the two started to think about how the situation could be improved. The massive penetration of mobile phones in remote parts of the country gave them the cue. The two completed their course, came to Jaipur and started Gram Power.

Micro-grid technology provider Gram Power has installed prepaid smart metres in Pali district, Rajasthan

After months of research, the smart metre was born. In 2012, Gram Power installed smart micro-grids in four villages in Rajasthan. It employed people like Udai Singh, who would recharge smart metres and get a 10 per cent commission on each recharge.

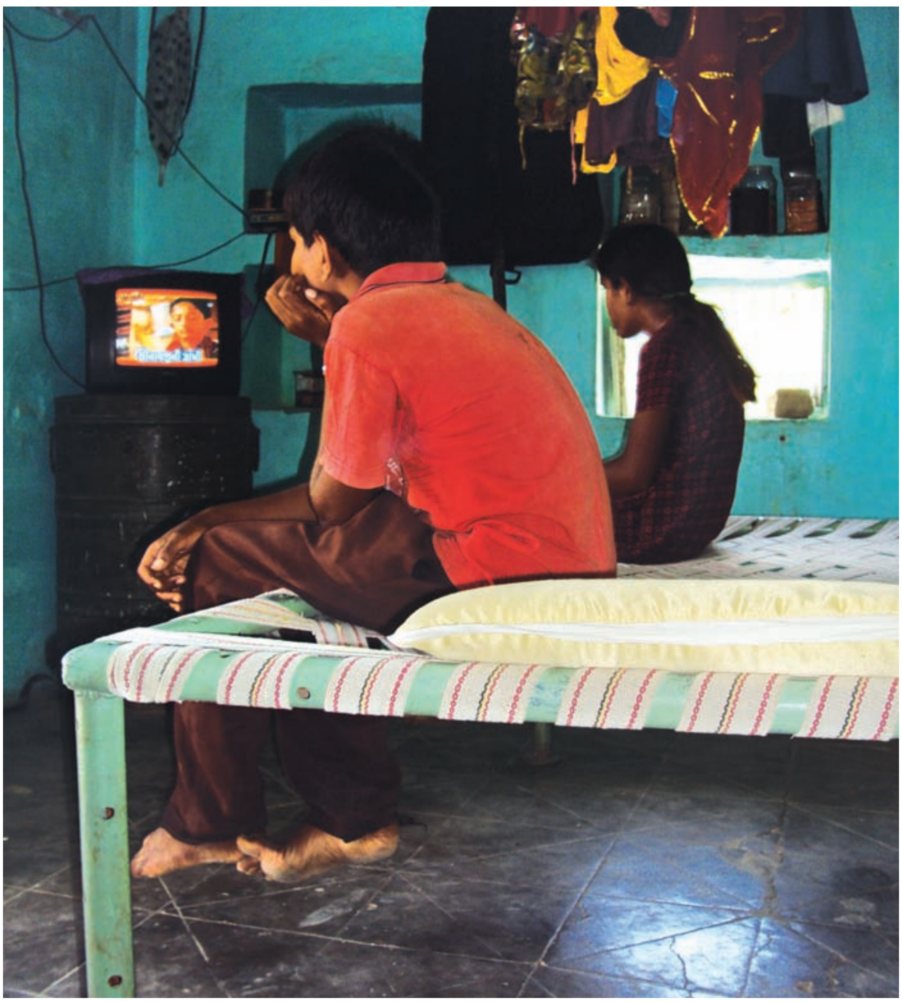
Gram Power holds intellectual property rights on the metre and plans to install it in 21 other villages in the state. It charges a non-refundable ₹3,500 per connection, which includes a smart metre and two 8-watt CFLs. The metre is, however, not the consumer's property. 'The prepaid system ensures that there is no payment default,' says Khaitan.

Khaitan set up the system in Neechli Babhan in mid-2013 before which people used either kerosene or Solar Home Lighting Systems (SHSs). Many prefer microgrids to SHSs because they are cheaper and take more load. A regular 37 Wp (Wattpeak) SHS costs ₹11,000, which is difficult for people to pay. Unlike SHSs, which give only two CFL points, microgrid power can reach almost every room of a house. The recurring cost of battery replacement in SHSs every five years is another deterrent. In many villages, SHSs are unused because people were not able to arrange for the money to replace batteries, which cost ₹4,000 each.

For necessity, not for comfort

Smart micro-grids work very well as long as people use electricity as a means to illuminate their houses. As soon as they expand its use, charges shoot up. Lighting an 8-watt CFL for an hour costs 25 paise. If a family uses two such CFLs for six hours a day, the monthly expenditure would be ₹90. But if they want to run a ceiling fan or a television, power becomes expensive.

Consider this: It costs ₹2.50 to run a 70-watt ceiling fan for an hour. If a family wants to sleep comfortably at night and use a fan for six hours, it would cost them ₹450 a month, an amount that can give people of Neechli Babhan, comprising mostly daily wagers, sleepless nights. To pre-empt this expense, women of the village gather under a big neem tree during the day. 'We save money to use a fan in the evening when our children study,' says Savita Rawat.



People in Neechli Babhan can now watch TV because of round-the-clock electricity

Service is another challenge. There have been times when Gram Power has taken 10 days to repair metres. 'We have trained vendors to fix small problems. For big problems, we send people from our head office. But big problems are few and far between,' says Khaitan.

He admits their rates are steep. The cost of power generation in micro-grids below 10 kW, including power storage, is ₹28 per unit. A back-of-the-envelope calculation by Centre for Science and Environment shows that consumers in Neechli Babhan pay about ₹34 per unit. 'That is why we developed a prepaid system. People can budget their power,' says Khaitan. 'This is the best we can do, else the model will be financially unviable for the company,' he adds. He hopes to recover the cost of micro-grid installation in five years.

Capital challenge

The capital cost of the smart micro-grid was ₹25 lakh. Gram Power availed a 30 per cent subsidy from the Union Ministry of New and Renewable Energy (MNRE) on capital cost for off-grid systems. The company collected ₹2.8 lakh from households as connection charge. The rest was raised through private investors. 'Low government subsidy makes it difficult for us to make financially viable projects and still supply electricity at a low rate,' says Khaitan. 'Better funding mechanisms are needed. Banks should provide low interest loans to developers working in off-grid areas,' he says.

Raza Ahmar, director, solar off-grid in MNRE, admits that high tariff is a problem in off-grid models. 'But we still do not have an off-grid model that can satisfy everybody. Giving high subsidy is not the answer,' he says. One way to make off-grid models financially viable is to set up small industries in one area and create a productive power load. This way tariff can be cross-subsidized for the poor. But not many people want to set up industries in off-grid areas.

Another big challenge for micro-grid developers is the fear of their grid being rendered useless once main grid reaches its area of operation. 'My system is compatible with the main grid,' says Khaitan. It can be connected to the main grid and serve as the distributor.

Workable model

In April 2013, Forum of Regulators (FOR), a group of consultants, endorsed a model, called distribution franchise, for electricity distribution in off-grid areas. The state electricity regulator decides tariff based on the cost of power generation to the developer. But the consumer is charged the conventional tariff.

The distribution company pays the difference to the developer. For example, the regulator decides the tariff as ₹15 per unit. The consumer pays the conventional tariff, say ₹5, to the developer. The distribution company pays the difference of ₹10 to the developer and save the state electricity regulator the cost of setting up infrastructure.

'It is a workable model, but it is yet to be proved successful,' says Ashwin Gambhir, policy researcher with Pune based non-profit Prayas Energy. 'It is important for the main grid to reach small areas because many developers charge unfair tariffs from the poor and do not want the grid to reach their areas of operation. This model will help both parties,' says Balwant Joshi of Mumbai-based consultancy ABPS Infra that prepared the report for FOR. ■

CASE STUDY

Rejoicing in power

A micro hydel project in Odisha gets community support

Villagers in Putsil transport transmission lines for electricity

A micro-hydel project that uses water from the Kodramb stream, a tributary of the Karandi River, runs close to Putsil village in Odisha's Koraput district. The stream provides water for paddy cultivation, the main agricultural activity of the local population.

The 14-kW micro hydel project was commissioned in August 1999 by Koraput-based Integrated Rural Development of Weaker Section in India (IRDWSI), a non-profit that helps the rural poor improve their livelihood options. The non-profit also identifies decentralized energy options for achieving development in remote regions.

Detailed project reports estimated a total power demand of 5.64 kW for the entire village (see *Table 2: Power demand*). When the project was conceived, it was recognized that grid power would not reach this remote village. During a feasibility study, it was estimated that the demand for electricity would require a 12-kW micro-hydel project for the first seven to eight years and a 20–25 kW project in the next 20.

Plant design

The project had to be designed to operate with the lowest stream flow to ensure year-round electricity supply. The dry season in the region extends from February to April. For the power plant design, a flow rate of 50 litres per second (l/s) was required, which would have affected irrigation during the dry season. The villagers deliberated the matter and concluded that they were over-irrigating their fields. They decided to let the

Table 1: Project synopsis

Location	Putsil Village, Koraput district, Odisha
Size	14 kW
Year of implementation	1,999
Households	72 (from a total of 120 households)
Overall cost of the plant	₹17,00,000
User tariff	₹40 for 6 months and ₹20 for 6 months
Implemented by	Integrated Rural Development of Weaker section in India (IRDWSI)
Funded by	Multiple sources including the local community
Energy services	Lighting, mill, television
Grid Interconnectivity	Not available
Grid Presence	No

Table 2: Power demand

(a) Domestic demand	
3 x 20 W lamps per household	60 W
Provision for radio/cassette	10 W
Total demand by all 72 households	
(70 W x 72)	5,040 W
(b) Street lighting	
15 lamps x 40 W	600 W
(c) Milling	
Grinding machinery	3,000 W
Total night-time power demand	5,640 W
Total daytime power demand	3000 W

Source: CSE analysis

power plant draw water at night, while continuing irrigation during the day. The discharge from the plant is diverted back into the stream via a tail-race channel.

Table 3: Project cost (in ₹)

Feasibility study	35,000
Civil construction	3,50,000
Pen stock	3,12,000
Turbine	70,500
Electronic load controller	2,60,000
Transmission lines	2,57,000
Generator	49,000
Consultancy	1,31,000
Transport and travel	1,60,000
Coordination	73,111
Total Cost	**16,97,611**

Source: CSE analysis

Trained villagers

The power station is about a kilometre from the village and is operated by two trained villagers. The plant operates for three hours in the morning and four hours in the evening. During this time, each household in the village receives electricity to suffice the household load of 60–70 watt, which is transmitted to the village via a kilometre-long low-voltage transmission line laid underground.

Although the initial estimate of the project was ₹19,30,000, the actual cost turned out to be less (see *Table 3: Project cost*). Funds for the project came from various sources. To promote ownership, Putsil's residents also contributed. Around 12.5 per cent of the project costs were borne by the villagers themselves who offered labour while the project was set up.

A worrying mismatch

The plant has been functioning since 2000. In its initial years, it generated only 4–5 per cent of its total capacity. 'Consumption was low and the power plant was taking time to stabilize with the periodic water flow,' says Benudhar Sutar, director, Desi Technology Solutions, the energy consultant which helped IRDWSI set up the project. However, after the third year of its installation, the plant's capacity utilization factor improved to 15 per cent because of the introduction of commercial loads. 'As of today, the plant generates about 22 per cent of its rated capacity,' Sutar adds. This means that over the past 14 years, an average of 9 per cent of the annual power generation has been dumped due to a mismatch in demand and supply (see *Table 4: Power generation*).

