“e[r] cluster” for a smart energy access

THE ROLE OF MICROGRIDS IN PROMOTING THE INTEGRATION OF RENEWABLE ENERGY IN INDIA

GREENPEACE

imprint

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recognize the need for partnerships among governments, enterprises, civil society and the people to create the conditions for a successful transition to the much desired and required clean energy system.

Solar Photovoltaic Power Plant in Tangtse

The 100 kWp stand-alone solar photovoltaic power plant at Tangtse, Durbuk block, Ladakh. Located 14,500 feet AMSL in the Himalaya, the plant supplies electricity to a clinic, a school and 347 houses in this remote location, for around five hours each day.

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contents

introduction and policy recommendations 6

Greenpeace Proposal to support a renewable energy]cluster 8

executive summary 10

1 access to energy – the concept 18

Rural electrification for universal electrification 19
Grid extension – the passive top-down approach – 19
Off-grid power generation –
the active bottom-up approach – 19
What is the problem with the current process? 20
Integration of renewable energies 20
Smart Energy Access 21
Microgrids 21
The Concept 22

2 microgrid design case study 24

Methodology 25
Overview of Bihar 26
Bihar Microgrid Village 27
Step 1: Assessment of Renewable Energy Resources in Bihar 29
Step 2: Assessment of System Demand 31
The resulting system demand for each demand scenario
is summarised in 32
Step 3: System sizing by production optimisation with Homer 33
Unit size considerations 34
Solar PV price sensitivity 34
HOMER Simulation Results 35
Conclusions from this section 39
Step 3: Technical feasibility check 40
Load-Related Assumptions and Network Design 40
Load distribution 42
Reactive Power Demand 43
Power Flow Analysis 44
Conclusions from this section 48
Step 4: Development of a Control Strategy
for the Switching Operation 49
The simple solution 49
Control issues 50
Conclusions from this section 53
Cost comparison with grid extension 54
Microgrid scale-up across the state of Bihar 55

3 grid technologies and definitions 58

Energy Access Options 59
Energy Homes Systems 59
Off-grid Distribution Systems 59
Microgrids 60
Distributed Generation Systems 60
Obstacles to Energy access Projects 60
Strengths and Weaknesses of Energy Access Options 61

4 references 64

solar photovoltaic power plant in tangtse
THE 100 KWP STAND-ALONE SOLAR PHOTOVOLTAIC POWER PLANT AT TANGTSE, DURBUK BLOCK, LADAKH. LOCATED 14,500 FEET AMSL IN THE HIMALAYA, THE PLANT SUPPLIES ELECTRICITY TO A CLINIC, A SCHOOL AND 347 HOUSES IN THIS REMOTE LOCATION, FOR AROUND FIVE HOURS EACH DAY.

Child in Ladakh
CHILD AT THE SAMSKIT TSONGPA (WOMEN'S GROUP) IN PUNPUN HAMLET, DURBUK BLOCK, LADAKH. THE GROUP DRAWS ELECTRICITY FROM A SOLAR POWER PLANT IN DURBUK.

foreword

Energy is central to nearly every major challenge and opportunity the world faces today. Access to energy for all is essential for creating jobs, developing economies, increasing incomes, food production, security or climate change. Approximately one and a half billion people around the world, still lack access to electricity and the majority of them live in developing nations. Countries like India still face a severe energy crunch, with millions of rural inhabitant's still lacking access to secure and assured electricity, making this a development priority.

The energy shortage is most acute among India's rural poor and in states such as Bihar, where more than 80% of the population still live in the rural areas; the majority of them still rely on conventional and traditional fuels for their energy needs. As governments and the energy sector seek to provide more modern and reliable energy services to these communities, there is a growing gap in the ever increasing demand and the shrinking supply of energy from conventional sources, as these are fast depleting. On the other hand, a fledgling market in cleaner, more efficient energy delivery models is emerging. Successful (though small scale) business models such as solar-based home electricity systems and electricity services generated from decentralized sources such as micro hydro and biomass gasifiers are increasingly finding a market among such households.

To facilitate energy access and a clean energy transition, a new approach has to be thought about. Sustainable technologies and innovative business models have to be implemented with governments, businesses, investors, and civil society coming together to solve public problems. Supplying modern energy services to the millions who now lack electricity and clean fuels is not just a social imperative but also essential for distributive justice in a growing economy. It can create millions of new jobs and increase productivity in rural areas, thus bringing about sustainable prosperity.

This report shows how microgrids could be a useful concept for accelerating current rural electrification efforts, support renewable energy integration into energy systems, and create a reliable electricity system. There could be divergence of views on the approaches to be adopted for achieving this object. However we should all be unanimous in recognizing the need for partnerships among governments, enterprises, civil society and the people to create the conditions for a successful transition to the much desired and required clean energy system.

May 2012

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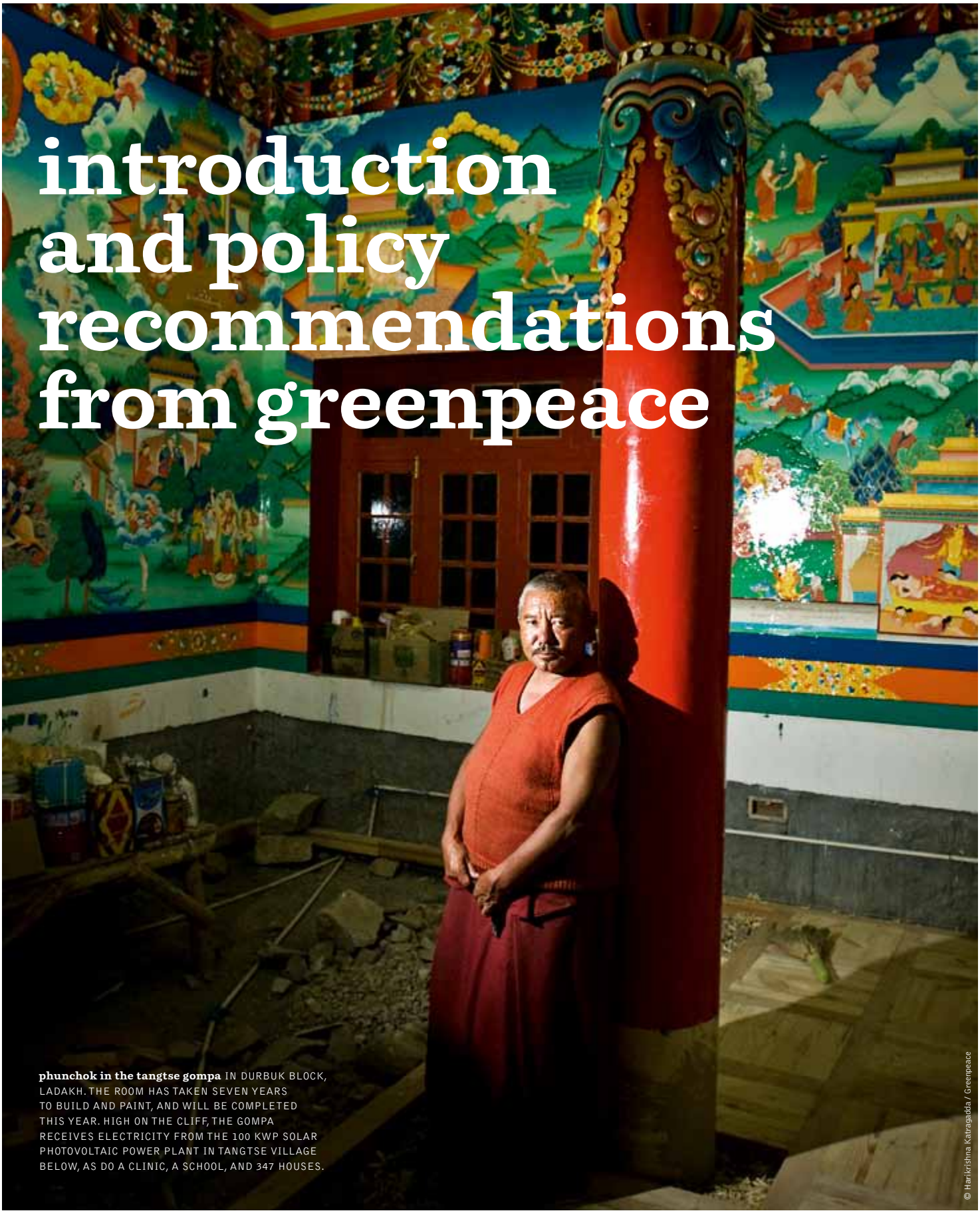
introduction and policy recommendations from greenpeace



phunchok in the tangtse gompa IN DURBUK BLOCK, LADAKH. THE ROOM HAS TAKEN SEVEN YEARS TO BUILD AND PAINT, AND WILL BE COMPLETED THIS YEAR. HIGH ON THE CLIFF, THE GOMPA RECEIVES ELECTRICITY FROM THE 100 KWP SOLAR PHOTOVOLTAIC POWER PLANT IN TANGTSE VILLAGE BELOW, AS DO A CLINIC, A SCHOOL, AND 347 HOUSES.

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access to energy in 2012: the international year of sustainable energy for all

In December 2010, the United Nations General Assembly declared that 2012 would be the International Year of Sustainable Energy for All; "...access to modern affordable energy services in developing countries is essential for the achievement of the internationally agreed development goals, including the Millennium Development Goals[1], and sustainable development, which would help to reduce poverty and to improve the conditions and standard of living for the majority of the world's population."

The General Assembly's Resolution 65/151 called on UN Secretary-General Ban Ki-Moon to organize and coordinate activities during the Year in order to "increase awareness of the importance of addressing energy issues", including access to and sustainability of affordable energy and energy efficiency at local, national, regional and international levels.

In response, a new global initiative, Sustainable Energy for All, was launched at the UN General Assembly in September 2011, along with its own High Level Group, designed to mobilize action from governments, the private sector and civil society globally. The initiative has three inter-linked objectives: universal access to modern energy services, improved rates of energy efficiency, and expanded use of renewable energy sources.

In the light of this opportunity Greenpeace initiated a renewable energy project in the state of Bihar, a rural area of northern India where over 82% of the population lacks access to electricity[2]. The idea was to develop a smart grid for rural electrification beginning by supplying only basic electricity needs to the area. However over time this can be expanded, as demand and supply grows, step by step to a full 24/7 supply with 100% renewables. Unlike the current rural electrification concepts, this research aimed to develop a system which functions as a "bottom-up" grid expansion. To help with this project, Greenpeace commissioned the German engineering firm Energynautics to present the technical possibilities and options both for a village and for an entire state based on this concept. Greenpeace publishes since 2005 global, regional and national energy scenarios under the name Energy [R]evolution. This report continues the sucessfull series with the first ever energy [r]evolution concept for villages. Therefore we call the concept presented in this report "E[R] cluster".