Further, the plant generates electricity when the flow of the stream is strong. This can be at any time of the day. But the plant lacks a battery bank. So electricity generated during times of the day when demand is lean cannot be stored.

Table 4: Power generation (kWh)

Year	Generation	Utilization	Dump load
2000	16,954	15,179	1,775
2001	15,729	14,300	1,429
2002	16,856	15,148	1,708
2003	15,239	14,230	1,009
2004	17,052	15,629	1,423
2005	23,450	16,560	6,890
2006	24,290	22,057	2,233
2007	24,710	24,066	644
2008	22,750	21,060	1,690
2009	23,590	21,720	1,870
2010	23,940	23,173	767
2011	24,430	23,055	1,375

Source: CSE analysis

Operation and maintenance

The supplier of the equipment for a plant provided training along with a set of tools to a select group of personnel from the village. Prior to the commissioning of the plant, all families in the village were educated about the project. They were given lessons on the judicious use of electricity and in caring for the plant.

Over the past 14 years, the annual maintenance expenditure of the plant has on average been ₹15,000. Villagers saved ₹3 lakh in labour cost out of the total allocated cost of ₹13.5 lakh. There are three operators in the village who are on rotational duty for 10 days each in a month. They earn about ₹150–200 per month.

The villagers are aware of the bulk cash they would need after a decade or two to replace major components of the hydro plant. This has prompted them to start saving—people in Putsil are planting cash crops to raise money. Further, to take care of recurring maintenance, the village residents have contributed to a savings account that now amounts to about ₹7,00,000.

High incentives

Women are the main beneficiaries of such rural electrification. They no longer have to rush home from the fields to cook before dark. Kitchen appliances running on electricity have taken care of backbreaking work such as pounding and grinding cereals. Villagers have also installed a 3-HP rice mill in the village.

People in the village would go to bed by 7 p.m. to save on kerosene. Now they can attend to household chores at leisure, watch television at the village community centre and enjoy other recreational activities. Children take an interest in their studies as they no longer need to study by candlelight, and the quality of cooking has improved. With the setting up of the rice mill, there has also been an increase in income-generating activities. Most families now generate an additional income of ₹10,000–12,000 a year.

For domestic use, electricity is supplied at 6–10 p.m. and 3–6 a.m. For the rice mill to run, it is again supplied at 6–8 a.m. The early morning power supply was demanded by women so that they could complete their household chores before leaving for the fields. During marriage, childbirth, serious illness and festivities, power is supplied as per requirement. ■

CASE STUDY

Powered by husk

Off-grid biomass plants light up villages; experts demand clarity on tariff regulation

Two 32-kW off-grid biomass gasification units in Sahebganj means that the village gets electricity in the evening and businesses such as the tea shop (above) are doing well.

It is 10 p.m., too late by village standards. But the four benches around Mote Singh's tea stall are occupied by people chatting and sipping tea. About a year ago, the stall in Sahebganj Village, in Bihar's Muzaffarpur district, would be empty by sunset. Singh's fortune has been illuminated by a 15-watt CFL. The village has an electricity grid but supply is negligible. 'Managing with kerosene lamps was expensive,' says Singh, the sole earner of a family of five. He used kerosene to light his house, which cost him ₹250 a month.

In June 2011, life changed for many in Sahebganj as they started getting electricity every day from 6 p.m. to midnight. Patna-based Husk Power Systems (HPS) installed two off-grid biomass gasification plants of 32-kW capacity each in the village. These plants convert solid biomass into gas used to generate electricity (see *Box: How biomass gasification works*). Each plant uses 300 kg of rice husk a day to power 40 per cent of the households in Sahebganj.

HPS charges ₹50 per household a month for a 15-watt connection for six hours a day. Money is collected in advance. Plant operators say village residents require power for only six hours. By mid-2012, HPS had set up 80 such plants of varying capacities across Bihar.

Table 1: Project synopsis

Location	Sahebganj Village, Muzaffarpur district
Size of power plant	32 kW
Number of households	400 connections
Overall cost of project	₹18,00,000
Tariff	₹30 for 100 W
LCOE	₹6.90
Implemented by	Husk Power Systems
Funded by	MNRE and Husk Power
Energy services for	Lighting, television, flour mill
Grid interconnectivity	Not grid-ready
Grid presence	Yes

HOW BIOMASS GASIFICATION WORKS

Biomass gasification is the conversion of biomass into a combustible gaseous mixture. In a reactor, commonly known as the gasifier, biomass undergoes chemical reactions under controlled air supply. First, drying of biomass takes place in the uppermost part of the gasifier. Biomass is heated at 90–100°C to remove its moisture. Then pyrolysis takes place, where dried biomass gets heated from 300°C to 400°C and volatile combustible matter is released. This leaves behind a carbon residue called char. The volatile combustible matter contains non-condensable gases and condensable oils like tar. In the third step of oxidation, controlled oxygen is provided that burns the volatile matter and char. When all the oxygen is consumed, a reducing atmosphere is created. In the reduction zone, the carbon dioxide and water vapour produced in the oxidation process get reduced to carbon monoxide, hydrogen and methane which essentially form the producer gas. Water is used to cool and clean the producer gas. Cleaning takes place through condensation. The gas is further cleaned through filters. Finally, the gas is fed into a gas engine which converts it into electrical energy.

When small is better—almost

With big grid-connected biomass plants suffering from feedstock issues, the Union Ministry of New and Renewable Energy (MNRE) is pushing for small off-grid plants. 'They need less biomass, and villages prefer selling it to developers because they get electricity.' says D.K. Khare, director of biomass gasification, MNRE.

Although most experts hail the HPS model, there are a few critics. Sunil Dhingra, senior fellow at Delhi-based NGO, The Energy and Resource Institute (TERI), says that developers are charging unreasonably because of unregulated tariff for off-grid energy solutions. A back-of-the-envelope calculation by researchers from the Centre for Science and Environment shows that HPS charges ₹18.51 per unit from consumers in the village. This is when an average urban consumer pays ₹4 per unit for conventional energy. 'States should decide on a reasonable tariff and subsidize it,' suggests Dhingra. 'For instance, if the government decides on ₹10 per unit as tariff and the cost of generation is ₹13, the balance (₹3) should be subsidized, he says.

Ratnesh Yadav, co-founder of HPS, clarifies: 'We operate in a market where if we charge irrationally someone will replace us,' he adds. The people of Sahebganj are happy with the tariff. 'It is cheaper than kerosene and diesel,' says Sohan Ram, who has a 30-watt connection. For diesel-operated energy, a 15-watt connection costs ₹100 for

People would prefer uninterrupted electricity supply if tariff were reasonable

four hours. Despite large-scale availability of biomass and the subsidies provided by MNRE, the power developers are charging high tariffs, says Dhingra. The ministry gives a capital subsidy of ₹15,000 per kW and ₹1 lakh per km for a transmission line up to 3 km. Going by this, if HPS—which claims that its 32-kW plant costs ₹18 lakh—avails the maximum subsidy, 45 per cent of its cost is subsidized.

The developer differs. 'It costs me ₹7 to generate a unit of power,' says Yadav. Comparing off-grid renewable energy solutions with grid-connected conventional power to calculate per unit cost is irrational, he adds. 'Our tariff is inclusive of transmission and service cost, which is not present in grid-connected power.'

Greenpeace India, which advocates the HPS model, proposes an alternative: the government should set up small distribution networks (mini-grids) in villages. 'It can enter into a power purchase agreement with the developer to buy power at a preferential tariff from the developer and collect the standard tariff amount from the consumer,' says Manish Ram, renewable energy analyst with Greenpeace India. Suppose that the government is buying power at ₹10 per unit from the developer, it can charge ₹4 per unit from the consumer and subsidize the rest over a period of time, until they reach grid-parity (the point at which the cost of renewable energy equals the cost of utility power from conventional sources). Later, the mini-grids can be interconnected with the main grid.

But an MNRE official, who wished to remain anonymous, says that HPS is charging what people can pay. The debate is useless because the Electricity Act exempts developers from taking any licence to provide power in rural areas. 'The Act also says that tariff should be decided by the electricity regulatory commission after consultation with the consumers,' says Ashwini Chitnis, senior researcher, Prayas Energy, Pune. The developer should not be given free hand, she adds.

HPS says that it consulted Sahebganj residents before deciding on the ₹50 tariff. Decentralized distribution guidelines of the Union Ministry of Power say that tariff in an off-grid village should not be more than that in the neighbouring grid-connected village.

Ram, along with rest of the residents of Sahebganj, says he would prefer an uninterrupted full-day supply of electricity, if tariff is reasonable. But developers say this would increase generation cost which will have to be passed on to the consumer. 'If a developer runs the plant for the whole day, an optimum load needs to be maintained. If tariff increases, people may reduce power consumption. The unused power is a cost to the developer,' says H.S. Mukunda, senior scientist at the Indian Institute of Science, Bengaluru. To match the extra load, small industries can be set up in a cluster of villages, he adds. The developer may then charge higher tariff from the industry and lower tariff from domestic users. 'Such an experiment is yet to happen,' says IIT-Delhi professor Sangeeta Kohli, who has worked as a consultant with biomass power developers.

Government no-show

In 2012, the World Bank published a report on the status of MNRE's Village Energy Security Programme (VESP) under which off-grid biomass plants were set up across India. The report, 'India: Biomass for Sustainable Development', states that since 2005, when VESP started, only 45 of the proposed 95 projects have been commissioned. Most of the commissioned projects were closed for long periods because of poor after-sales service. Other reasons include inadequate training and lack of interest among people in operating the plant and supplying biomass due to absence of incentives. VESP was discontinued in 2009. N.P. Singh, director of biomass, MNRE, says projects failed because people did not take responsibility.

Kohli says that to increase acceptance among people for off-grid energy solutions, employment generation is the way to go. Yadav of HPS agrees. He says, 'We have employed women to make incense sticks out of char, a byproduct of biomass gasification.' Of the total biomass used in a gasifier, 40 per cent converts into char.

Technological glitches

A major problem in the gasification process of biomass is the production of tar and wastewater. The gasifier runs best on woody biomass because light biomass, like rice husk which is used in most plants in Bihar, can choke the reactor where combustion takes place.

Rice husk has the highest ash content (20 per cent) among all the agricultural residues used in gasification process. If this husk is burnt at the regular temperature of 1,000°C in the gasifier, ash produces clinkers that jam the reactor. To avoid clinkers, temperature has to be lowered to 850°C. This drop in temperature results in more tar.

To reduce tar, briquetting technology has to be used. 'If husk is made into briquettes of appropriate size, say, 5 cm x 5 cm, it will reduce the surface area of biomass which is inversely proportion to tar production,' explains Mukunda. Briquettes also increase the density of husk, facilitating its flow inside the reactor. In its original form, husk gets stuck inside the reactor. Despite the positives, developers stay away from briquetting machines because they increase operation cost by 30 per cent.

Yadav of HPS says, 'We regularly clean our system and mix the tar with char.' Inside the gasifier, water is used to clean the gas of impurities by cooling. Impurities either condense or get dissolved in water. This water can be used for a month in the system, after which it becomes saturated with impurities. 'It needs to be treated before letting it out of the system,' says Mukunda. With no checks in place, plants often avoid it.

For HPS, efficiency is not a priority. Most existing plants are based on the basic technology with 65 per cent efficiency. 'Technology with up to 85 per cent efficiency is costly and requires skilled and expensive manpower,' says Yadav. A 35-kW plant with 85 per cent efficiency would cost ₹30 lakh. 'Our priority is to give employment to village residents, who may not be able to operate plants based on a sophisticated technology,' he adds. ■

CASE STUDY

The Chhattisgarh way

The state has a fifth of all the solar-powered villages in the country

Deba village had its last power black out in 2010

Tucked away in Barnawapara Wildlife Sanctuary of Chhattisgarh is a small village, Deba. The national power grid is still to reach there. But there is no interruption in the scheduled power supply to its 75 households.

Power cuts are frequent in grid-connected villages across the state, but the only time Deba residents experienced a blackout since they started receiving electricity since 2003 was in October 2010. Phool Devi, in her 40s, recalls that the black out was caused by powerful lightning that hit the power transmission cables and damaged the inverter of the solar power plant. The government officials replaced the inverter within two weeks and the village was illuminated again just before Diwali.

The 4-kW solar power plant that uses photovoltaic cells to tap solar power generates 28 units (1 unit = 1 kWh) of electricity a day. It is sufficient to light all the houses and lanes of Deba with CFLs (compact fluorescent lamps) for seven hours—it does so from 4–6 a.m. and from 6–11 p.m. Devi says the solar power plant, installed by the Chhattisgarh Renewable Energy Development Agency (CREDA) in 2003, has been a boon to the village residents who had always relied on kerosene lamps and lanterns.

'Now that the village has streetlights, I do not fear snakes or wild animals in the night,' Devi says with a smile. She is happy that her children now study even after nightfall.

Deba is one of the 50 villages and hamlets dotting the dense Barnawapara forest that benefits from the solar power plants installed under the Remote Village Electrification Programme (RVEP) of the Union Ministry of New and Renewable Energy (MNRE). The programme, as the name suggests, aims to electrify villages and hamlets in remote and difficult areas, such as forests, hills and deserts, which are not feasible to link, using renewable energy, with the national grid. Solar power is popular for such electrification due to its abundance and the simple plug-and-play nature of the technology.

But solar off-grid projects under RVEP have been reported to be not so successful across the country, Chhattisgarh being the only exception. With assured illumination to 1,400 remote villages, the new state boasts of being home to over one fifth of the solar-powered villages across the country, reckon MNRE officials.

Tanushree Bhowmik, programme director (energy) of the United Nations Development Programme-India, says that renewable off-grid projects tend to fail in most remote villages because of lax monitoring and poor maintenance of installed systems. Though states are responsible for installation and maintenance of off-grid power generation systems, most lack the intent to monitor. There have been reports of systems getting stolen or lying defunct in several states, she adds.

Chhattisgarh went the extra mile to ensure that installed solar systems remain functional. In 2003, CREDA installed Solar Home Lighting Systems (SHS) in 500 villages. It also set up micro-grids wherever possible and introduced a standardized operation and maintenance system for solar power.

Initial hiccups

SHS is an assembly of 37 Wp (Watt-peak) solar panels, cables, an inverter, a battery and two 11-watt CFLs. 'More than half of the panels got stolen within a year. Some were even sold or mortgaged for money, says S.K. Shukla, director of CREDA. A survey in 2004 showed that of the 617 solar panels installed in tribal hostels, ashrams and primary health centres, 500 were stolen. This is when CREDA opted for micro-grids.

'Micro-grids require more investment from the state exchequer because the subsidy by MNRE is limited to ₹18,000 per household covered by the micro-grid. But they prevent theft and require minimal maintenance,' Shukla adds.

As per the estimates of CREDA, a solar module of 37 Wp costed about ₹14,000 when the projects were being implemented. Factor in the 90 per cent subsidy by MNRE and each module costs the state ₹2,750. Compare this with the cost of setting up a micro-grid (solar photovoltaic power plant and transmission cables) per household, which is approximately ₹25,000. The state shells out about three times the amount for a microgrid than a solar home lighting system. CREDA installed its first micro-grid in 2004.

Status of micro-grid implementation

As of June 2013, 1,476 remote villages, including 622 hamlets, in Chhattisgarh have received electricity through micro-grids (see *Table 1: Micro-grids in Chhattisgarh*). The total capacity (including micro-grids and solar-powered water pumps and street lights) adds up to 3,066 kW, serving about 58,000 households in the state. Such installations have also been set up in tribal hostels (1,633), rural health centres (446) and remote police camps (256). The rest of the villages and hamlets, where houses are scattered, have been provided with solar home lighting systems. 'It is not feasible to invest in wiring over long

Table 1: Micro-grids of CREDA

Implemented under the Central government programme till June 2013

District	No. of villages/ hamlets	Beneficiary	Un-electrified villages
Raipur	0	0	0
Gariaband	128	4,265	0
Baloda Bazar	22	1,535	0
Mahasamund	5	165	0
Rajnandgaon	51	1,401	0
Durg	0	0	0
Balod	0	0	0
Bemetara	0	0	0
Kabirdham	67	2,795	0
Bilaspur	50	1,216	0
Mungeli	45	2,413	0
Raigarh	12	552	0
Korba	238	9,142	0
Janjgir-Champa	1	62	0
Sarguja	15	721	0
Balrampur	2	306	0
Surajpur	42	2,066	0
Jashpur	183	7,262	0
Koria	123	6,354	0
Dhamtari	41	1,911	0
Kanker	114	3,179	0
Kondagaon	5	324	0
Jagdalpur	44	2,037	5
Sukma	4	430	125
Dantewada	215	8,562	36
Narayanpur	9	170	131
Beejapur	23	1,100	109
Total	**1,476**	**57,968**	**406**

Source: Chhattisgarh Renewable Energy Development Agency

Most households now require more than the lighting that was initially provided to them

distances in scattered villages,' says Shukla.

The state depends on funds under RVEP. Since 2001, when the programme was first initiated by the Centre, the state received about ₹34.35 crore under the programme from the Centre. Although, it is claimed that the funds from the Centre cover up to 90 per cent of the capital cost, the ground reality is far from this.

CREDA uses standard specifications while setting up micro-grids in remote villages. 'There are so many projects on the ground that a certain standard design for the micro-grid has been evolved out of the experience. Currently CREDA follows these specifications but can differ as per the village,' says Sanjeev Jain, chief engineer, CREDA. CREDA designs micro-grids to support two 11 Watt CFLs which is the norm suggested by MNRE. Although the system specifications set by MNRE are met in the process, the benchmark cost that is set by MNRE does not match with the actual costs (see *Tables 2* and *3: Specifications for solar micro-grids* and *Cost of setting up a solar micro-grid*). In many cases, the benchmark of MNRE only matches with the system cost. This means that the cost of other capital infrastructure, such as control room, fencing and public distribution network, has not been included.

Table 2: Specifications for solar micro-grids

Capacity (kWp)	Households	Proposed load per household (in watts)	Maximum connected load (in watts)	Street lights	Battery bank
1	10	60	600	3	300 Ah/40 V
2	20	60	1,200	6	600 Ah/48 V
3	30	60	1,800	9	800 Ah/48 V
4	40	60	2,400	12	600 Ah/96 V
5	50	60	3,000	15	800 Ah/96 V
6	60	60	3,600	18	1000 Ah/96 V
8	80	60	4,800	24	800 Ah/120 V
10	100	60	6,000	30	1,000 Ah/120 V

Source: Chhattisgarh Renewable Energy Development Agency

Table 3: Cost of setting up a solar micro-grid

Capacity (kWp)	System cost (₹ lakh)	Cost of control room (₹ lakh)	Cost of fencing (₹ lakh)	Cost of public distribution network (₹ lakh)	Operation and maintenance for 5 years (₹ lakh)	Total project cost (₹ lakh)	Net cost per watt (₹ lakh)	Benchmark of MNRE —cost per watt (₹)
1	2.23	1.80	0.24	2.08	0.69	7.04	704.00	315
2	4.68	2.25	0.36	4.16	1.38	12.83	641.50	315
3	7.15	2.70	0.48	6.24	2.07	18.64	621.33	315
4	9.56	3.00	0.56	8.32	2.76	24.20	605.00	315
5	11.80	3.40	0.60	10.40	3.45	29.65	593.00	315
6	14.67	3.75	0.72	12.48	4.14	35.76	596.00	315
8	18.02	4.25	0.80	16.64	5.52	45.23	565.38	315
10	22.60	4.80	0.86	20.80	6.9	55.96	559.60	315

Source: Chhattisgarh Renewable Energy Development Agency

Table 4: Projects set up by creda

Details of a few projects under the CREDA model. The state government of Chhattisgarh had to chip in for a significant part of the costs

Site	No. of households	Capacity (KW)	Cost of PP (₹)	Cost of PDN (₹)	Total (₹)	Share of MNRE (₹)	Share of GoCG (₹)	Per cent share of MNRE
Surve	43	3	13,68,000	4,09,066	17,77,066	7,74,000	10,03,066	43.55
Bimalta	60	5	23,54,000	6,56,057	30,10,057	10,80,000	19,30,057	35.87
Dokarmana	51	4	19,01,000	5,46,829	23,57,829	9,18,000	14,39,829	38.93
Hirvadoli	40	4	19,01,000	2,84,888	21,85,888	7,20,000	14,65,888	32.93
Tapara	34	3	13,68,000	2,84,655	16,52,655	6,12,000	10,40,655	37.03

Source: Chhattisgarh Renewable Energy Development Agency

The benchmark cost is only 32–44 per cent of the net cost of the project. A 90 per cent subsidy on these costs suggests that only 28–36 per cent of the actual net project cost is covered by the Central government (see *Table 4: Projects set up by CREDA*).

Maintenance and servicing

CREDA envisaged a three-tier system for maintenance and servicing. An operator was chosen from each solar-powered village to clean solar modules every day and repair any wiring glitches. For this, he charges ₹5 from each house a month. For regular maintenance of batteries and inverters and for fixing technical problems, CREDA enrolls an operation and maintenance contractor, who appoints a cluster technician for every 10–15 villages. The technician directly receives a payment of ₹25 per household per month from the state government. This is equivalent to the subsidy that the Chhattisgarh government provides to families below the poverty line in grid-connected areas for availing one unit of electricity a day.

'The technician files a monthly monitoring report for every solar installation. The solar equipment that are not working and the problems associated are also recorded," says Shashi Dwivedi, an operation and maintenance contractor.

The third tier is managed by CREDA, which monitors all installations through monthly reports and replaces equipment in case of major breakdowns like that in Deba.

'Not many states have asked for large-scale solar system connections like in Chhattisgarh,' says Moola Ramesh, deputy general manager of Tata BP, a leading solar equipment manufacturer in the country, now known as Tata Power. Even states that install solar systems hardly seek maintenance, he adds.

Lighting is not enough

Though solar power provides illumination, its limited capacity does not meet the demand of complete electrification. Consider this. Kaya Bara, the village neighbouring Deba in Barnawapara sanctuary, has a 3-kW solar power plant that generates 24 units of electricity a day. Till two years ago it was sufficient to light 45 households in the village for eight hours a day.

Now with three TV sets in the village, the load on the grid has increased and residents get light barely for two hours a day. The operator, Monu, blames those who own TV sets for the load-shedding as a TV set can gobble up the entire 24 units of electricity in just a couple of hours. But there is no let up in their use. Instead, more residents in Kaya Bara are planning to buy TV sets and other electrical equipment, like fan and water pumps.

Discontent with limited electrification is palpable across solar-powered villages. Take, for instance, Kalaar Baahra, a tribal hamlet in Dhamtari. Each of the 15 houses in the hamlet has a solar home lighting system. In 2010, the government declared it electrified. Residents still demand link to the grid, just half a km away.