The "traditional" rural electrification concept cannot be expanded in a bottom-up manner to a full grid system, but generally leaves regional systems as island systems. However, villages enjoying such rural electrification programmes often lost priority for grid connection programmes. Therefore many communities rather wanted to wait till the expanded grid reached their village. In this report we present a technical concept on how to use renewable energy clusters to organize bottom up electrification across the entire state of Bihar. Greenpeace hopes to inspire other developing countries with this concept. However, in order to help implementing renewable energy clusters, policy changes and specific national and international support programs are required.

policy recommendations for renewable energy cluster

The need for an integrated approach to rural electrification is an imperative for developing nations such as India, and in context for states like Bihar to progress economically. Energy capacity increase should align with other developments and electricity infrastructure strategies. The elements of policy, governance and capacities suggested in this section are based on the principle of inclusion, state's increasing investment capacity, generation of developmental benefits and reduction of environmental damage. The proposed framework takes a bottom-up approach to achieve universal electrification; this requires extensive institutional and government intervention. The vision for overall energy-led development for the State of Bihar emerges as follows:

> **"a state-wide network of decentralised energy plants (stand alone and micro-grids), developed with support from state government agencies in collaboration with private entrepreneurs for a high impact and accelerated economic development of the state"**

The most important step in this direction would be to develop a resource and technology plan for rural electrification,

- Identify population, energy needs at different times of the year, investment required, local investment possibilities and financial capacities of the population.
- Identify nature and amount of raw material available for decentralised renewable energy systems at different times of the year.

- Analyse and develop feasible technologies and locations emerging from the above- mentioned two points.
- Map the locations in districts and blocks and enlist the government infrastructure support, required and available.

The changes are recommended at the policy level, supported by various implementation processes and structures.

- Cluster based development: Clubbing of areas to form 'economic clusters'.
- All infrastructure development to be geared for technology-related development.
- A major thrust on providing market linkages based on product cluster formation and effective strengthening of the credit and marketing links for security of the entrepreneur.
- Training of relevant government personnel for commitment and institutional support to the entrepreneurs and need for a semi-autonomous cell or unit in the Department of Industry to supervise, coordinate and promote rural industrialisation.
- Finance resource building at the government and private level by the establishment of a council for rural industrialisation and establishment of related coordination committees at district level.
- Integrated energy planning: state-wide natural resources and appropriate technology.
- State incentivised emergence of new private enterprise models, particularly energy services companies (ESCOs), developed through innovative and alternative business opportunities in the electricity sector by use of decentralised generation
- Empowerment of relevant government agencies to drive the expansion of decentralised energy.
- Showcasing the state as an evolved decentralised energy market, nation-wide and worldwide.
- Transform the state's economics and energy supply through use of decentralised energy by creating facilitative policy structures.
- Create supportive institutional avenues for micro-grids.
- Institutionalise supportive regulatory structures and encourage governance support through the Electricity Regulatory Commission.
- Develop innovative energy pricing models by mixing regulation and competition.

This can be the mandate of district administrations and the Bihar Rural Electrification Corporation (REC). The district level plans will identify the areas having raw material potential for their own energy systems outside the grid. The plan will also define the areas (state-wide), having economic viability for private (single, multiple, or cooperative) ownership of electricity systems. This investigation will provide the state with a clear district/area-wise plan to meet the electricity needs of the state. However, infrastructure support, financial assistance and policy support is required for this plan to work effectively. The other most important step to take would be to design a tariff mechanism to encourage micro grids and decentralised systems. Tariff and pricing structure can have a significant impact on the economic viability of distributed energy system. Therefore, a fair tariff and pricing system is essential. The pricing system should include:-

- The contractual agreement between the ERC and the DE operator should supersede the basic rate set by the ERC for the public utility. In the early stages of any new technology, market-based pricing can make the new system uneconomic. Hence, to encourage DEs it is essential for the regulator to have separate tariff setting, which ...
- Includes any grants from national and international agencies.
- Includes incentive slabs based on amount of generation (system efficiency and system reliability).
- Includes incentive slabs based on supply (number of customers served).
- Can be seasonal or periodic depending on the cost cycle of the DEs (the time frame and tariff should strike a balance between the raw material price fluctuations and an affordable price to the rural consumer).
- Defining the grid-DE interconnection standards to avoid any tariff manipulations, for instance, either prohibiting access to the grid by providing expensive power (by the utility) or by supplying to the grid at a significantly high cost (by the operator).
- Mechanisms such as the FTSM (Feed in Tariff Support Mechanism) have to be explored to support the large scale expansion of micro grids based on renewable energy technologies which is presented in detail below.

greenpeace proposal to support a renewable energy]cluster

This energy cluster system builds upon Greenpeace's Energy [R] evolution scenario[3] which sets out a global energy pathway that not only phases out dirty and dangerous fossil fuels over time to help cut CO_2 levels, but also brings energy to the 2 billion people on the planet that currently don't have access to energy. The most effective way to ensure financing for the energy [r]evolution in the power sector is via Feed-in laws.

To plan and invest in an energy infrastructure, whether for conventional or renewable energy, requires secure policy frameworks over decades. The key requirements are:

a. long term security for the investment
The investor needs to know the pattern of evolution of the energy policy over the entire investment period (until the generator is paid off). Investors want a "good" return of investment and while there is no universal definition of a good return, it depends on the long term profitability of the activity as well as on the inflation rate of the country and the short term availability of cash throughout the year to sustain operations.

b. maximize the leverage of scarce financial resources
Access to privileged credit facilities, under State guarantee, are one of the possible instruments that can be deployed by governments

Tseway Motup in Ladakh
TSEWAY MOTUP AND HIS FAMILY WATCH TELEVISION IN THE EVENING IN UDMAROO VILLAGE, NUBRA VALLEY, LADAKH. ELECTRICITY IS SUPPLIED TO THE VILLAGE FOR SIX HOURS EVERY EVENING BY A 30 KVA MICRO-HYDRO POWER UNIT INSTALLED ON A MOUNTAIN STREAM ABOVE THE HIMALAYAN VILLAGE. THE FAMILY ALSO HAVE A MUSIC SYSTEM, AN ELECTRIC BUTTER CHURNER AND CFL LIGHTS IN THEIR HOME.

table ES: key results for e[r] villagecluster - state of bihar (rural) - emplyoment. environment + fit

SCENARIO		EMPLOYMENT			CO_2 SAVINGS		FIT
		GENERATION	GRID	TOTAL	SPECIFIC	TOTAL	AVERAGE ACCROSS ALL TECHNOLOGIES
		JOBS	JOBS	JOBS	t CO_2 /GWh	million t CO_2/a	INR /kWh
SCENARIO A: SOLAR + BIOMASS							
D1	Absolute Minimum (state-wide)	1,778	10	1,788	1,100	0.8	25
D2	Low income demand (state-wide)	5,936	75	6,011		6.7	19
D3	Medium income demand (state-wide)	14,326	153	14,479		13.4	25
D4	Urban households (state-wide)	16,340	447	16,787		32.0	19
SCENARIO B: SOLAR + SMALL HYDRO + BIOMASS							
D1	Absolute Minimum (state-wide)	1,778	10	1,788	1,100	0.8	25
D2	Low income demand (state-wide)	2,782	141	2,922		6.7	11
D3	Medium income demand (state-wide)	11,742	343	12,085		13.4	13
D4	Urban households (state-wide)	15,770	541	16,311		32.0	13
SCENARIO C: SOLAR + WIND + BIOMASS							
D1	Absolute Minimum (state-wide)	1,778	10	1,788	1,100	0.8	25
D2	Low income demand (state-wide)	5,936	75	6,011		6.7	19
D3	Medium income demand (state-wide)	14,326	153	14,479		13.4	25
D4	Urban households (state-wide)	21,470	410	21,880		32.0	21

Source: GREENPEACE INTERNATIONAL

to maximise the distribution of scarce public and international financial resources, leverage on private investment and incentivize developers to rely on technologies that guarantee long term financial sustainability.

c. long-term security for market conditions

The investor needs to know if the electricity or heat from the power plant can be sold to the market for a price which guarantees a "good" return of investment (ROI). If the ROI is high, the financial sector will invest; if it is low compared to other investments then financial institutions will not invest. Moreover, the supply chain of producers needs to enjoy the same level of favourable market conditions and stability (e.g. agricultural feedstock).

d. transparent planning process

A transparent planning process is key for project developers, so they can sell the planned project to investors or utilities. The entire licensing process must be clear, transparent and fast.

e. access to the (micro) grid

A fair access to the grid is essential for renewable power plants. If there is no grid connection available or if the costs to access the grid are too high the project will not be built. In order to operate a power plant it is essential for investors to know if the asset can reliably deliver and sell electricity to the grid. If a specific power plant (e.g. a wind farm) does not have priority access to the grid, the operator might have to switch the plant off when there is an oversupply from other power plants or due to a bottleneck situation in the grid. This arrangement can add high risk to the project financing and it may not be financed or it will attract a "risk-premium" which will lower the ROI.

a rural feed-in tariff for bihar

In order to help implement the E[R] clusters in Bihar, Greenpeace suggests starting a feed-in regulation for the cluster, which will be partly financed by international funds. The international program should add a CO_2 saving premium of 10 Indian Rupee (INR) per kWh for 10 years. This premium should be used to help finance the required power generation as well as the required infrastructure (grids). In the **table ES** the CO_2 savings, rough estimation of employment effects as well as the required total funding for the CO_2 premium for the state of Bihar are shown.

e[r] cluster jobs

While the employment effect for the operation and maintenance (O&M) for solar photovoltaics (0,4/MW), wind (0,4/MW), hydro (0,2/MW) and bio energy (3,1/MW) are very well documented,[4] the employment effect of grid operations and maintenance are not. Therefore Greenpeace assumed in this calculation that for each 100 GWh one job will be created. This number is based on grid operators in Europe and might be too conservative. However it is believed that the majority of the jobs will be created by the O&M of power generation; grid operation may be part of this work as well.

Due to the high uncertainty of employment effects from grid operation, these numbers are only indicative.

1 MILLENIUM DEVELOPMENT GOALS – FOR DETAILS SEE : HTTP://WWW.UN.ORG/MILLENNIUMGOALS/
2 HTTP://WWW.INDIATRIBUNE.COM/INDEX.PHP?OPTION=COM_CONTENT&VIEW=ARTICLE&ID=8574:ONLY-164-IN-BIHAR-HAVE-ACCESS-TO-ELECTRICITY&CATID=125:GENERAL-NEWS&ITEMID=400
3 ENERGY [R]EVOLUTION – A SUSTAINABLE ENERGY WORLD ENERGY OUTLOOK 2012, GREENPEACE INTERNATIONAL, AMSTERDAM – THE NETHERLANDS, JUNE 2012
4 INSTITUTE FOR SUSTAINABLE FUTURES (ISF), UNIVERSITY OF TECHNOLOGY, SYDNEY, AUSTRALIA: JAY RUTOVITZ, ALISON ATHERTON

executive summary

electricity management committee
(L-R) LOBZANJ TSEPHEL (56), TSERINJ RINGCHEN (56) AND TASHI NAMGIAL (59), MEMBERS OF THE ELECTRICITY MANAGEMENT COMMITTEE, MEET TO DISCUSS THE MANAGEMENT OF THE MICRO-HYDRO POWER UNIT IN UDMAROO VILLAGE, LADAKH. EVERY CUSTOMER IN UDMAROO IS A MEMBER OF THE COMMITTEE, THOUGH THE SOCIAL AND TECHNICAL GOVERNANCE OF THE SYSTEM IS THE RESPONSIBILITY OF AN ELECTED BODY OF SIX VILLAGERS.07/30/2010

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Microgrids can offer reliable and cost competitive electricity services, providing a viable alternative to the conventional top-down approach of extending grid services. The microgrid approach is "smart" because it can facilitate the integration of renewable energies, thereby contributing to national renewable energy (RE) targets. In addition it can reduce transmission losses by having generation close to demand. Being built from modular distributed generation units, it can adequately adjust to demand growth. It can operate both in island mode and grid-connected mode, making operation flexible and can also offer grid support features.