Illumination is not sufficient, says Itwarin Bai, in her 50s. She likes the solar panel on her rooftop, but is envious of the people living in a village half a km away who have access to the grid. 'Bada bijli matlab bada aamdaani (grid electricity means more income),' she says. 'Solar-powered pumps are very expensive. We cannot afford them. If we have access to the grid we can buy the regular water pumps and grow vegetables even in summers like people in the neighbouring village. We can also draw water when the level dips,' Bai explains.

Limiting energy services

Villagers in Mohda say they would prefer the grid electricity over the electricity that is being supplied by solar panels since the panel only provides electricity for a maximum of one to two hours in a day. This was because the generation was below the rated capacity.

The plant was designed to cater to 70 households in 2004. Currently, there are around 180 households in the village, with more connections. But the supply has not been enhanced beyond 4 kW. Now 700–800 people live in the village.

In Mohda, the capacity was not enhanced as the Central government programme does not have scope for enhancing the capacity and the state government resources are limited. Increase in capacity has to be able to balance the growing demand, which is currently lacking in the model.

The limited supply of electricity does not suffice for the lighting needs of the beneficiaries in the village who continue to buy kerosene for lighting. An average household spends ₹15 per litre of kerosene through their ration card, which allows two litres, and ₹25 per litre for the remaining four to six litres that is still required for lighting. On the whole, a household spends ₹150–180 a month for lighting through kerosene and ₹5 per month for lighting through solar. Wood is still used for cooking.

A few km away, another village, called Bar, located within the Bar-Nawapara Wildlife Sanctuary, also had installed a 4-kW micro-grid. But it was generating just 5 units of electricity per day against the claim of 16 units per day. This was too little for people who relied on solar pumps for growing vegetables.

The Centre now plans to resettle the people of Bar in a neighbouring grid-connected area as part of its plan to shift people living within wildlife sanctuaries to outside areas. The households do not oppose the move because they look forward to the grid connection in the new village along with other benefits—about two hectares of farm land, ₹50,000 and a house for all the families.

CREDA has electrified many villages. But most other states have not been able to follow suit. The observations in the villages visited were that one to two hours of electricity for just lighting is not adequate to address the issue of rural electrification. Households continue to use kerosene, though in reduced amounts, for lighting. Another issue is that once the micro-grids are installed, these villages are deemed electrified on government documents, no matter whether micro-grids fulfil needs of the people or not. These villages then are not eligible for any other sources of electricity. In village Rawan, after an installation of 7 kW micro-grid, the village is not getting a grid extension.

Pitfalls and the way ahead

Managing the load is more important than the total capacity because only 30 per cent of the capacity is currently utilized. Very often, households overload the lines, and it trips the voltage. This happens at least once a day, so a lot of generated electricity goes without being utilized.

Demand is growing and peaking, but the plants are not designed for peak demand. Inverter and system sizing is based on 10 years ago, which is completely different from the situation today. This is largely because people now use the power for applications other than lighting. Their aspirations have increased and the current model of electrification does not take this into consideration.

Researchers from Centre for Science and Environment (CSE) found that the plants were operating at only one-third of the capacity. This is largely for two reasons. First, overload and voltage trips lead to frequent plant shut-downs. By the time the operator reaches for checks, there has been no electricity for hours. The operators are paid on the basis of number of days of operation rather than operation on an hourly basis. Secondly, systems were designed for taking only lighting needs into consideration and without factoring in aspirational needs and increasing population.

Capacity enhancement is not able to keep up with the growing demand. When a system is installed, it has to be oversized many times. Anticipating the demand for one and half years involves huge capital costs. Even the Census data for the villages is around 10 years old. They do not have demographic data about the number of mobile phones, TVs, fans and lights in the villages to estimate the demand.

There are discussions on how to reform the system to meet the increasing electricity needs of households. One of the ideas is to involve the private sector and provide tariff for every unit of electricity that has been consumed by the households.

Under this model, the consumers are charged for electricity but at a rate lower than the actual cost of generation. This gap will be provided by the state to make the model viable. ■

CASE STUDY

Gram Oorja: Renewable Energy Solutions

A working pilot based on CSR funds

Gram Oorja installed a 9.8-kW solar-PV-based mini-grid to electrify 36 households

Darewada is a remote hamlet about 100 km from Pune, in Khed Taluka of Pune district. Until August 2012, its residents depended solely on kerosene for their lighting needs. In early 2012, Bosch Solar Energy AG and Gram Oorja Renewable Energy solutions, both based in Pune, stepped in to the village through a partnership in order to provide basic electricity requirements with a solar-based micro-grid (see *Table 1: Darewada—a project synopsis*).

Table 1: Darewada—a project synopsis

Location	Darewada , Pune, Maharashtra
Size of power plant	9.36 kW
Number of households	36 connections + street lights + pumps
Overall cost of project	₹30,00,000
Tariff	₹20 per unit (prepaid meter)
LCOE	₹22
Implemented by	Gram Oorja
Funded by	CSR fund from Bosch solar
Energy services for	Lighting, television, irrigation
Grid interconnectivity	Not grid ready
Grid presence	No

Gram Oorja Renewable Energy Solutions, headquartered in Pune, was founded by four graduates with diversified backgrounds and a keen interest in approaching the problem of energy access in rural areas by creating a local micro-grid based on renewable energy sources (solar, biogas, biomass, small wind, micro hydro etc.). Anshuman Lath of Gram Oorja said, 'Villagers

Table 2: Costs involved in the micro-grid project

Capacity (kWE)	Panel cost (in ₹ lakhs)	Battery cost (in ₹lakhs)	Inverter cost (in ₹lakhs)	Cost of fencing (in ₹lakhs)	Cost of public distribution Network (in ₹lakhs)	Other costs (in ₹lakhs)	Total project cost (in ₹lakhs)	Net cost per watt (in ₹)	Benchmark cost of MNRE per watt (in ₹)
9.36	6.75	2.65	6.5	0	5	9.1	30	320.51	300

Source: Interview with Gram Oorja executive

pay a fee for the use of the energy, which in most cases is enough only for the operations and maintenance (O&M) of the system. Therefore, the capital expenditure for setting up the micro-grids is entirely dependent on grants or subsidies.'

The power plant provides lighting to all 36 households in the hamlet, with 17 poles erected to help provide power distribution. 'Due to the solid rock foundation in most areas in the hamlet, they had to be blasted in order to fix the poles, and these measures were adhering to Maharashtra State Pollution Control Board standards,' Lath said.

Every household has a basic connection of one 2-watt LED light and two 4-watt LED lights. 'Some of us could afford a TV set, and there are currently seven TV sets in the village,' says Vijaya Borhade, a resident of the village. Apart from these, there are ten street lights with a 12-watt LED light each. 'A 2-HP water pump has been proposed to be added due to the demand by the residents of the village,' said Priya Purwar of Gram Oorja. The entire distribution system is designed at 230 volts AC, at 50 Hz frequency, single phase. Twenty-four Amaron batteries of 600 Ah, 48 V are placed in the control room right next to the power plant to provide power during night.

The entire cost of the project, including equipments, was borne by Bosch Solar. The overall cost of the project, including infrastructure, transport of material etc., was ₹30 lakh. The land for the project (about 50 x 30 feet) was donated, free of cost, by a resident, Shivaji Shelke. This is the first pilot for both the parties and learning from the project will help reduce the cost at least by 5 per cent in the next one provided land is free (see *Table 2: Costs involved in the micro-grid project for the breakdown of the cost of the major components*).

24 x 7 electricity but at high tariff

The electricity generated is currently being used for residential as well as commercial applications—there is no break up of the electricity allotted for commercial and residential purposes. Power for residential applications is available throughout the day. Commercial application has a time restriction and can be used only between 11 a.m. and 4 p.m. under peak condition.

Electricity tariff has two components—fixed and variable. The fixed component is the same for both domestic and commercial connections, at ₹90 per month per connection. The variable component is charged at ₹20 per unit. However, due to small consumption levels and high per unit cost, 0.1 kWh is considered as one unit for which ₹2 is charged. An energy metre is installed against each connection and collection is carried out as per the metre reading. Most residents pay an average monthly bill of ₹100–140. Those with a TV pay more, depending on usage. One villager had to pay ₹480 for a month for the electricity consumption. To prevent overdrawing of power, a protection unit or load checker has been installed with each energy metre. Anil Lau, a resident of the village and the trained operator of the power plant, carries out the collection.

O&M expenses are fully recovered

Having completed nearly one year (i.e. 11 months) of operation at the time of the CSE visit, the plant had generated about 3,230 kWh. This points us to an average daily generation of around 9.7 kWh per day, meaning that the company is able to generate at least ₹70,000 of revenue per year, excluding the fixed costs. Adding the fixed cost of ₹90 per connection per month for 36 households, the annual revenue collection goes up to ₹1.38 lakh per year. This means the company would be able generate enough revenue for all O&M expenditure including replacement of batteries in a cycle of four to five years. The plant is currently operating at a very low plant load factor and has the ability to cater to a larger demand and earn more revenue.

The collected revenue is currently deposited in a trust bank account—Vandev Gramodyog Nyas—which has been opened in order to take care of O&M expenditure of the project. The operator has another job—farming—for the most part of the month. 'As an operator, I am being paid a very small sum of ₹300 per month due to the few hours of work required per month. I am primarily a farmer,' said Anil.

The plant experienced its first monsoon this year and, as expected, the system managed to tide over the rains. The villagers noted that there was only one occasion when the plant did not function for little over a day because the battery had got completely drained because of an elaborate function with speakers and amplifiers the previous night. So loads were disconnected from the system and the batteries were allowed to get charged for a day.

'The TVs are used almost every day,' said Borhade, a local youth. They are usually on for an hour or so, but occasionally run for much longer. Borhade said further, 'I am happy for the younger generation. They can now study under electric lights.'

Bhimabai, another resident said, 'We can cook comfortably at night. My children can play outside freely in the evenings.'

The residents are upbeat about the solar power system, which has impacted their lifestyle and happiness positively. 'We feel connected to the rest of the world as we follow the news and many cricket matches,' says Sudhatai Lande, deputy sarpanch of the village.

Meeting capital expenditure through grant—a challenge

Having successfully implemented the pilot project, Gram Oorja plans to execute 10 micro-grids in the next year, providing 24/7 electricity. They intended to target 1,000 villages after satisfactory demonstration of the commercial viability of the pilot projects in another three to four years. The company is in discussions with villages in several parts of central India, mainly Bundelkhand and Madhya Pradesh, to educate the people about this non-conventional method of electrification. Initial surveys have also been completed in several villages in north Kanara district of Karnataka, where the company has identified the design, resource for power generation and demand, and estimated the funds required for each of these villages. However, nothing much is happening on the ground for the want of upfront grants. ■

CASE STUDY

Solaris—funded by Grand Lodge of India

A philanthropic attempt turned futile

Solaris put up a 7.2-kW mini-grid to supply power to 80 households

Village Fughala in Kasara Taluka of Thane district is approximately 105 km from Mumbai and about 30 km from Kasara, off the Mumbai–Nashik highway. The village has fewer than 100 dwellings. About a kilometre from this village is Anghanwadi, another village similar to Fughala. Both villages are in a valley connected by a kachha road to the rest of the world. In June 2011, solar power plants of 3.6 KW_E were commissioned in each of these villages by Solaris to provide basic lighting to villagers. The project was funded by Grand Lodge of India (GLI), an association of free masons called jyotirgamaya, and funds were collected through donations.