This report demonstrates with a case study how this bottom-up approach with microgrids would work. It focuses on development in the state of Bihar in India.

step 1: renewable resource assessment

The first step to this approach is to make an assessment of the resources available in the area. In the case of Bihar, these are biomass, hydro and solar PV power. While there are no detailed wind measurements available, there are indications that in some areas wind turbines could operate economically as well.

step 2: demand projections

The second step is to assess the level of electrical demand that will need to be serviced. Once there is access to electricity services, demand will almost always grow, accompanying economic growth. For the case of Bihar the following demand levels were considered, which are characterised by total energy consumption, peak demand and daily load profiles as shown in **Figure 1** below.

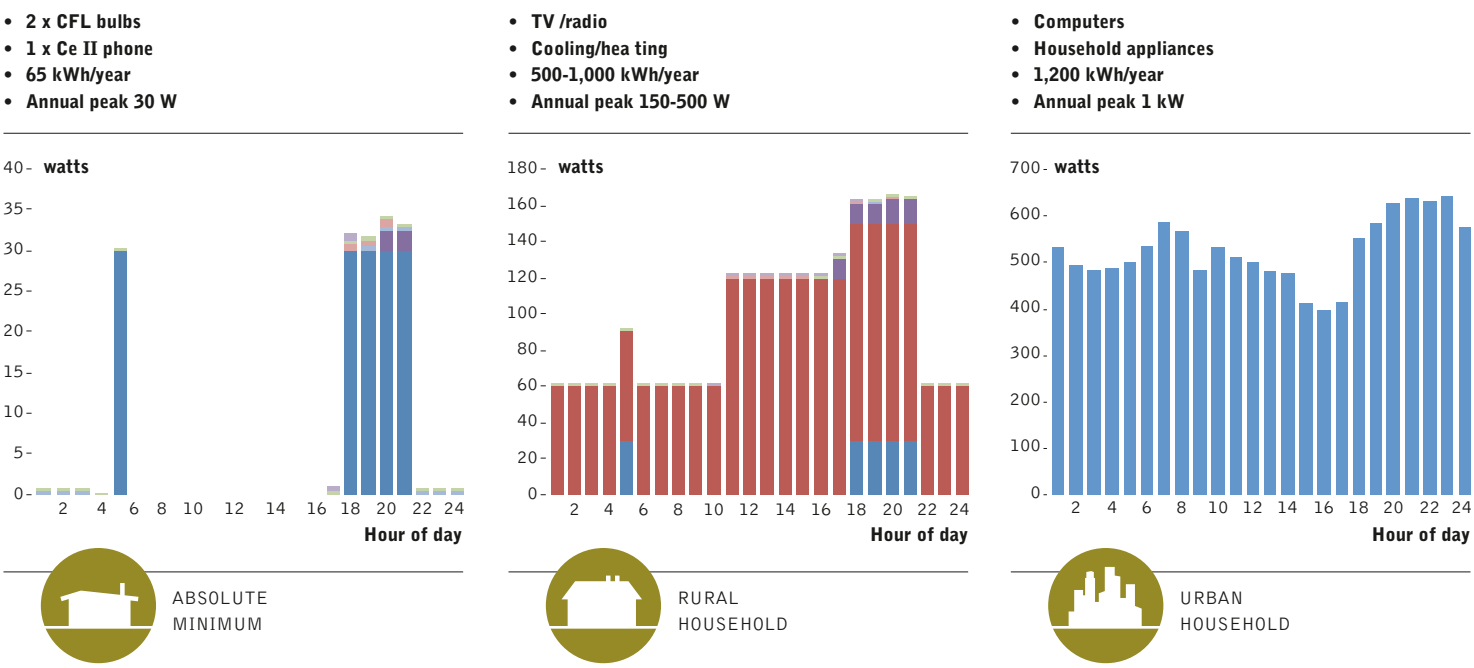
As the proposed bottom-up electrification approach starts on a per-village basis, a set of village demand profiles is generated based on these hypothetical household demand profiles. The village demand profiles also contain assumptions about non-household loads such as a school, health stations or public lighting.

The village-based electricity supply system forms the smallest individual unit of a supply system. Therefore the matching set of generation assets is also determined on a per-village basis.

step 3: define optimal generation mix

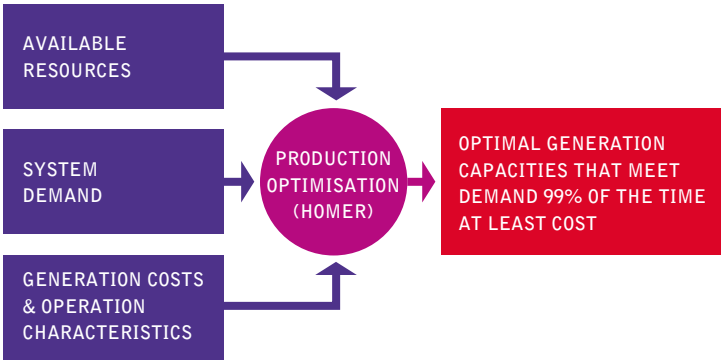
The third step in this approach is to design a system which can serve the demand using the resources available in the most economic manner. At this point it is of utmost importance that the system design uses standard components and is kept modular so that it can be replicated easily for expansion across the entire state. In designing such a system, an appropriate generation mix needs to be developed, which can meet demand 99% of the time at the lowest production cost. This can be determined using production simulation software such as HOMER[5], which calculates the optimal generation capacities based on a number of inputs about the installation and operation costs of different types of generation technologies in India.

figure 1: illustration how the demand ("development of the household") will change over time



Source: GREENPEACE INTERNATIONAL

figure 2: process overview of supply system design by production optimisation

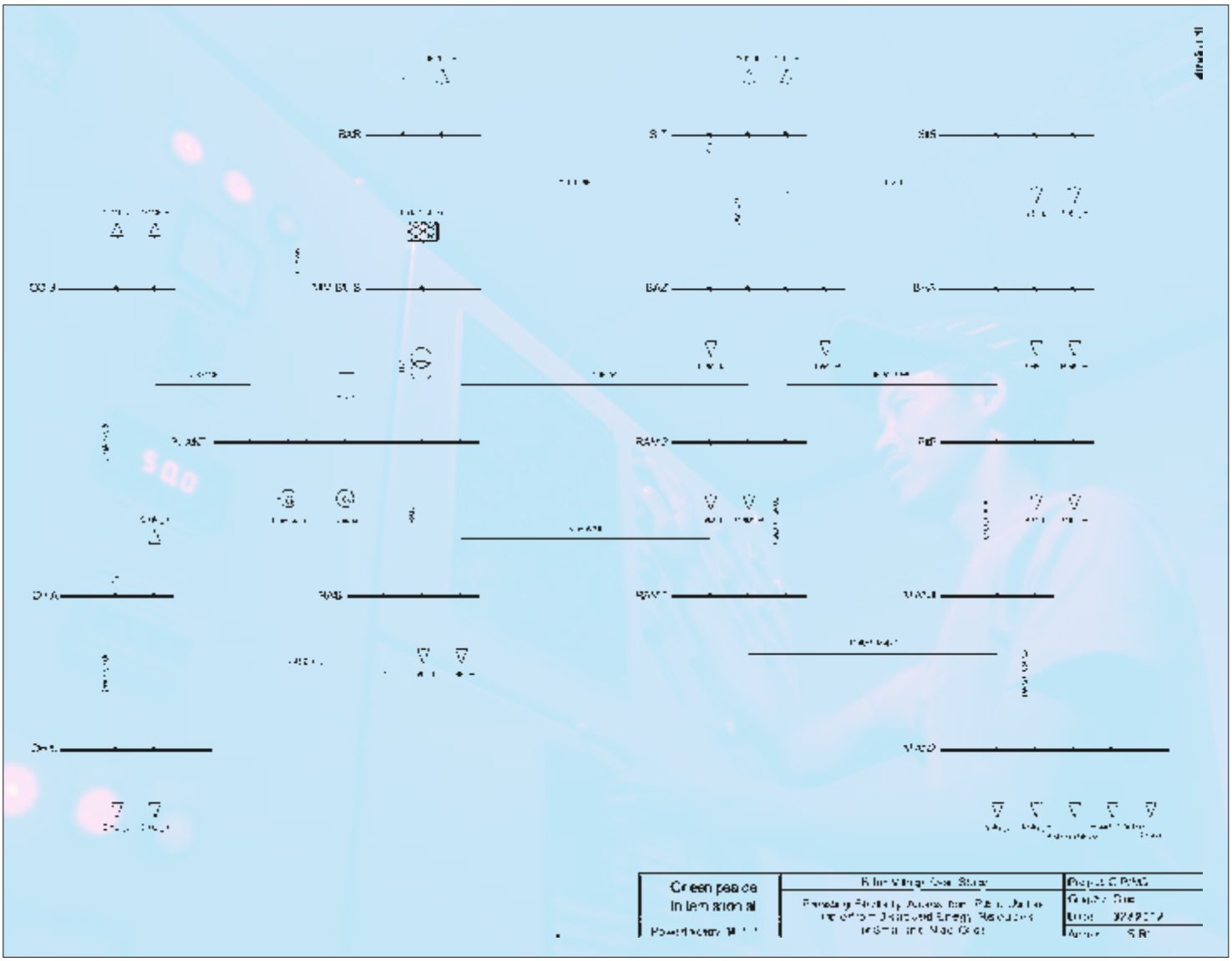


Source: ENERGYNAUTICS

step 4: network design

Once the optimal supply system design is determined, it is also important to make sure that such a supply system can be distributed through a physical network without breaching safe operating limits, and that the quality of the delivered electricity is adequate for its use. This can be done by modelling the physical system using power system simulation software such as PowerFactory[6]. In this way the behaviour of the electrical system under different operating conditions can be tested, for example in steady-state power flow calculations. **Figure 3** shows a diagram of the village power system model used in this study.

figure 3: diagram of the powerfactory grid model



Source: ENERGYNAUTICS

Electric Cooker in Udmaroo Village
SONAM TSOMO MAKES DINNER ON AN ELECTRIC COOKER IN THE EVENING IN UDMAROO VILLAGE, NUBRA VALLEY, LADAKH. ELECTRICITY IS SUPPLIED TO THE VILLAGE FOR SIX HOURS EVERY EVENING BY A MICRO-HYDRO POWER UNIT INSTALLED ON A MOUNTAIN STREAM ABOVE THE HIMALAYAN VILLAGE.

table 1: village cluster demand overview

DEMAND SCENARIOS				SUPPLY NEEDS	
SCENARIO		DEMAND PER DAY [kWh/day]	TOTAL ANNUAL DEMAND [kWh/a]	PEAK DEMAND [kWpeak]	TOTAL INSTALLEDCAPACITY [kW]
D1	Absolute Minimum village	111	40,514	22	31.5
D2	Low income village	881	321,563	99.4	106
D3	Medium income village	1,754	640,117	271	265
D4	Urban households village	4,192	1,530,037	554	800

Source: ENERGY [R]EVOLUTION CLUSTER - SMART ENERGY ACCESS, ENERGYNAUTICS MAY 2012 AND GREENPEACE INTERNATIONAL

step 5: control system considerations

The final part of the system design involves the development of a suitable strategy for switching between grid-connected and island modes. Depending on the quality of service required by the loads in the microgrid, the regulations stipulated in the grid code for operation practices, and number of grid support features desired, several different designs could be developed. For microgrids as part of rural electrification efforts in developing countries however, design simplicity and cost efficiency weighs more than the benefits of having an expensive but sophisticated control system.

Through the use of microgrids, the gap between rural electrification and universal electrification with grid expansion can be met, while at the same time bringing many additional benefits both for the consumers and grid operators. By developing a system which is modular and constructed using standard components, it makes it easier to replicate it across wide areas with varying geographic characteristics. The method demonstrated in this report can be used to develop roadmap visions and general strategy directions. It must be noted however, that detailed resource assessments, cost evaluations, demand profile forecasts and power system simulations are always required to ensure that a specific microgrid design is viable in a specific location.

results

This report shows how microgrids could be a useful concept for accelerating current rural electrification efforts, supporting renewable energy integration into power systems, and creating a reliable power system. The key to the wide-spread adoption of such a strategy is to come up with system designs which are cost competitive, and can be constructed using standard components in a modular fashion. The process to develop such system designs is demonstrated with a case study in Bihar, India.

In the first instance, the microgrid can be designed as an off-grid system with its own voltage and frequency control. It is recommended that conventional voltage and frequency droop control be used, rather than building a costly control scheme at this stage of development. The first priority for an un-electrified village in accessing electricity is to have access to lighting, which can extend productive work hours. Therefore at absolute minimum, a microgrid must be able to supply a demand based on the use of basic lighting, being 2 compact fluorescent lamps (CFL) per household.

This can be achieved most efficiently with a predominantly biomass-powered system, such as the Husk Power Systems[7], which are already in application in a number of villages in Bihar today. While the husk power system operates by charging around 18 INR/kWh, the system designs based on HOMER calculations indicates a system cost of approximately 24 INR/kWh. The discrepancy is attributed to the fact that the optimal system calculated by HOMER is designed to assure supply reliability 99% of the time.

Once an electricity service is available, people generally increase their consumption. In India, this means adding appliances such as fans, television sets and cellular phones. For a basic service which can supply these types of appliances, a system that provides approximately 500 kWh per year per household is required. This can be achieved with a predominantly PV-biomass system or a PV-biomass-hydro system (if a suitable hydro resource is available in the vicinity of the village). Such systems can be achieved at costs of around 19-24 INR/kWh, or 11-13 INR/kWh respectively.

In the E[R] Village Cluster concept, the demand grows step by step as the economy grows and ultimately reaches the level of an Indian household in a city. Such a system would need to provide for a consumption of around 1,200 kWh per year per household. These systems can be achieved also at costs of 19-24 INR/kWh, or 13-17 INR/kWh respectively.

The more important point in achieving this system level is the way in which the system is expanded. For example, biomass systems based on rice husk (husk power systems) are available in unit sizes of 32 kW and 52 kW, while hydro power is not profitable for units sizes below 100 kW (based on the general flow conditions assumed for the state of Bihar). On the other hand, solar PV systems are assumed to be roof-top systems, so as not to compete for land space with agricultural production. Therefore the unit sizes are much smaller, in the range of 100-1,000 W. Therefore it would be up to the system owner to decide how best to expand the system in a piecewise fashion. However the energy clusters in the Greenpeace concept are operated entirely with sustainable biomass and other renewable energy sources. Three different energy mix options have been calculated, based on different resource availabilities in the State of Bihar.

table 2: village cluster calculated energy mix

		INSTALLED CAPACITY MANJHARIA VILLAGE				GENERATION BY TECHNOLOGY			
SCENARIO		PV	WIND	HYDRO	BIO ENERGY	PV	WIND	HYDRO	BIO ENERGY
		[kW]	[kW]	[kW]	[kW]	[kWh/a]	[kWh/a]	[kWh/a]	[kWh/a]
		MEDIUM PV COST			MEDIUM PV COST	MEDIUM PV COST			MEDIUM PV COST
SCENARIO A: SOLAR + BIOMASS									
D1	Absolute Minimum village	1.5			30	2,582			39,480
D2	Low income village	6.0			100	10,329			319,710
D3	Medium income village	25.0			240	43,037			627,320
D4	Urban households village	600.0			200	1,032,885			925,648
SCENARIO B: SOLAR + SMALL HYDRO + BIOMASS									
D1	Absolute Minimum village	1.5			30	2,582			39,480
D2	Low income village	6.0		100	40	10,329		588,285	18,355
D3	Medium income village	25.0		250	180	43,037		1,332,918	128,860
D4	Urban households village	400.0		250	200	688,590		1,332,918	351,076
SCENARIO C: SOLAR + WIND + BIOMASS									
D1	Absolute Minimum village	1.5			30	2,582			39,480
D2	Low income village	6.0			100	10,329			319,710
D3	Medium income village	25.0			240	43,037			627,320
D4	Urban households village	400.0	100		300	688,590	240,159		867,518

Source: ENERGY [R]EVOLUTION CLUSTER - SMART ENERGY ACCESS, ENERGYNAUTICS MAY 2012 AND GREENPEACE INTERNATIONAL

Since the village of Manjharia seems to have no wind potential which would allow to operate wind turbines economically[8], both scenario A and B shown in **Table 2** (see above) could be implemented there. Scenario C however shows a generation mix for villages with wind potential (6 m/s average wind speed).

When the system demand reaches a certain level, it becomes financially interesting for the central grid to extend its services. Therefore it is assumed that such microgrids will eventually be connected to the central grid. Since microgrids retain the ability to function as an autonomous system, when the grid finally comes, certain switching arrangements can be implemented to allow the microgrid to operate both in grid-connected mode and island mode, depending on the situation. For example, when there is a prolonged blackout in the central grid, such as during rotating blackouts at peak demand periods, the microgrid can disconnect from the grid and operate in island mode, supplying loads locally. Also when the microgrid is connected to the grid and receiving standard service conditions, the generators connected to the microgrid can reduce their outputs and let the cheap grid supply provide electricity to the loads.

For a microgrid system to be able to manage the transitions to and from grid-connected mode to island mode with minimal interruption to grid operation, generators and loads, sophisticated control schemes are required, which monitor, communicate and coordinate control of all of these elements. Such a control system would be expensive to develop, and some functions are still subjects of R&D in laboratory conditions or in pilot project stages in regions like the USA, Europe and Japan.

However it would be difficult to implement such a system in a rural area in a developing country which has financial barriers as well as less operational capacity, market flexibility, and regulatory considerations. This is why a simplified design concept which limits the transition from grid-connected mode to island mode to periods with prolonged blackouts, and following this, the transition from island to grid-connected mode and hand over control back to the central grid.

This strategy would involve manual switching following a system blackout, to disconnect the microgrid from the central grid. Once the microgrid is fully disconnected from the central grid it can be restarted, and continue operation in island mode. Later, when the central grid is back up and running, the microgrid would again experience a brief blackout, while the connection to the grid is switched back on, at which point the loads can be supplied again, by the central grid supply[9].

Required Investment for a E[R]village Cluster

The first phase of this concept, corresponding to demand scenario 1, would require an investment of 40 million INR for generation assets and network equipment. With growing demand both the investment in new generation and the income from selling the electricity would grow. Compared to a supply scenario that includes Diesel, the 100% renewable energy mix would be slightly more expensive, also due to higher storage needs from photovoltaic power generation. Unlike the Diesel supply option, the money would remain in the community, as the fuel is local, adding more economic benefits to the village. In order to bridge the cost gap Greenpeace suggests supporting E[R] village clusters with national and internal access to energy programmes.

ID: GP0260IHouse in Tangtse Village
CHHEMAT DORJAK (35, LEFT) AND STANZIN DOLMA (28, RIGHT) WATCH TELEVISION IN THEIR HOME IN TANGTSE VILLAGE, DURBUK BLOCK, LADAKH. THEIR ELECTRICITY IS SUPPLIED BY A SOLAR PHOTOVOLTAIC POWER PLANT IN TANGTSE, 14,500M AMSL IN THE HIMALAYA. THEY PAY A TWICE-YEARLY FEE TO A LOCAL COMMITTEE, ELECTED TO MANAGE THE PLANT.

table 3: village cluster supply system investment overview

SCENARIO		INVESTMENT FOR 3 DIFFERENT SCENARIOS: INVESTMENT POWER GENERATION US$	THOUSAND INR	INVESTMENT NETWORK EQUIPMENT US$	THOUSAND INR	TOTAL INVESTMENT US$	THOUSAND INR	OPERATION & MAINTAINANCE US$ /year	THOUSAND INR	GENERATION COSTS US$ /kWh/a	INR /kWh/a	COST DELTA TO DIESEL OPTION US$ /kWh/a	INR /kWh/a
SCENARIO A: SOLAR + BIOMASS													
D1	Absolute Minimum village	67,706	3,555	696,100	36,545	763,806	40,100	10,347	543	0.47	25	0.01	1
D2	Low income village	164,406	8,631	808,100	42,425	972,506	51,057	97,333	5,110	0.37	19	0.10	5
D3	Medium income village	439,337	23,065	808,100	42,425	1,247,437	65,490	245,636	12,896	0.47	25	0.17	9
D4	Urban households village	2,205,136	115,770	1,242,200	65,216	3,447,336	180,985	278,073	14,599	0.37	19	0.09	5
SCENARIO B: SOLAR + SMALL HYDRO + BIOMASS													
D1	Absolute Minimum village	67,706	3,555	696,100	36,545	763,806	40,100	10,347	543	0.47	25	0.01	1
D2	Low income village	385,745	20,252	850,200	44,636	1,235,945	64,887	20,060	1,053	0.22	11	0.01	1
D3	Medium income village	769,450	40,396	850,200	44,636	1,619,650	85,032	57,939	3,042	0.24	13	0.04	2
D4	Urban households village	1,932,728	101,468	1,242,200	65,216	3,174,928	166,684	146,604	7,697	0.26	13	0.09	5
SCENARIO C: SOLAR + WIND + BIOMASS													
D1	Absolute Minimum village	67,706	3,555	696,100	36,545	763,806	40,100	10,347	543	0.47	25	0.01	1
D2	Low income village	164,406	8,631	808,100	42,425	972,506	51,057	97,333	5,110	0.37	19	0.10	5
D3	Medium income village	439,337	23,065	808,100	42,425	1,247,437	65,490	245,636	12,896	0.47	25	0.17	9
D4	Urban households village	2,075,296	108,953	1,242,200	65,216	3,317,496	174,169	342,264	17,969	0.40	21	0.12	6

Source: ENERGY [R]EVOLUTION CLUSTER - SMART ENERGY ACCESS, ENERGYNAUTICS MAY 2012 AND GREENPEACE INTERNATIONAL

table 4: key results for e[r] village cluster - overall demand and supply - bihar state rural

DEMAND STATE OF BIHAR RURAL: SCENARIO		DEMAND PER DAY [GWh/day]	TOTAL ANNUAL DEMAND [GWh/a]	SUPPLY STATE OF BIHAR RURAL: PEAK DEMAND [MWpeak]	TOTAL INSTALLED CAPACITY [MW]
D1	Absolute Minimum (state-wide)	2	770	418	599
D2	Low income demand (state-wide)	17	6,110	1,889	2,140
D3	Medium income demand (state-wide)	33	12,162	5,149	5,641
D4	Urban households (state-wide)	80	29,085	10,526	15,357

Source: ENERGY [R]EVOLUTION CLUSTER - SMART ENERGY ACCESS, ENERGYNAUTICS MAY 2012 AND GREENPEACE INTERNATIONAL

Bottom up electrification, local planning with local technicians (education & training required[10]) and top-down financing could make access to energy a true success story in a win-win situation.