Micro-grids will not sustain without a clear business model

Every household was fitted with one 11-watt CFL lamp to provide the basic lighting needs and each village was given four streetlights. Each project cost around ₹5 lakh which was funded by GLI. There were 15 panels of 245 watt each arranged in three arrays. Lines were drawn from each of these arrays to connect 25–35 households, depending on the village structure. The power provided to the household was free of charge.

One villager was trained to operate the plant. 'I was only taught the basics of how to turn off a particular line in case of overload. I would also turn off the line if the batteries had not charged properly and turn them back on later,' said Sitaram, the operator. 'I am a taxi driver, and usually remain busy everyday after 10 a.m. I check the solar power plant before and after my service. I can check faults in wiring and minor external troubles. When the charge controllers or the batteries fail, I have to call the developers for a maintenance check.' he added. He has a mobile phone and the villagers generally inform him in case of problem. He is not paid for his service.

'The maintenance provided by Solaris is very poor,' complained Sitaram. 'It takes them at least a month to respond to any complaint and sometimes we have to make do

Table 1: Fughala and Anghanwadi—a project synopsis

Location	Fughala and Anghanwadi, Thane, Maharashtra
Size of power plant	3.6 KW x 2
Number of households	80 x 2 connections
Overall cost of project	₹5,00,000 X 2
Tariff	Nil
LCOE	–
Implemented by	Solaris
Funded by	Grand Lodge of India (GLI) Grant
Energy services for	Lighting
Grid interconnectivity	Not grid-ready
Grid presence	No

Table 2: Power schedule

Time slot	Power availability
7–9 a.m.	Available
9–11 a.m.	No power
11–3 p.m.	Available
3–6 p.m.	No power
6–7 p.m.	Available
7–9 p.m.	No power
9–11 p.m.	Available
11–7 a.m.	No power

Total hours without power: 15

Source: Residents of Anghanwadi and Fughala

ourselves, specially the CFLs given to us. About seven months ago, two of the three lines in Anghanwadi stopped working. At first I thought there was a problem with the inverter and tried to fix it myself as the company technician did not turn up. Now, I feel there must be a problem with the wiring. I tried to check and fix it but could not. The lines have not been working since then. The problem worsened when children got access into the power plant when I was away and now it is a complete mess,' he added.

The technician from Solaris has not showed up even once in the last seven months. However, the third line to Anghanwadi is still working and powering about 27 households. In Fughala, however, the entire system stopped working and villagers had to go back to kerosene lamp and lanterns.

RGGVY failed to meet needs and aspirations

A few months ago, both the villages were electrified under the RGGVY scheme and the villages were happy to receive grid power. They could use more electrical and electronic appliances and demand in both villages has gone up significantly. The solar power plant remained unused except for the single line in Anghanwadi supplying power to 27 households as a back-up when the grid power fails. 'Power cuts in both villages are regular,' said Ekanath, the operator of the solar power plant in Fughala. The grid power is scheduled for eight hours per day and consumers are charged ₹5 per unit. 'Households generally consume about 9 to 10 units per month if they have TVs and other appliances. Otherwise, consumption does not cross 5 units,' said Sitaram (see *Table 2: Power schedule*).

Both operators feel that Solaris is not interested in operation and maintenance of the solar micro-grids. It is evident that the absence of ownership and revenue mechanism virtually defanged these solar plants and that Solaris will not spend from its own pocket for O&M to keep these systems in order. One resident of Anghanwadi, where the solar powered light is still working, said, 'The light has become much dimmer these days. It flickers a lot and we have to turn it off as the light from kerosene is better then.'

Eight hours of grid power is not consistently supplied either; some months had no grid power at all. As a result villagers had to rely on kerosene for their lighting and cooking needs. 'We spend about ₹150 per month on kerosene for lighting and cooking,' says Dadu Chendar Agan, a villager of Anghanwadi. The TVs and other electrical/electronic gadgets purchased by villagers become useless without any power. ■

CASE STUDY

Grid-ready infrastructure

AC versus DC

A view of the solar mini-grid in Rajanga Village in Odisha

The Energy and Resources Institute (TERI), along with its grass-roots partner, the Institute for Research and Action on Development Alternatives (IRADA) implemented an AC/DC mini-grid project for a cluster of five villages inside the Kandhara Reserve Forest. The total population of these clusters was a little more than 550, comprising around 140 households. The project was funded under Off-grid Access System for South Asia (OASYS South Asia) and Rural Electrification Corporation (REC) in a ratio of 80:20. The total project cost was around ₹60 lakh for the five mini-grids, Rajanga (6 kWp), Kanaka (5 kWp), Baguli (2.4 kWp), Rajanga Hamlet (400 Wp) and Chadoi (400 Wp).

₹60 lakhs were invested in the project, 20 per cent of which was provided by Rural Electrification Corporation (REC) as a subsidy and the remaining paid by OASYS South Asia. OASYS is a research association led by the UK-based De Montfort University to identify techno-economically viable, institutionally feasible, socio-politically acceptable and environmentally sound solutions for decentralized off-grid electricity generation in South Asia. The total project cost includes cost of building a community hall for the villagers as well. The developers estimate that the cost of the project would be reduced by ₹8–10 lakh if we excluded building costs.

These projects are a combination of both AC and DC mini-grids which were strategically planned to accommodate the needs of the people. The people living in villages and hamlets of the Kandhara Reserve Forest have had access to electricity; these

Table 1: Project details

Location	Dhenkanal district, Odisha
Size	13.8 kWp
Year of implementation	2014
Households	140 households
Overall cost of the plant	₹60 lakh
User tariff	₹50 per month
Implemented by	The Energy and Resources Institute (TERI) and Institute for Research and Action on Development Alternatives (IRADA)
Funded by	Off-grid Access System for South Asia (OASYS South Asia)—80% and Rural Electrification Corporation (REC)—20%
Energy services	LED lighting, mobile phone charging, livelihood opportunities
Grid interconnectivity	Grid ready
Grid presence	No

Table 2: Mini-grids installed in the Dhenakanal

Village	AC mini-grid/ DC micro-grid	Power plant capacity	Number of connections (household and public buildings)	Date of commissioning
Rajanga	AC mini-grid	6 kWp SPV power plant, 6 kVA inverter (grid tied), 48 V 500 Ah battery bank	34	5 Jan 2014
Kanaka	AC mini-grid	5 kWp SPV power plant, 5 kVA inverter, 48 V 600 Ah battery bank	39	12 Mar 2014
Baguli	AC mini-grid	2.5 kWp SPV power plant, 2 kVA inverter, 48 V 500 Ah battery bank	32	6 Mar 2014
Rajanga Hamlet	DC micro-grid	400 Wp, 24 V 200 Ah battery bank	14	5 Jan 2014
Chadoi	DC micro-grid	400 Wp, 24 V 200 Ah battery bank	13	11 Feb 2014

projects intended to provide them lighting needs first. According to Debajit Palit of the Energy and Resources Institute (TERI), 'Since the villagers have never interacted with power before, you have to give them some time. Demand projections in these instances become next to impossible.' One major flaw in the system has been that the project does not take into account the aspirational needs of the people.

In addition to lighting and facility for mobile phone charging for all households, the project was also established to provide various livelihood opportunities, such as spices grinders, packaging, 'saal leaf' plate-making, irrigation facilities and installation of fans and street lamps in community areas and institutions. Lalita Pradhan, Member, Village Energy Committee, Rajanga mini-grid project, said, 'We were living on the roots and fruits from the forest and didn't know what light was. Now my children are able to study at school in the daytime and at home in the evening. They even take tuitions in the evening. I am really grateful for the light.'

There was also the question of whether a single mini-grid of a higher capacity should be considered rather than smaller distributed mini-grids. A single system makes more operational sense, but the cost of distribution would have been too large as these five hamlets are at scattered distances. A better-designed model that does not need frequent maintenance made more sense than a centrally located system. However, for the management of the system, a single entity was formed covering the group of villages.

Every household pays about ₹50 per month for the use of five to six hours of electricity in a day. If consumers use the livelihood services, they pay a service charge for each activity as well.

Community-managed projects

As one of the models under the OASYS South Asia, this project was designed so that the community would be an integral part of the development. The idea was not just to provide lighting services to the community but also to generate new activities for the livelihood of the inhabitants. To make sure that the community was involved at every step of the development of the project, a Village Energy Committee (VEC) was formed. This committee was responsible for the operation and management of the project.

Grid-ready infrastructure: distribution network

There is some confusion over what can be deemed as a grid-ready mini-grid project. In terms of distribution infrastructure, the project uses insulated cables for distribution lines and standard 30 feet concrete polls. These are based on the prescribed norms of the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) and are technically sound. They follow all the safety measurements defined by RGGVY.

The project was designed so that when the actual grid reached the village and a transformer or supporting capacity is set up for the supply of power, the distribution lines would be capable enough to carry power to the villagers without any damage to the infrastructure and inhabitants of the village to cater to the existing demand. These distribution lines have been tested by the electrical inspector authorized by the state electrical licensing agency as well.

Grid-ready infrastructure: generation equipment

A mini-grid that is grid-interactive would have an inverter that would draw power from the grid in case there is a deficit, and supply any excess generation back to grid. The inverter that we use in our homes to supply electricity while there is a power outage, in contrast, only charges the battery with power from the grid and supplies electricity to homes when required. It cannot transport excess electricity back to the grid.

In case of this project, SMA inverter has been used in one of the three villages based on AC mini-grid. This has the capability of not just drawing power from the grid but also exporting power back to grid. The SMA inverters are 30 per cent more expensive than regular inverters in the market because of their dual function of drawing and exporting.

AC versus DC

The project includes five mini-grids, two based on AC mini-grids and two on DC mini-grids. The hamlets where DC mini-grids have been set up are very small villages, with just 12–15 households. The DC mini-grid made more sense for power supply for lighting needs as well as rationalizing the costs of transmission lines. Also, these two DC mini-grids have been operating without any issues for one and a half years, since there is

Figure 1: **Monthly kerosene consumption per household**

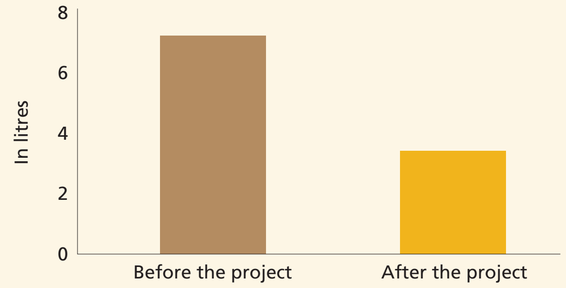
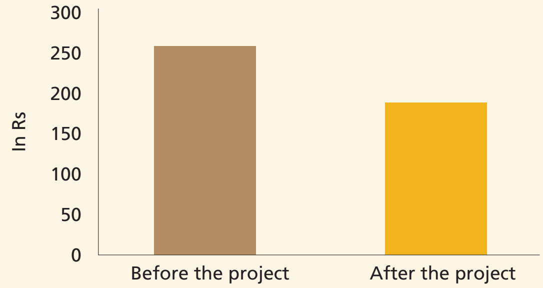


Figure 2: **Monthly household expenditure on kerosene**



Source: Debajit Palit et al. (February 2015), Impact assessment of implementation of solar PV mini-grids in five off-grid villages of Dhenakal district, Odisha, TERI. New Delhi

no inverter in the mini-grid model. Inverters require a lot of maintenance. There is an increased possibility of a short circuit in the system if there is no proper maintenance, especially after rains. DC mini-grids have solar panels and a battery bank and no need for an inverter.