Up-scaling the E[R]cluster

To replicate this type of microgrid design across the entire state of Bihar, a rough approximation based on geographical division indicates that 13,960 villages can be supplied by a non-hydro no-wind system and 3,140 villages with a hydro system. It is assumed that there is potential for up to 1900 systems where wind power may be used, and that a total number of 19,000 villages are appropriate to cover all rural areas in the state of Bihar.

With such an expansion strategy, at minimum (corresponding to demand scenario 2) approximately 1700 MW of biomass, 314 MW of hydro and 114 MW of PV power installations would be required. At the stage when microgrids are fully integrated with the central grid (demand scenario 4), it is expected that at least 4,000 MW of biomass, 785 MW of hydro and 10,000 MW of PV power installations would be required.

Future Energy Mix in rural Bihar

Should the E[R] village clusters be implemented across all rural areas in the state of Bihar, then all three generation options (Scenario A, B and C) will be implemented. The generation mix depends on the available resources and therefore will vary significantly. However, we assumed that the majority of the villages will have a mix of bio-energy, solar and small hydro - with a few clusters including wind.

table 5: bihar state rural calculated energy mix

SCENARIO		INSTALLED CAPACITY BIHAR STATE RURAL				GENERATION BY TECHNOLOGY			
		PV [MW]	WIND [MW]	HYDRO [MW]	BIO ENERGY [MW]	PV [GWh/a]	WIND [GWh/a]	HYDRO [GWh/a]	BIO ENERGY [GWh/a]
HIGH PV COST SCENARIO									
D1	Absolute Minimum (state-wide)	29	0	0	570	49	0	0	750
D2	Low income demand (state-wide)	114	0	314	1,712	196	0	1,847	5,128
D3	Medium income demand (state-wide)	475	10	785	4,372	818	27	4,185	10,349
D4	Urban households (state-wide)	10,012	570	785	3,990	17,235	1,369	4,185	15,804
MEDIUM PV COST SCENARIO									
D1	Absolute Minimum (state-wide)	29	0	0	570	49	0	0	750
D2	Low income demand (state-wide)	114	0	314	1,712	196	0	1,847	5,128
D3	Medium income demand (state-wide)	475	0	785	4,372	818	0	4,185	10,354
D4	Urban households (state-wide)	10,392	190	785	3,990	17,890	456	4,185	15,673
LOW PV COST SCENARIO									
D1	Absolute Minimum (state-wide)	29	0	0	570	49	0	0	750
D2	Low income demand (state-wide)	114	0	251	1,712	196	0	1,478	5,105
D3	Medium income demand (state-wide)	2,458	0	785	4,372	4,231	0	4,185	8,724
D4	Urban households (state-wide)	12,358	0	785	3,800	21,274	0	4,185	14,080

Source: ENERGY [R]EVOLUTION CLUSTER - SMART ENERGY ACCESS, ENERGYNAUTICS MAY 2012 AND GREENPEACE INTERNATIONAL

The overall installed capacity of solar photovoltaic systems would be in the range of 12,000 MW, while the rice husk and bio-energy generators would add up to around 3,800 MW. The overall regional bio-energy potential of 16 TWh/a would be sufficient to fuel the fleet of generators, significantly decreasing Bihar's dependence on imported fuels.

Investment requirements for the state for Bihar

The overall investment requirement for each E[R] villager cluster would be in the range of 1 to 1.5 million US Dollar (50 to 60 million INR)[11] – a investment volume which is quite typical for small to medium size energy projects, but importantly without the need to import fuel. Large parts of the money invested in E[R] cluster would remain within the community and would contribute to the local economy.

The case study in Bihar, India, clearly demonstrates how to realise the active bottom-up approach of the Smart Energy Access strategy. The transition from rural-electrification to universal electrification is made possible by making use of the versatility of microgrids. That is, its functionality as an off-grid system, the ability to incorporate multiple generation sources, adapt to demand growth, and to be integrated with the central grid, while retaining the ability to separate and operate as an island grid if needed. By building prototype microgrid designs, which can be created using standard components, mixed and matched according to the type of renewable resources available in the area, adoption and implementation can be made efficient and effective, and suitable for wide-spread application in developing countries.

footnotes

5 HOMER IS AN ENERGY MODELLING SOFTWARE FOR DESIGNING AND ANALYSING HYBRID POWER SYSTEMS. A TRIAL VERSION OF THE SOFTWARE CAN BE DOWNLOADED FOR FREE AT THE WEBSITE: HTTP://WWW.HOMERENERGY.COM/

6 POWERFACTORY IS A POWER SYSTEM SIMULATION SOFTWARE FOR DESIGNING AND ANALYSING POWER SYSTEMS. IT IS A LICENSED PRODUCT DEVELOPED BY DIGSILENT.

7 WWW.HUSKPOWERSYSTEMS.COM

8 THE AVERAGE WIND SPEED IS ONLY ABOUT 4 M/S. FOR ECONOMIC OPERATION OF WIND TURBINES AT LEAST 6 M/S CAN BE CONSIDERED AS A MINIMUM REQUIREMENT.

9 THIS IS NEEDED WHERE GENERATOR MODES OF OPERATION OR PROTECTION SETTINGS ARE DIFFERENT BETWEEN ISLAND OPERATION AND GRID-PARALLEL OPERATION AND CANNOT BE SWITCHED AUTOMATICALLY.

10 COSTS FOR EDUCATION PROGRAMS ARE NOT INCLUDED IN THIS CALCULATION

11 MEDIUM PV COST SCENARIO, DEMAND SCENARIO 4, COST NOT INCLUDING NETWORK EQUIPEMENT.

diesel truck on ladakh-manali route

A DIESEL TRUCK ON THE LADAKH - MANALI ROUTE. DIESEL IS THE MAIN FUEL FOR TOWNS AND VILLAGES IN THIS REMOTES REGION, AND MUST BE BROUGHT BY ROAD: OFTEN A JOURNEY OF MULTIPLE DAYS. DUE TO SNOWS AND LANDSLIDES, DELAYS ARE COMMON.

Electric Saw in Udmaroo Village
CARPENTER TSEWANG STOBDAN OPERATES AN ELECTRIC SAW UNIT IN UDMAROO VILLAGE, NUBRA VALLEY, LADAKH. HE IS A MEMBER OF A MEN'S SELF-HELP GROUP THAT HAS STARTED USING THE ELECTRIC MACHINE SINCE A MICRO-HYDRO POWER UNIT WAS INSTALLED ABOVE HIS VILLAGE IN THE HIMALAYA. THEY CAN NOW WORK FASTER AND TSEWANG ESTIMATES HAVING THE MACHINE HAS DOUBLED THEIR INCOME.

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table 6: bihar state rural supply system investment overview

SCENARIO		INVESTMENT POWER GENERATION MILLION US$	INVESTMENT POWER GENERATION BILLION INR	INVESTMENT NETWORK EQUIPMENT MILLION US$	INVESTMENT NETWORK EQUIPMENT BILLION INR	TOTAL INVESTMENT MILLION US$	TOTAL INVESTMENT BILLION INR
HIGH PV COST SCENARIO							
D1	Absolute Minimum (state-wide)	1,334	70.1	13,226	694.4	14,560	764.4
D2	Low income demand (state-wide)	4,109	215.7	15,486	813.0	19,595	1,028.8
D3	Medium income demand (state-wide)	10,198	535.4	15,486	813.0	25,684	1,348.4
D4	Urban households (state-wide)	60,257	3,163.5	23,602	1.239.1	83,859	4,402.6
MEDIUM PV COST SCENARIO							
D1	Absolute Minimum (state-wide)	1,286	67.5	13,226	694.4	14,512	761.9
D2	Low income demand (state-wide)	3,819	200.5	15,486	813.0	19,305	1,013.5
D3	Medium income demand (state-wide)	9,384	492.7	15,486	813.0	24,870	1,305.7
D4	Urban households (state-wide)	40,796	2,141.8	23,602	1,239.1	64,397	3,380.9
LOW PV COST SCENARIO							
D1	Absolute Minimum (state-wide)	1,250	65.6	13,226	694.4	14,476	760.0
D2	Low income demand (state-wide)	3,665	192.4	16,074	843.9	19,739	1,036.3
D3	Medium income demand (state-wide)	11,461	601.7	16,154	848.1	27,615	1,449.8
D4	Urban households (state-wide)	26,860	1,410.2	23,602	1,239.1	50,462	2,649.3

Source: ENERGY [R]EVOLUTION CLUSTER - SMART ENERGY ACCESS, ENERGYNAUTICS MAY 2012 AND GREENPEACE INTERNATIONAL

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1

access to energy - the concept

Woman with Solar Lantern in Bihar
A WOMAN BRINGS A SOLAR LANTERN TO THE KOTAK URJA 3 KVA SOLAR STATION. THE STATION WAS SET UP IN APRIL 2010 IN A HAMLET OF MUSAHARS - THE POOREST OF THE POOR CASTE IN BIHAR - WHICH HAS NEVER HAD AN ELECTRICITY CONNECTION. THE SOLAR PLANT, INSTALLED AT SIKANDARPUR, ALSO PROVIDES POTABLE WATER, COMMUNITY TV, A TELEPHONE BOOT AND CELLPHONE CHARGING POINTS. SIKANDARPUR VILLAGE, DANAPUR, BIHAR.

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1 ACCESS TO ENERGY – THE CONCEPT

With growing demand, rising fossil-fuel prices and international pressure to reduce greenhouse gas emissions, developing nations are facing two pressing issues that need to be addressed in parallel: increasing energy access to pull people out of poverty, while integrating as much renewables as possible.

RURAL ELECTRIFICATION FOR UNIVERSAL ELECTRIFICATION

Rural electrification programs are considered an important part of the strategy to achieve universal electrification in developing countries. These programs provide access to electricity services either by extending the central grid, or building off-grid generation capacity. Since the ultimate goal is to provide reliable electricity services at affordable costs, the cheaper of the two options is usually the one that is implemented.

Grid extension – the passive top-down approach –

For a village that is not yet electrified, connecting to the grid is seen as the preferred option; because it means that it will be integrated directly into the central grid and can access cheap power supply (due to economies of scale). However, in many developing countries there isn't enough central grid supply to cover all demand, and small rural connections are often cut off in favour of maintaining supply to cities and industries (resulting in frequent blackouts). Another issue is that the central grid operators often do not know exactly how much power is consumed where in the system, due to lack of metering equipment and rampant energy theft. This makes it difficult to control the power quality such as maintaining voltage and frequency within standard operating limits. Furthermore in some cases, even if extending the grid is the cheaper option, rural communities may not be able to afford the interconnection costs.

Off-grid power generation – the active bottom-up approach –

Under these circumstances, the option of building off-grid supply systems such as solar home systems and mini-grids may be better than extending the grid. This is because it can provide reliable electricity supply at a relatively low cost. Power can be sourced from local renewable resources, and due to short distances between generators and consumers, there are very little electrical system losses. Furthermore, such systems can be installed and setup for operation in a relatively short length of time. The negative aspects of these systems are that they are typically designed for a particular consumption profile; therefore require additional equipment to cater for increases in demand. Also, once an off-grid supply system is provided, the village is often neglected in further electrification considerations because from the central system's point of view its work is done on electrifying that village.

What is the problem with the current process?

Although in principle rural electrification programs lead to universal electrification, in reality, there are obstacles that need to be overcome until the desired level of electricity service can be available to all. These obstacles are created by the limits imposed by the imperfect system, such as inadequacies of the central grid infrastructure and operation capability, high initial costs of projects, and lack of foresight in system design that is adopted. These act to create a gap between the top-down approach of extending the grid, and the bottom-up approach of building off-grid systems (Figure 4).

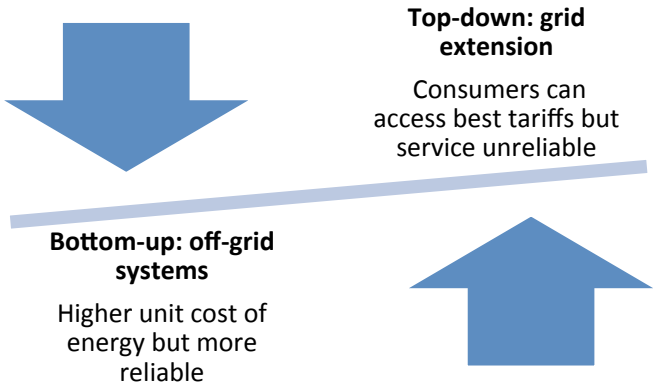

Figure 4: Top-down versus bottom-up approach to electrification. Source: energynautics

For an un-electrified rural village, gaining access to electricity services provided by the central grid can be the cheapest solution. However, often the supply reliability and quality is compromised because of rampant supply shortages and electricity theft. On the other hand, home energy systems and off-grid distribution systems can provide more reliable services. These options are particularly suitable for villages that are remote from the grid, or even if it is close to the grid cannot afford the connection costs, or where the grid supply is limited. Once an off-grid solution is implemented however, often it is dropped from the priority list to extend grid services, therefore creating a gap that prevents reliable universal electrification with grid expansion to be achieved.

INTEGRATION OF RENEWABLE ENERGIES

"Energy access is a prerequisite for development"

Then, access to renewable energy is a prerequisite for sustainable development. For the maximum number of people to access renewable energy in the most economic manner, economies of scale would dictate that the traditional top-down approach of large-scale power generation feeding into a central grid is the most appropriate way. However, for developing countries where the central grid reaches only a fraction of the population, and where it is difficult to finance large capital costs, a bottom-up approach maybe better, since it can provide energy directly to unsupplied areas without having such a high initial cost.

There are a number of bottom-up approaches to renewable energy development. These are: home energy systems, off-grid distribution systems, microgrids, and distributed generation systems (Figure 5). The choice of which energy supply option to use depends on the resources that are available, the financial capacity of the project executor, technical feasibility and flexibility, environmental impacts and social adaptability. For more information on these systems refer to chapter 3.

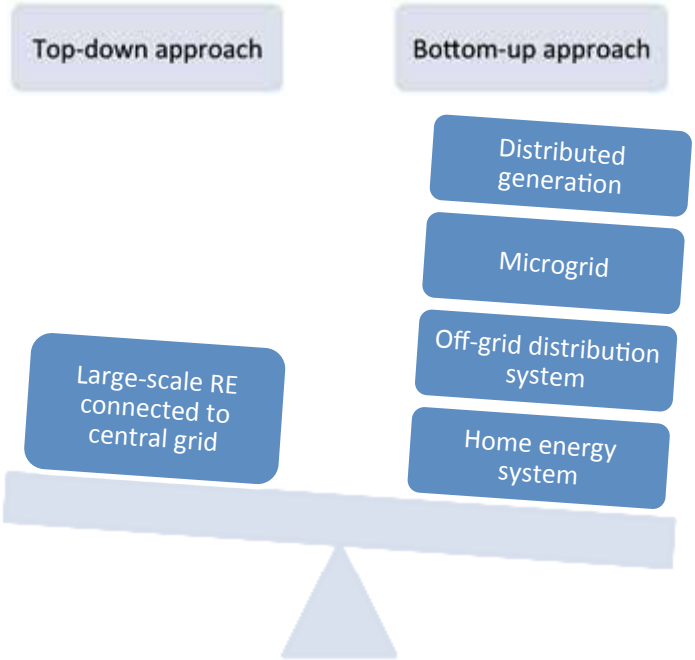

Figure 5: Top-down versus bottom-up renewable energy development approaches. Source: energynautics.

SMART ENERGY ACCESS

To get from rural electrification to a fully integrated grid while promoting renewable energies, we suggest microgrids for the following advantages/features.

Microgrids

The concept of microgrids, in particular, with *the ability to switch between island operation mode and grid-connected mode*, presents an interesting case. Microgrids are distribution grids which can be developed using a bottom-up approach, just like home energy systems and off-grid systems, using local renewable energy sources to supply local demand. However, unlike these island systems, power supply is more flexible and reliable because there is the option to source it from local or centralized generation, according to its availability and price. In this way, cheap power can be accessed from the grid during low demand periods, while local supply can be activated to power local demand during blackouts in the main grid. Furthermore, microgrids can control the balance between local supply and demand; therefore manipulate the power flow at the

point of common coupling with the grid. This enables the microgrid to support the larger grid in managing power quality as well as supply security, by injecting or consuming active or reactive power when required, and aiding in black-start situations.

Grid expansion for universal electrification using "bottom-up" approach with Microgrids

The Concept

Smart Energy Access is a strategy for universal electrification. It indicates a path from basic rural electrification using locally available renewable resources to a system that is fully integrated with the central grid. The method suggested as the vehicle for this transition, is what is known as the "Microgrid". The unique feature of a microgrid is that it has the ability to operate as an island system, without being connected to the central grid, but also as an integrated system, connected to the central grid, and operated as a standard part of the existing grid system. This feature allows microgrids to be developed as part of a "bottom up" approach to grid expansion. In rural areas where grid-connected electricity services do not exist, power can be generated locally by off-grid supply systems (in the form of energy home systems or mini-grids) relatively quickly. If these systems are designed in such a way that they can be turned into microgrids, they can be easily integrated into the central grid later when the grid is finally extended (Figure 6).

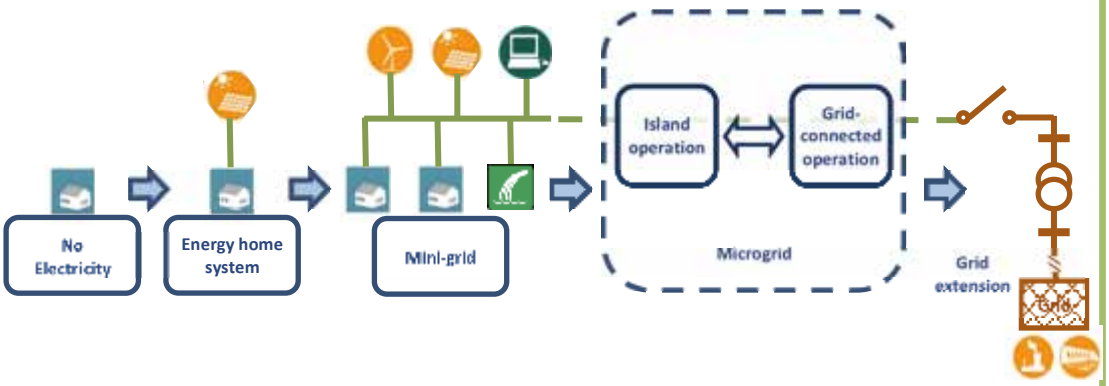

Figure 6: Development stages of the *Smart Energy Access* strategy. Source: energynautics.

Benefits of Microgrids for central grid:

Demand is supplied locally so the stress on central supply system is reduced

Voltage can be controlled at the point of common coupling (PCC) to support the central grid

Depending on design of the microgrid, it can contribute to frequency control and black start of the central grid

Furthermore, since the loads are supplied by local power generation, there will be less stress on the central grid to allocate supply from its already constrained supply system. If desired there is also potential to source extra supply from the microgrid to cover the shortages in the central grid, and the control systems of microgrids allow easy voltage control at the point of connection (this aids with keeping the central grid within healthy operating conditions). If the control system is sophisticated enough, there is also potential for the microgrids to contribute to frequency control and black starts, keeping the power supply quality in check and aiding with the recovery of the central grid from blackouts.

If it is such a great tool then, why aren't microgrids used already?

because of the additional capability of being able to switch between grid-connected and island operation modes. The associated system costs are also higher because of the additional control structure that is required. However, if these systems can be designed using standard components in such a way that they are replicable, the costs will eventually come down as more microgrid structures are implemented, due to economies of scale. Furthermore, the initial investment need not be for the final full microgrid solution, because microgrids can be built from standalone energy home systems and off-grid distribution systems. Therefore it gives flexibility in the timing of financial investment, starting with a simpler system and adding features as time goes by until it is fully integrated with the central grid system.

That is why in this report we try to give suggestions on how to simplify the microgrid design to be constructed out of standard components as replicable modules which can be implemented across the globe for a truly sustainable universal electrification.

2 microgrid design case study for bihar

Solar System on Hospital in Bihar
AN ELECTRICIAN AT TRIPOLIA HOSPITAL IN PATNA, OPERATES THE CONCENTRATED SOLAR POWER (CSP) SYSTEM ON THE HOSPITAL ROOF. THE SYSTEM HAS FOUR LARGE MIRROR DISHES, WHICH REFLECT THE SUN'S RAYS ONTO A HEADER PIPE CONTAINING WATER. AS THE RAYS ARE DIRECTED ONTO A SINGLE POINT, THE HEAT TRANSFERRED IS VERY GREAT, AND CREATES STEAM FROM THE WATER. TRIPOLIA'S CSP SYSTEMS NOW CREATE STEAM TO STERILISE ALL OF THE HOSPITAL'S MEDICAL INSTRUMENTS, DRESSINGS, BEDSHEETS AND LAUNDRY, USING THE FREE AND RENEWABLE ENERGY OF THE SUN.

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2 MICROGRID DESIGN CASE STUDY

The case for microgrids in promoting "smart" integration of renewable energy and expanding energy access in developing countries is demonstrated with a case study in the state of Bihar, India.

To give an example of the application, microgrid designs suitable for the state of Bihar in India are presented. Simple system designs are suggested that can be adopted in most villages across the state, to achieve the goal of universal electrification through Smart Energy Access.

METHODOLOGY

The first step to this approach is to make an assessment of the resources available in the area.

The second step is to assess the level of electrical demand that will need to be serviced.

The third and final step in this approach is to design a system which can serve the demand using the resources available in the most economic manner. At this point it is of utmost importance that the system design uses standard components and is kept modular so that it can be replicated easily for expansion across the entire state.

The size of the generation system is determined based on production optimisation using software called HOMER[12]. This program evaluates different combinations of generation technologies and determines the most cost efficient generation mix that meets the demand.