It was difficult for the implementers to explain that the output from both the AC and DC mini-grid are the same, and that there would be no issues as far as power supply is concerned. However, for the other services, such as livelihood opportunities of the marketplace, the people from Rajanga and Chadoi hamlets have to go to the Rajanga village.

Since the villages had both AC and DC mini-grids, it was imperative that the quality and quantity of services provided to each household remain exactly the same.

The project has made a difference in the lives of the villagers. The consumption of kerosene has decreased and there are also savings for villagers. ■

Annexure I

Design of a standalone solar photovoltaic mini-grid system

Villages in India have populations ranging from less than 200 people to over 10,000. In 2011, there were 833,463,448 villagers living in 167,826,730 households—which means five persons per household on an average. On the basis of this household size, we may assume that a small village with 200 villagers (smallest size of village in India as per Census 2011) will comprise at least 40 households (200/5).

Mini-grids can ensure that every household in India has at least 12 hours of electricity. Since solar energy is the most widely available resource, we are trying to provide the technical and economic answers to designing a solar PV-based mini-grid.

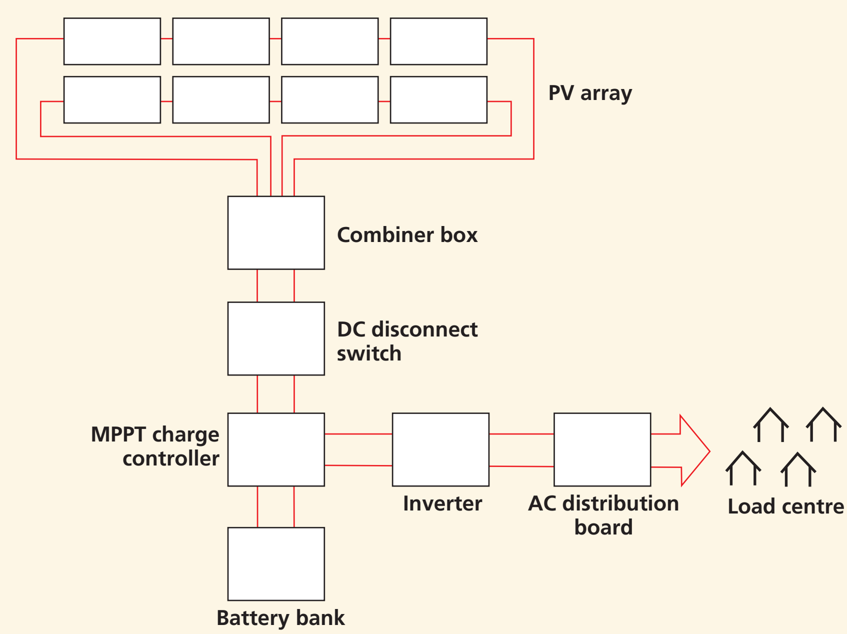
System description

A solar PV mini-grid has several electrical and electronic components. The purpose of a mini-grid is to harness the sun's energy for our domestic needs. In a mini-grid system, the PV modules perform the extraction work and the remaining part of the system is purely management and utilization of the extracted energy. (See *Figure 1: Typical standalone mini-grid system*).

PV array: The PV modules (which when combined will form an array) convert the energy from sunlight into electrical energy. A single module would produce power in the range of a few watts to a few hundred watts. To meet high demands, the modules are connected in many series and are parallel to form a PV array (series and parallel connections are discussed in the section 'Design'). By forming a PV array, the output power is increased to the range of the demand of the users.

Combiner box: A combiner box connects the cables from partially connected PV modules and forms a complete PV array. Apart from array formation, it provides surge

Figure 1: Typical standalone mini-grid system



protection. Surge protection is the process of protecting the components from power surges, which are sudden spikes in power lasting for up to 50 microseconds. Power surges are a common cause of damage to electronic components.

DC disconnect switch: A switch to disconnect the PV array from the system as a protection measure. The DC disconnect switch is usually mounted inside the combiner box.

MPPT charge controller: A critical component to the mini-grid system. It performs two separate functions. The first function is that it charges the battery as per the battery's specification. The power from PV modules cannot be directly connected to batteries because batteries operate in a different voltage than that of the PV modules. Moreover, batteries should not be overcharged or discharged beyond the manufacturer's specification. The MPPT charge controller looks after these working conditions of the batteries. The second function of an MPPT charge controller is to operate all the PV modules at its maximum power point or MPP (MPP is discussed further in 'Design' section). In other words, it will extract the maximum possible power from the PV array.

Battery bank: The main difference between a standalone and a grid-connected PV system is the battery. For a standalone PV system, batteries are crucial to provide power when there is no sunshine, especially nights. The storage capacity of a single battery is far less than the energy range of a mini-grid system. Therefore, similar to PV array, the batteries are connected in several series parallel to each other for an array of batteries, which is commonly referred as a battery bank.

Inverter: The function of an inverter is power conversion, i.e. converting DC power (that is generated by the PV array) to AC. Up to the battery bank, the power is in DC. However, most home appliances, such as fans and lights, run in AC power. (Note: The power in our homes from the state DISCOM is in AC.) For this reason, the DC power from batteries is converted to AC before distribution. Inverter not only converts power, but also delivers AC power at the national standard (grid standard) of 230V, 50Hz. Note: Power flows in two different forms—alternate and direct current (AC and DC).

Load centre: A load centre is the collection of households in a village where generated power is delivered. An energy metre is usually connected to each house to monitor consumption.

AC distribution board: A component of AC power supply system used to distribute the AC power from inverter to the load. The cables from the distribution board are connected to the load via an energy metre to monitor the PV generated energy. Additionally, a surge protection device can be incorporated in the board.

Designing

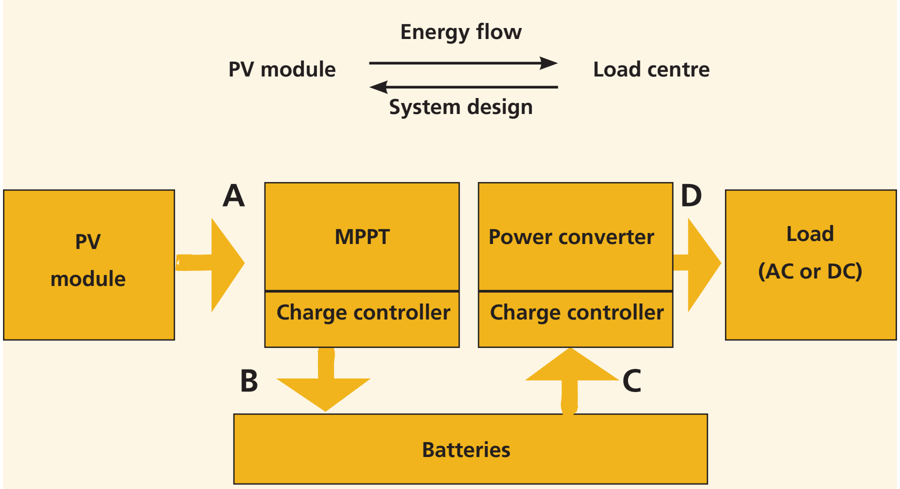
Designing a mini-grid solar PV system involves five steps, including:

1. Load estimation
2. Electronic components selection (i.e. inverter, charge controller)
3. Battery sizing
4. PV module and array sizing
5. Other components

The mini-grid design proceeds in the opposite direction to energy flow of the system. The direction of energy flow is from PV modules to the load centre, which in our case will be the village households. The system design, on the other hand, starts from the load centre and proceed towards the PV array.

Figure 2: Energy flow in a mini-grid system shows the energy flow in a typical standalone solar mini-grid system. Power from PV module is stored in batteries and then used for various DC and AC loads in households. This is achieved by the use of electronic components like MPPT, charge controller and power converter.

Figure 2: Energy flow in a mini-grid system



Source: Solanki, C.S., 2013. 'Solar Photovoltaic Technology and Systems,' Delhi: PHI Learning Private Limited

Load estimation

In this first step, we determine the total load required to supply electricity to a village with 40 households. It involves power estimation of all the appliances used in a typical household and their operation hours. For instance, a ceiling fan consumes power of about 25 W and is operated for around 12 hours a day. The energy consumption of the fan is about 300 Wh per day per house (25W times 12h). *Table 1: Electricity demand of the village* shows the electricity demand of a typical village comprising 40 households.

The appliances considered for this study remain identical for all the households in a typical village. The total power shown in Table 1: Electricity demand of the village is the

Table 1: Electricity demand of the village

The total power is the product of the appliance's power rating, its quantity and total number of households

Appliances	Power (W)	Nos.	Households	Consumption hours (h)	Required power (W)	Required energy /day (Wh)
Lights (LED)	4	2	40	6	320	1,920
Lights (LED)	2	2	40	6	160	960
Ceiling/table fan	25	1	40	12	1,000	12,000
Mobile charging	8	1	40	3	320	960
Television	12	1	40	5	480	2,400
VCD/set-top box	30	1	40	5	1,200	6,000
Street light	12	14	--	10	168	1,680
				Total	**3,648**	**25,920**

product of appliance's power rating, its quantity and total number of households. For instance,

Total power demand from 4W LED lights = 4 W x 2 lights x 40 households = 320 W

The energy demand is the product of the calculated power and its hours of consumption. The important figure to observe from this section of designing is the total power and energy of all households i.e. 3,648 W and 25,920 Wh respectively.

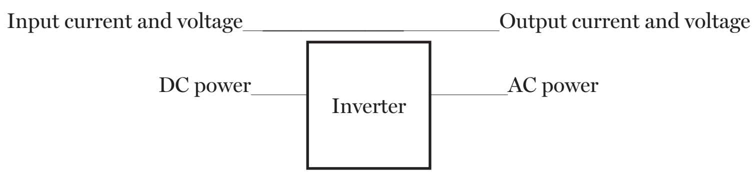
Selection of electronic components

The next step in the design process is proper selection of electronic components, which are inverters and MPPT charge controllers. The voltage and current of the load plays an important role in selection of these components.

Inverter selection

The inverter can be construed as the heart of the system. The purpose of an inverter is to convert the DC power from battery to AC power, which can then be used in home appliances. It determines the mini-grid system's voltage and current. The inverter capacity is determined by the product of voltage and current of the load. The total load of the system is 3,648 W.

The output from the inverter should not only meet the total consumer load (i.e. 3,648 W) but also accommodate for the power loss during transmission and distribution (T & D losses) from the mini-grid to the load centre. According to the World Bank, the T&D loss of India is 21 per cent of generation.[1] Therefore, the output of the inverter should accommodate T&D losses.

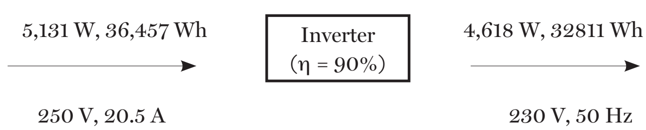


$$\text{Output power of inverter} = \frac{\text{Total load}}{(1-0.21)} = \frac{3648}{0.79} = 4{,}618 \text{ W}$$

$$\text{Input power of inverter} = \frac{\text{Output power of inverter}}{\text{Inverter efficiency}} = \frac{4618}{0.9} = 5{,}131 \text{ W}$$

Assuming an inverter efficiency of 90 per cent, the input power of the inverter is estimated.

In a similar fashion, the output and input energy of the inverter is ascertained.