To ensure that such a supply system could actually be delivered through a physical network, power flow simulations are performed using software called PowerFactory[13]. In this way different network topologies can be evaluated, and equipment needed to maintain system frequency and voltages can be determined.

The final part of the system design involves the development of a suitable strategy for switching between grid-connected and island modes. Depending on the quality of service required by the loads in the microgrid, the regulations stipulated in the grid code

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[12] HOMER is an energy modelling software for designing and analysing hybrid power systems. A trial version of the software can be downloaded for free at the website: http://www.homerenergy.com/

[13] PowerFactory is a power system simulation software for designing and analysing power systems. It is a licensed product developed by DIgSILENT

for operation practices, and number of grid support features desired, several different designs could be developed. For microgrids as part of rural electrification efforts in developing countries however, where design simplicity and cost efficiency weighs more than the benefits of having a expensive but sophisticated control system, a simple strategy is proposed.

The process used to design the microgrid for this case study is shown in Figure 7.

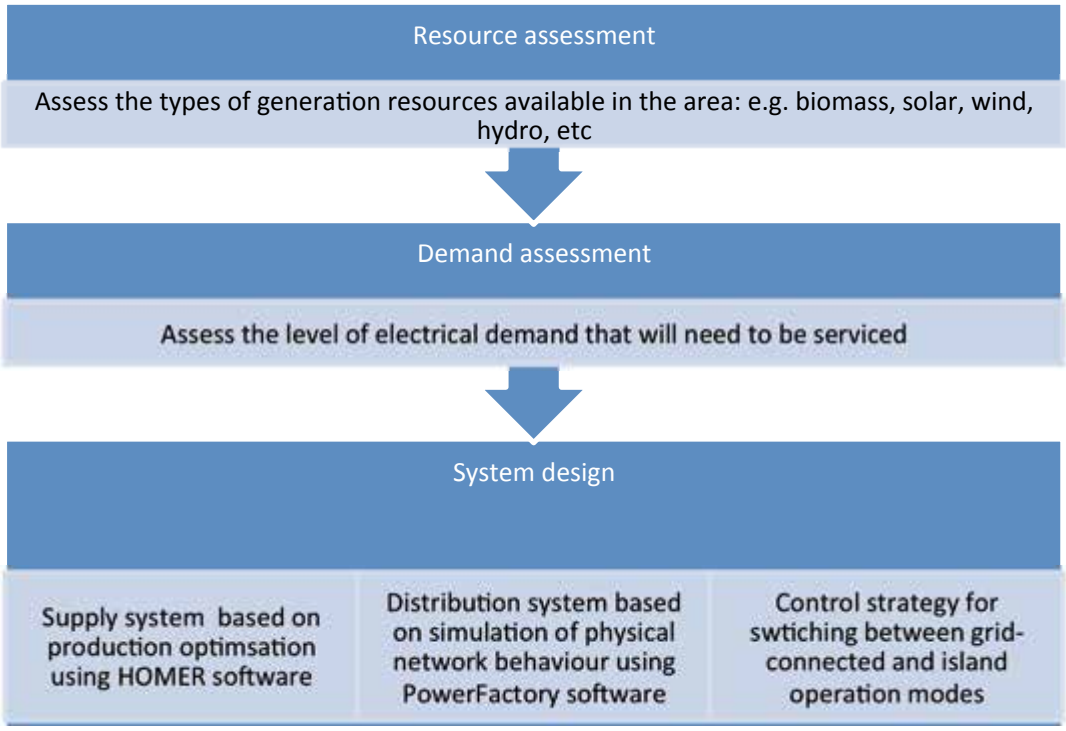

Figure 7: Process for designing the microgrid in the Bihar case study. Source: energynautics

OVERVIEW OF BIHAR

Bihar is a state in the north east of India. It consists mainly of flat plains and is interlaced with several rivers (Figure 8). It has a population of over 100 million[14], of which almost 85% live in rural areas. Agriculture is the main form of economy, owning to its fertile ground and plentiful water source. Temperatures can vary from 5 °C in winter (December to February) to 45 °C in summer (March to May)[15], and there is a monsoon season extending from June to September. The period from October to November is known as the post monsoon season.

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[14] http://gov.bih.nic.in/Profile/default.html

[15] http://www.biharonline.in/About/Profile/Geography/climate.html

Figure 8: Physical map of Bihar. Source: Modified from http://www.openstreetmap.org

The electrification rate in Bihar is one of the lowest in the country at 61%[16]. There is a rural electrification program[17] which aims to connect villages to the grid, however, even if there is a connection to the grid, due to the severe supply shortage[18], the quality and reliability of service are often compromised, with some villages reporting only 2 days of service per month[19].

Bihar Microgrid Village

A typical village in Bihar is mostly rural, with a school, a health centre, and administrative office, but normally there is very limited industry and commercial buildings[20]. The number of people per household is said to be around ten. This is higher than the national average of five people per household, but not an atypical situation, as it is common for several generations to live together under the same roof in rural parts of India.

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[16] http://www.iea.org/country/Poverty_India/Electrification.pdf

[17] Known as the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), the program has succeeded in electrifying 20,526 villages out of the target of 29,862 villages since 2005. http://gov.bih.nic.in/documents/Economic-Survey-2011-English.pdf Pate 161

[18] Acoording to http://gov.bih.nic.in/documents/Economic-Survey-2011-English.pdf Pate 164, there is a peak deficit of 51% and an energy deficit of 46%

[19] http://www.greenpeace.org/india/Global/india/report/Empowering-Bihar.pdf, Page 11

[20] http://www.icssr.org/Paschim%20Champaran%20final%5B1%5D.pdf Page 2

For the case study, a village in the northwest of the state called Manjharia was considered. This village has a population of 6,000 living in 12 conglomerations (called clusters in this report), and there are approximately 600 households in the area[21].

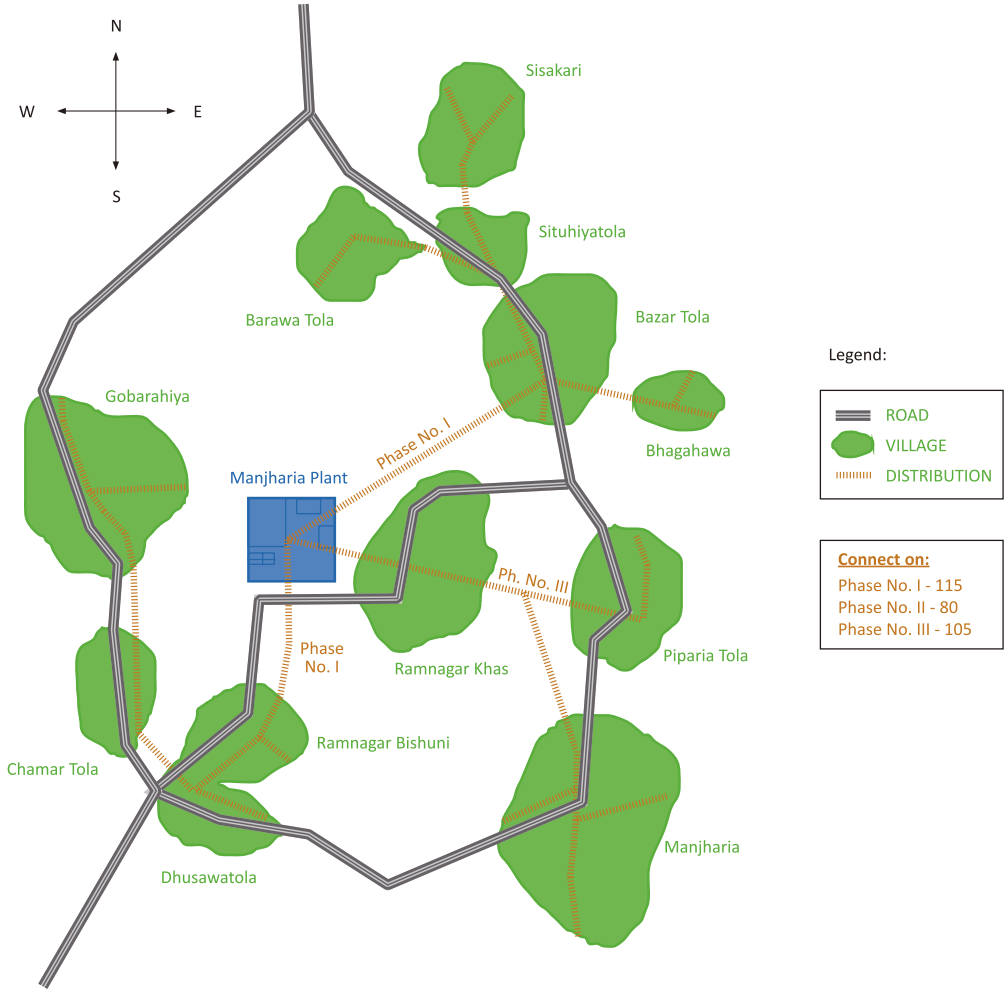

Figure 9: Map of Manjharia village. Source: Greenpeace.

The average annual income in Bihar (excluding the capital, Patna) is approximately 7,875 INR (1,750 USD) per capita [1]. Therefore for a household of ten people this amounts to just over 6,500 INR (145 USD) per month. Electricity delivered from the grid costs around 3 INR per kilowatt-hour [2], and the average per capita consumption is 122 kWh per year [3]. This means that approximately 300 INR/month is required for the most basic electricity service, if the grid can in fact provide it. It has been stated that, without access to the grid, or with access but poor service quality, villagers are willing to pay up to 15-20 INR/kWh for electricity services [2]. In the case of Manjharia, the district has no

[21] Information provided by Manish Ram

grid connection. Instead it is electrified by Husk Power Systems[22], a biogas power generation system based on rice husk. The service is available 6 hours a day, at a charge of 100 INR per month per 30 W of supply. This works out to be approximately 18 INR per kilowatt-hour, serving as a cost effective alternative to grid-supplied electricity.

The closest village with distribution infrastructure is Narkahawa approximately 3 km away. However, this village is currently not electrified. The closest village which is electrified is Mangalpur across the Gandak river, with a direct line distance of approximately 10 km (Figure 10).