The next step is to specify the system voltage. The system voltage is the output voltage of the battery bank, which will be the input voltage of the inverter. We need to form an array of batteries to raise the system voltage. The idea is to raise the system voltage and thereby reduce the current flowing through the battery, as the lesser the current flows through the battery, the lesser is the energy loss in the battery. Assuming a system voltage of 250 V, the system current can be calculated as follows:

$$\text{System current} = \frac{\text{Battery output power}}{\text{System voltage}} = \frac{5{,}131}{250} = 20.52 \approx 21\ \text{A}$$

MPPT charge controller
MPP tracking and charge controlling are two different functions performed by a single device called MPPT charge controller.

Charge controller
As the name implies, it controls the flow of charge into the batteries and prevents from overcharging and discharge. The manufacturer specifies the Depth of Discharge of the battery (or DoD, discussed in the section 'Battery sizing'), beyond which it should not be discharged. Doing so can significantly harm the lifetime of the battery.

MPP tracker
PV modules deliver power depending on the load connected to them. When the voltage is zero, current delivered by the module will be the maximum. As the voltage increases, current remains almost constant and power delivered by the module increases.

Note: Power = Current *x* Voltage　　　　Energy = Power *x* Time

This trend continues up to a certain point and voltage increase beyond this point leads to decreasing trend in power. This point is called the maximum power point (MPP) of the module. Operating the modules at this point would mean the optimum use of them. An MPP tracker is the device that operates all the connected modules at the maximum power point and extracts maximum power from them.

The MPPT charge controller rating for our project is depicted in *Table 2: Parameters of a mini-grid system*.

Battery sizing
The output energy of the battery bank is the input energy for the inverter. The formula for estimating the battery bank capacity is:

$$\text{Battery bank capacity (Ah)} = \frac{\text{Input energy of Inverter (Wh)} \times \text{Days of autonomy}}{\text{System voltage (V)} \times \text{DoD (\%)}}$$

The battery capacity depends on four factors, namely, inverter's input energy, number of

Table 2: Parameters of a mini-grid system

MPPT rating is determined by the system voltage and current

Energy (Wh)	Wattage (W)	System voltage (V)	Maximum current (A)	MPPT rating
36,457	5,131	250	20.5	250 V, 21 A

Source: CSE analysis

days of autonomy, system voltage and depth of discharge (DoD). The days of autonomy is the number of days the system can supply power independent of the sunlight. This means that if we want to store energy for one extra day, the battery capacity should be double and the days of autonomy would be 2.

Depth of discharge: In practical applications, all the charge stored in a battery cannot be discharged to run load. Only some percentage of the full capacity can be discharged. This allowable percentage of discharge for a battery is called depth of discharge (DoD). Usually the manufacturers specify the DoD for their batteries. For instance, if the DoD is 50 per cent, then the battery can be discharged to 50 per cent of its full capacity. Discharging a battery below the specified DoD could drastically reduce the lifetime of the battery.

The battery chosen for our system is a standard one of rating 12 V, 150 Ah. The DoD is assumed as 50 per cent and the days of autonomy as one day.

$$\text{Battery bank capacity (Ah)} = \frac{36457\ \text{Wh} \times 1}{250\ \text{V} \times 50\ \%} = 292\ \text{Ah}$$

A single standard battery cannot fulfill the demand of 250 V, 292 Ah. To achieve this we need to create an array of batteries by connecting them in series and parallel (series and parallel connections are discussed in 'PV array sizing'). Such an array is referred to as battery bank.

When batteries are connected in series, their voltage gets added up while current remains the same and when they are connected in parallel, their current gets added up and the voltage remains constant. The required number of batteries to be connected in series can be calculated by dividing the system voltage by the battery voltage.

$$\text{Number of batteries in series connection (Ns)} = \frac{\text{System voltage}}{\text{Battery voltage}} = \frac{250\ \text{V}}{12\ \text{V}} \approx 21$$

$$\text{Number of batteries in parallel connection (Np)} = \frac{292\ \text{Ah}}{150\ \text{Ah}} \approx 2$$

The total number of batteries in the battery bank is 42 and the array size is 21 x 2.

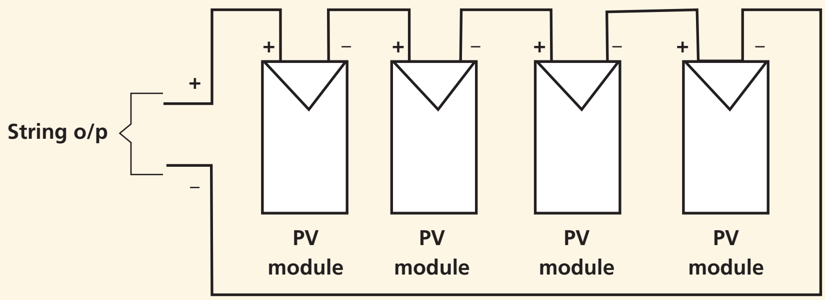
PV module and array sizing

The solar PV modules should produce the required energy of the load plus the energy loss in the battery. Assuming the batteries are 90 per cent efficient, the required energy from the PV module is:

$$\text{PV modules (Wh) output energy} = \frac{\text{Output energy of battery}}{\text{Battery efficiency}} = \frac{36{,}457\ \text{Wh}}{0.9} = 40{,}507.8\ \text{Wh}$$

The next step in PV module sizing is the estimation of average sun hours of the locality. (The power production of module is directly dependent on the amount of sunlight the modules receive.) The daily solar radiation is measured in KWh/m^2/day. In India, the average solar radiation ranges from 4 to 7 KWh/m^2 per day.[2] While manufacturing, the solar modules are rated for solar radiation intensity of 1 KW/m^2 under standard testing condition (STC). Therefore, assuming our village has a solar radiation of 6 KWh/m^2 per day, the average sun hours is calculated as follows.

Figure 3: Series connection of modules



Note: When modules are in series connection, a single row of series-connected PV module is referred to as string.
Source: Solanki, C.S., 2013. 'Solar Photovoltaic Technology and Systems,' Delhi: PHI Learning Private Limited

$$\text{Daily hours of sunlight (h)} = \frac{\text{Daily solar radiation}}{\text{Power density in STC}} = \frac{\text{6 KWh per sq.m}}{\text{1 KW per sq.m}} = \text{6 hpours}$$

The total PV wattage can be determined by dividing the energy demand by daily sun hours.

$$\text{Total PV wattage (W)} = \frac{\text{Energy demand (Wh)}}{\text{Average sun hours (h)}} = \frac{40507.8}{6} = 6751.2 \text{ W}$$

The module chosen for our system is Tata Power Solar – TP 260. The power rating of the chosen module is 260 W and the voltage (V_{mpp}) and current (I_{mpp}) at maximum power point are 30.6 and 8.49 respectively. [3]

$$\text{Total modules required} = \frac{\text{Total PV wattage (W)}}{\text{Module power (W)}} = \frac{6751.2}{250} = 25.9 \approx 26 \text{ modules}$$

It would require 26 modules of the chosen module type to fulfill the required power demand.

Series connection

Series connection of modules is achieved by connecting together opposite polarity terminals of the modules as shown in *Figure 3: Series connection of modules*. The main reason for connecting PV modules in series is to increase the output voltage. Since the PV system voltage requirement is more than the maximum voltage delivered by a single module, the PV modules are connected in series.

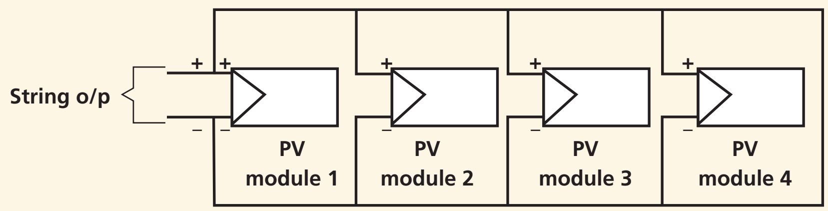
When PV modules are connected in series, the output voltage of the series is the sum of the voltage of all the PV modules in the series. Since all the modules are identical in our system, the output voltage is the product of the module voltage and the number of modules in series.

$$\text{System voltage (V)} = \text{Module voltage (V)} \times \text{Number of modules in series (Ns)}$$

$$\text{Number of modules in series (Ns)} = \frac{\text{System voltage}}{\text{Module voltage}} = \frac{250}{30.6} = 8.2 \approx 9 \text{ modules}$$

In our system, by connecting nine PV modules in series, the required system voltage of 250 V can be achieved.

Figure 4: Parallel connection of modules



Source: Solanki, C.S., 2013. 'Solar Photovoltaic Technology and Systems,' Delhi: PHI Learning Private Limited

Parallel connection

The parallel connection of modules is achieved by connecting together same polarity terminals of the modules as shown in *Figure 4: Parallel connection of modules.* The reason to connect PV modules in parallel is to increase the output current of the combination.

When PV modules are connected in parallel, the output current of the combination is the sum of the current of all the PV modules in the connection. The output current is the product of the module current and the number of modules in parallel connection.

System current (V) = Module current (V) *x* Number of modules in parallel (Np)

$$\text{Number of modules in parallel (Np)} = \frac{\text{System current}}{\text{Module current}} = \frac{20.52}{8.49} = 2.4 \approx 3 \text{ modules}$$

In our system, by connecting 3 PV modules in parallel, the required system current of 20.52 A can be achieved.

Array formation

A PV array of modules is formed by connecting them in both series and parallel combinations. From our calculation, the maximum number of modules that can be connected in series (Ns) and parallel (Np) are 9 and 3 respectively. Therefore, the PV array of our system would consist of 27 modules (9 x 3) with three strings connected in parallel and each string consisting of nine modules.

Total system capacity (KW) = 27 modules *x* 260 W = 7.02 KW

At the beginning of PV array sizing, we calculated that the total modules required for the project is 26. However, now in the process of array formation, the result obtained is 27 modules. This mismatch arises due to array formation, as 26 modules cannot be reasonably split to form an array with the given specifications.

Other components

A PV installation will have many components apart from the main components like modules and batteries.

Table 3: Facts and assumptions of the project

It is assumed that the operating life of the mini-grid system would be 25 years along with various other parameters

Installed capacity	7.02 KW	Capital cost	₹ 902,816
Annual generation	9838 KWh	Depreciation rate (10 yrs)	5.28 %*
CUF	19 %	Depreciation (after 10 yrs)	3.72 %*
Transmission loss	21 %	Discount factor (DF)	14.2 %*
Plant life	25 years	Debt-equity ratio	70 : 30
Tariff period	25 years	Equity return (10 yrs)	20 %
O&M Cost	₹ 10 lakhs/MW/yr#	Equity return (after 10 yrs)	24 %
O&M escalation	5.72 %*	Loan interest	12 %*
Assumed tariff	₹ 5 per KWh	Loan period	12 years
Interest on working capital	12 %*	Maintenance spares	15 %[6]

Source: Compiled by CSE from various sources
*Sourced from ABPS Infra (2012), Policy and Regulatory Interventions to Support Community Level Off-Grid Projects, On request of Forum of Regulators (FOR), New Delhi
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Wiring

Wire sizing is done differently for DC and AC side of the system, as the power rating is different for both sides. The aim of wire sizing is to reduce the total power loss across the entire length of the cable to within 2–3 per cent of the rated output power. For solar PV applications, copper wires are commonly used, because of its low electrical resistance. The main factors for selecting a wire are the operating voltage and maximum current of the circuit.

For DC side,
Operating voltage (V) is the system voltage, i.e. 250 V

$$\text{Maximum current (A)} = \frac{\text{Max Power}}{\text{System voltage}} = \frac{6751.2}{250} \approx 28\text{ A}$$

Similarly, for AC side,
Operating voltage (V) is 230 V

$$\text{Maximum current (A)} = \frac{\text{Max Power}}{\text{System voltage}} = \frac{4618}{230} \approx 21\text{ A}$$

Table 4: First year interest on working capital

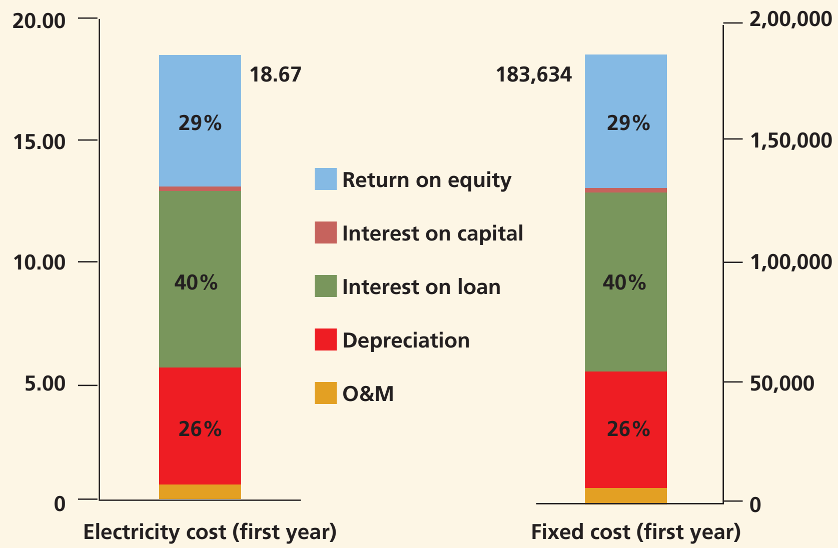
O&M expenses would be increasing every year at the rate of 5.72 per cent

Working capital	First year	Formula
O&M expense	₹7,020.00	Plant capacity × O&M cost
Receivables (billed every two months)	₹8,198.33	(Generation × assumed tariff) ÷ 6
Maintenance spare	₹87.75	Monthly O&M × maintenance %
Total working capital (TWC)	₹15,306.08	Sum of all the above
Interest on working capital	₹1,836.73	TWC × interest %

Source: CSE analysis

Figure 5: Cost break-up of a mini-grid system

Interest on loan is the major contributor of the cost of a mini-grid system



Metering

Energy metres are used to monitor energy mainly at two ends. They are the energy distributed from the plant and energy consumed by households. Each household shall be connected with an AC energy metre to monitor its consumption. Alternatively, an additional DC energy metre can also be connected at the end of the PV array to measure the total PV generated energy.

Cost analysis

Cost analysis is important to understand what the levelized cost of electricity (LCOE) is. LCOE is a financial tool used by the power utilities and helps compare various power-generating entities. It is calculated by dividing all of a system's expected lifetime costs (including construction, financing, operation and maintenance and incentives) by its lifetime expected power output (KWh).

When LCOE is relatively low, it means the power is being produced at a lower cost and with higher returns for the investor. The LCOE of PV technology is still higher than the grid power (₹S3–4/KWh), mainly due to production cost and poor efficiency of the modules.

The lifetime cost of the system is the sum of five factors, namely, operation and maintenance (O&M) expenses, depreciation cost, interest on term loan, interest on working capital and return on equity. The operation and maintenance cost for the project is assumed as 10 lakh per MW per year. The O&M expense for each year is the product of the plant's capacity and O&M cost for that year.

O&M expense for first year = 7.02 x 1000 = ₹7,020

The report, Policy and Regulatory Interventions to Support Community Level Off-Grid Projects by ABPS Infra to the Forum of Regulators (FOR) calculated the capital expenditure for Solar PV system as ₹1,50,000/KW in 2012 with a 5 per cent reduction every year.

Capital cost = $7.02 \times 150{,}000 \times (1-0.05)^3$ = ₹ 9,02,816

According to Table 2, depreciation cost for the first 10 years of the project is 5.28 per cent of the capital cost and it reduces to 3.72 per cent after 10 years.

⇨ Depreciation cost for first 10 years = ₹47,669

⇨ Depreciation cost after 10 years = ₹33,585

The mini grid project runs on 70 per cent debt i.e. ₹631,971. The loan period is 12 years i.e. 144 installments with 13 per cent interest rate. The interest on term loan reduces each year. As the loan period comes to end, the interest gets less significant. The formula for interest calculation is:

Principal amount is ₹4,389 (Loan amount / Loan period).

For the first year, the interest on term loan, which is the sum of interests of each installment, is calculated as ₹72,940.

The second form of interest is the interest on working capital and is dependent on four different factors. The value of these factors for the first year is tabulated below along with their respective formulae.

The mini-grid project runs on 30 per cent equity with return on equity as 20 per cent for the first 10 years and 24 per cent thereafter.

Return of equity (first year) = 20 per cent X 30 per cent of capital cost = ₹54,169

Now, getting back to system's lifetime cost, which is the sum of the above calculated five factors.

Total cost of the system (first year) = 7,020 + 47,669 + 72,940 + 54,169 = ₹1,83,634

The lifetime cost of the system for the entire period of 25 years is determined by summing the total system cost of each year.

$$\text{Cost of electricity (first year)} = \frac{\text{Total cost of the system (first year)}}{\text{Annal generation KWh}} = \frac{₹183{,}634}{9838 \text{ KWh}} = ₹18.67$$

The cost of electricity for each year is calculated in similar manner for the period of 25 years.

Levelized cost of electricity (LCOE)

The cost of electricity for the first year is estimated as ₹18.67. To estimate the levelized cost of electricity, we need to include discount factor (DF) into this tariff. The discount factor is used to determine the present value of the future cash flows. It takes into account not just the time value of money but also the uncertainty of future cash flows. The higher the uncertainty, the greater is the DF. The discount factor for our system is 14.2 per cent.

The levelized cost of electricity (LCOE) for our system is calculated to be ₹15.58. ■

Annexure II

Bihar—implementing the model on the ground

State: **Bihar** • District: **Samastipur** • Sub-district: **Bibhutipur**

In order to illustrate the proposed model, we have chosen Bibhutipur sub-district of Samastipur district in Bihar. According to census data, this particular sub-district has 13 large size villages having population of more than 10,000 each. At the same time, electrification rate in this sub-district is one of the lowest in Bihar. Hence, it becomes an ideal cluster to study the finances required for developing a mini-grid model which can then be extrapolated to the rest of India.

According to the GARV dashboard, the entire district of Samastipur only has 16 non-electrified villages. Latest data (21 June 2016) suggests 14 of these villages are now electrified. The sub-district of Bibhutipur has 43 inhabited villages, out of which 13 are non-electrified and 30 previously electrified ones have been taken up for further electrification under 10th and 11th Five Year Plans.[31]

Bihar is among the most electricity impoverished state in India. As per census 2011 data, about 82 per cent of the households in Bihar used kerosene for lighting.

The total number of households in Bibhutipur, as per 2011 census data, is 67,023. The household growth rate between 2001 and 2011 was 4.2 per cent annually. Considering this growth rate, the total households in Bibhutipur in 2016 is estimated to be 82,427. Again, from 2001–11 census data, we find that the rate of growth of electrification in Bihar stood at 0.53 per cent per annum. Applying the same growth of electrification to Bibhutipur, we find that the rate of electrification in 2016 is 6.92 per cent. This implies that out of 82,427 households, 76,721 do not have access to electricity. We further assume that out of the households that have been electrified, 75 per cent do not receive even one unit every day. Therefore, the total number of households that need to be supplied one unit of electricity per day is 81,000.

Electricity supply

If we want to ensure that the entire sub-district receives at least one unit of electricity per household every day through renewable energy-based mini-grids using solar and biomass energy in the ratio of 40:60 respectively, we need to generate 29.16 million units per year, on an average. Out of this solar based mini-grids will contribute 11.66 million units whereas biomass based mini-grids will contribute 17.50 million units per year.

Table 1: State of electrification in Bibhutipur

Sub-district	Bibhutipur
No. of non-electrified and de-electrified villages taken up for electrification	13
No. of previously electrified villages taken up for intensive electrification	30
Total	43

Source: DDUGJY website

Table 2: Energy sources used in Bibhutipur

Source of lighting	No. of households
Electricity	2,864
Kerosene	63,535
Solar energy	217
Other oil	152
Others	237
No lighting	18
Total	67,023

Source: Census 2011 data

Table 3: Bibhutipur villages population categories

Village population size	No. of villages	Total population	Average population size per village
Less than 200	1	149	149
200–499	2	634	317
500–999	1	804	804
1,000–1,999	3	5,311	1,770
2,000–4,999	11	41,344	3,759
5,000–9,999	12	78,735	6,561
>10,000	13	211,172	16,244
Total	43	338,149	7,864

This means installations of several generating stations based on solar and biomass gasification technologies which will accomplish 7.1 MW of solar power and 3.1 MW of biomass power to fed the entire village populations.

Capital cost

Assuming the same parameters of capital costs and cost of generations, the total capital expenditure required to set up the entire mini-grid is Rs 93.10 crore.

Feed-in-Tariff (FiT)

Considering FiT mechanism to support the mini-grids over its life cycle of 20 years, we find that the government will have to provide a total of Rs 27.60 crore in the first eight years of the project. Since the tariff paid by rural customers is assumed to increase by 3 per cent per year, the government support will reduce by that extent year on a yearly basis. Applying a discount factor of 10.67 per cent (as per CERC guidelines), we find that the government will have to give Rs 19.59 crore at the net present value. This means for the present population of 338,149, over an eight year period, the subsidy given by the government would be Rs 6 per person per month.

Table 4: Capital expenditure required to set up mini-grids

Type of finance	Share (%)	Total
Equity	23.45	21.83
Debt	46.91	43.67
Subsidy for distribution	29.64	27.60
Total	100.00	93.10

Table 5: Bibhutipur—CSE model's vital statistics

Description	Unit	2011	2016
Census data on rural households	No.	67,023	82,427
Rural households with access to electricity	Per cent	4.27	6.92
Rural households with access to electricity	No.	2,864	5,707
Rural households without access to electricity	No.	64,159	76,721
Rural households receiving less than one unit electricity a day (assumption)	Per cent		75
Rural households receiving less than one unit electricity a day	No.	2,148	4,280
Households that need to be supplied one unit of electricity per day	No.	66,307	81,000
Households to be covered by mini-grids	Per cent		100
Electricity required to serve the target number of households per year at the rate of 30 units per households	kWh		29,565,181
Penetration of solar mini-grids by 2016	Per cent		40
Penetration of biomass mini-grids by 2015	Per cent		60
Number of units required to be generated from the solar mini-grids installed during the year	kWh		11,826,073
Number of units required to be generated from biomass mini-grids installed during the year	kWh		17,739,109
Required installed capacity of the solar mini-grids considering 19 per cent CUF	MW		7.11
Required installed capacity of the biomass mini-grids considering 65 per cent CUF	MW		3.45
Cost of solar based mini-grids per KW	Rs		104,353
Cost of biomass based mini-grids per KW	Rs		60,833
Government subsidy of 90 per cent per KW for setting up the distribution system	Rs		27,000
Total capital required for solar-based mini-grids per year excluding government subsidy	Rs crore		54.96
Total capital required for biomass-based mini-grids per year excluding government subsidy	Rs crore		11.66
Total capital required for mini-grid development	Rs crore		66.62
Total government support required for mini-grid development till 2025	Rs crore		27.60

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