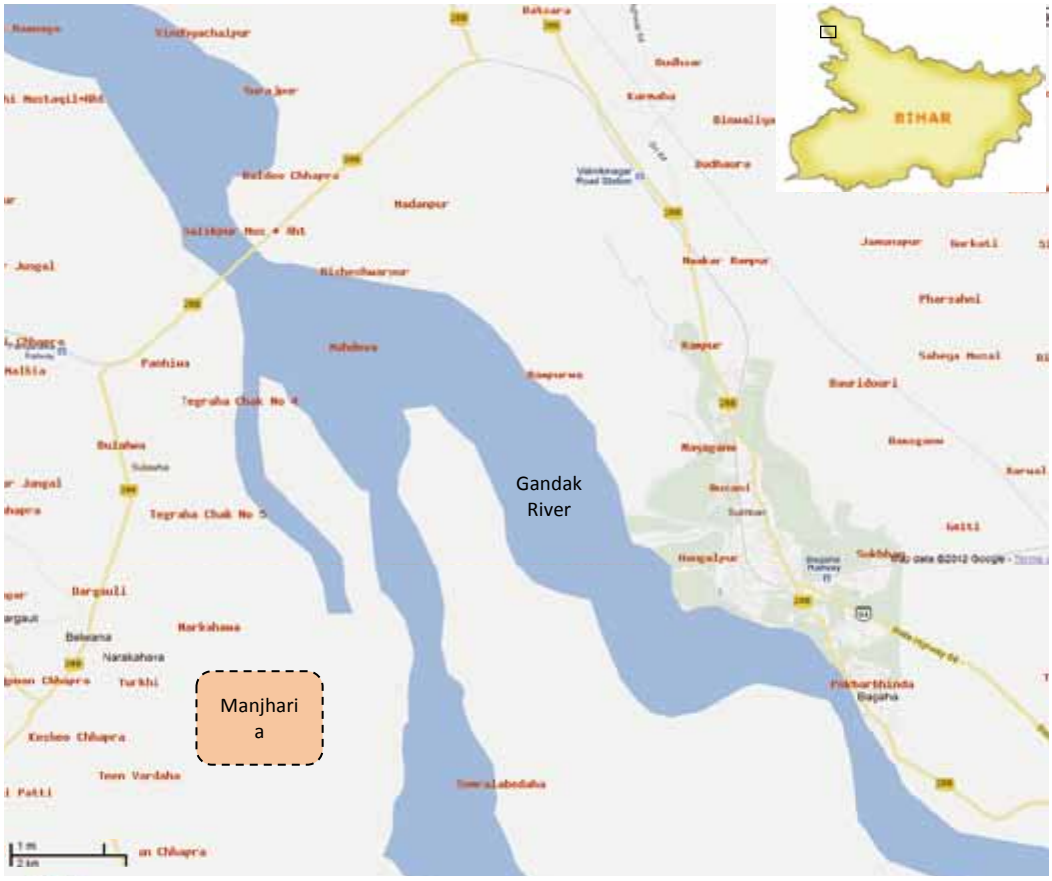

Figure 10: Map location of Manjharia. Modified from http://www.geolysis.com/ (Map data from Google Maps)

STEP 1: ASSESSMENT OF RENEWABLE ENERGY RESOURCES IN BIHAR

The economically exploitable renewable resources in Bihar are solar, wind, hydro and biomass.

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[22] *www.**huskpowersystems**.com*

With an average solar irradiation of 4.8 kWh/m^2/day and average daily sunshine of around 8 hours, solar power is a very attractive energy resource[23]. If the installation costs are competitive enough, solar photovoltaic technology is tipped to dominate the scene as it can be implemented almost anywhere in the state for electricity production. For the application of microgrids in rural villages, it is expected that most of the development will focus on rooftop solar PV systems, so as not to compete for land space with agricultural production.

Wind power on the other hand, is not a very attractive resource in Bihar. This is mainly due to the low average wind speeds across the state[24]. The resource may be exploitable with low power wind generation systems in the range of 100-1,000W turbines; however it is expected that the penetration rate of such systems will not be dominant due to the higher installation costs compared to other technologies.

With so many rivers and canals in the state, hydro power is also an attractive resource. However, due to the flat land topology, flow rates and available head heights are not very high[25], limiting the applications to low power hydro schemes. In addition, the low-lying flat plains are prone to flooding during monsoon season, and canals are used extensively for irrigation. Therefore the available flow for operation of a hydro power plant is highly seasonal, in some cases operation is interrupted for 4 months of the year[26]. Micro hydro technology is a well-established and economic sound technology however; therefore even with the limitations on resource availability it is expected to remain an exploitable resource.

A variety of biomass resources are available in Bihar, such as domestic waste, native shrubs, and by-products from agricultural production such as rice and wheat husks. The latter option is the most attractive as it can co-exist with production of much needed food products, and the largest waste product from rural areas of Bihar is agricultural waste, rather than domestic waste. Furthermore, power generation systems based on rice husk gasifiers are already application in a number of villages[27] as economically viable alternatives to electrification by grid extension.

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[23] Climatological Solar Radiation (CSR) data from NREL

[24] At a hub height of around 50m, the average wind speed is approximately 4 m/s according to http://energy.bih.nic.in/docs/RE-PA-AP-Bihar.pdf, Pages 18-19

[25] Most hydropower plants currently under operation in Bihar run on a design flow rate of around 200 litres per second and a head height of 4 metres.

[26] According to Natwar S.H. P. Salient Features provided by Bihar State Hydroelectric Power Corporation.

[27] See Husk Power Systems: *www.**huskpowersystems**.com*

Table 7: Electrical energy potential from bio-energy sources in the state of Bihar. Source: Greenpeace (modified from WISE[33])

No	Energy Source	PJ/a
	Agricultural Residues	
1+2	Rice husk (50% + 100% availability)	14.3
3	Rice straw (50% availability)	24.0
4	Maize cobs (50% availability)	1.6
5	Sugarcane bagasse	9.5
Sub total		49.3
	Urban Waste	
6	Municipal Solid Waste (thermochemical conversion)	0.8
7	Municipal Solid Waste (biochemical conversion)	0.5
8	Municipal Liquid Waste	0.7
Sub total		2.0
	Other Industrial Wastes	
9	Distillery (spentwash)	0.4
10	Dairy (washings, whey)	0.0
11	Sugar (waste water, pressmud)	0.1
Sub total		0.6
Total		51.9

STEP 2: ASSESSMENT OF SYSTEM DEMAND

The second step is to assess the level of electrical demand that will need to be serviced. The first priority for an un-electrified village is electricity service for lighting. Therefore the absolute minimum demand scenario assumes that every household is equipped with two CFL lights. The service is assumed to have limited availability, being 5-6 hours of electricity supply service per day

Once there is access to electricity, demand will most certainly grow. The second demand scenario also considers electricity services for space cooling and entertainment, being a fan and a television, which is considered to be the minimum standard for a low income household [4].

The ensuing scenarios allow for increased demand growth until the level of electricity consumption in a city is reached. For the purpose of this study, it was assumed that all households have more or less the same consumption pattern, with the following appliances considered in each scenario. The total energy consumption and peak demand are also given.

Table 8: Summary of appliances considered in the consumption patterns of residential demand for each scenario. Source: energynautics

	Scenario 1 Absolute minimum	Scenario 2 Low income household	Scenario 3 Medium income rural household	Scenario 4 Urban household
Lighting	✓	✓	✓	✓
Cell phone	✓	✓	✓	✓
Fan/Cooler		✓	✓	✓
Radio/TV		✓	✓	✓
Water pump			✓	✓
Other				✓
Peak demand per household	30 Wp	150 Wp	500 Wp	1 kWp
Annual energy demand per household	65 kWh	500 kWh	1,000 kWh	1,200 kWh

In addition to the residential sector, demand from the following sectors was also considered for all scenarios.

Table 9: Summary of appliances considered in the consumption patterns of non-residential demand for all scenarios. Source: energynautics

	Public lighting	School	Health station	Administrative building
Lighting	✓	✓	✓	✓
Fan/Cooler		✓	✓	✓
Water pump		✓	✓	
Refrigerator			✓	

The resulting system demand for each demand scenario is summarised in Table 10 below.

Table 10: Total annual demand and system peak demand for each scenario. Source: energynautics

	Scenario 1 Absolute minimum	Scenario 2 Low income household	Scenario 3 Medium income rural household	Scenario 4 Urban household
Total demand per year	40 MWh	320 MWh	640 MWh	1,540 MWh
System peak demand	20 kW	100 kW	270 kW	554 kW

STEP 3: SYSTEM SIZING BY PRODUCTION OPTIMISATION WITH HOMER

An optimal generation mix was then calculated using production simulation software called HOMER[28]. This software uses generation capital and operating costs as well as operation characteristics as input to calculate different combinations of generation units and sizes. It finds the least cost combination based on energy production simulation to meet the demand. The assumptions made regarding the generation costs and operation are summarised in Table 11 below.

Table 11: Generation cost assumptions used in the HOMER simulation for Bihar. Source: Various.

Generation type (unit sizes considered)	Capital cost (per kW)	O&M cost	Notes regarding operation
Solar PV (0.1-1 kW)	1,260-4,204 USD (114,000-190,000 INR) [5]	3% of CAPEX/yr [6]	Average irradiance: 4.87 kWh/m^2/day Installed as solar home systems Price without battery
Biomass (10-50 kW)	1,100-2,215 USD (50,000-100,000 INR) [7]	20% of CAPEX/yr [8]	Source: Rice husk Fuel cost: 0 USD/tonne[29] Consumption rate: 1.4-1.7 kg/kWh
Hydro (10-250 kW)	1 x 10 kW: 10,950 USD (495,000 INR) [9] 2 x 20 kW: 5,340 USD (241,250 INR) [10] 2 x 50 kW: 2670 USD (95,000 INR) [11] 250 kW: 1,900 USD (85,600 INR) [12]	5% of CAPEX/yr [9] [10] [11] [12]	Design flow rate: 7,250 L/s available between April to November
Wind (650-1,500 W)	4,250 USD (192,500 INR) [13]	3% of CAPEX/yr [13]	Average wind speed: 6 m/s at 20 m hub height
Diesel[30]	553 USD (25,000 INR) [14]	0.01 USD/h/kW (0.25 INR) [15]	Fuel cost: 0.97 USD/L (50 INR/L) Consumption rate: 0.3 L/kWh
Battery (50-200 Ah)	150-1,300 USD (6,800-58,750 INR) [31]	Negligible	Batteries are installed as part of the solar home systems
Grid extension	8,000 USD (360,000 INR) per km [16]	400 USD/yr (18,000 INR/yr) [16]	Excludes distribution grid components

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[28] HOMER is an energy modelling software for designing and analysing hybrid power systems. A trial version of the software can be obtained from the website: http://www.homerenergy.com/

[29] Originally estimated to 33 USD/tonne. However, the actual cost can be assumed zero because additional revenue can be gained from selling the by-product from gasification (called char), which can offset the original fuel cost.

[30] Diesel is used only for a reference simulation to be able to calculate a cost difference, but is not included in the proposed energy mix.

[31] Default values are given by HOMER. Figures were verified by comparing with price information obtained online.

Unit size considerations

At this point the unit sizes considered need to take into account that the system design must use standard components and is kept modular so that it can be expanded to cater for demand growth. For example, biomass systems based on rice husk (husk power systems) are available in unit sizes of 32 kW and 52 kW [17], but can be considered to come in sizes varying from 10-50 kW [7]. Small hydro power systems starting from 100 kW are under operation, in construction or have been planned for utilising various existing canals in Bihar[32], but it may be possible to implement micro hydro power schemes such as those described in the Model Detailed Project Reports [9] [10] [11] published by the Ministry of New and Renewable Energy[33] . Solar PV systems are assumed to be roof-top systems, so that they do not to compete for land space with agricultural production. Therefore the unit sizes are much smaller, in the range of 100-1,000 W. Furthermore, home solar systems are usually equipped with battery storage in the range of 50-200Ah because the main use for electricity is for lighting, which is not required during the day when the sun is shining and solar energy is available. Diesel generators are available in all sizes as they are a more conventional product. Therefore it would be up to the system owner to decide how best to expand the system in a piecewise fashion.

To demonstrate that these systems can be adopted in other regions of the world (not only limited to Bihar or India), wind power was also included in the generation mix. Only small wind systems are considered however, with unit sizes ranging from 650-1,500 W. These types of systems have a hub height of around 20 metres, and do not require heavy civil works to be installed.

The unit sizes that should be considered and their corresponding prices may differ between the type of resources that are locally available and the region of operation. Therefore, to use this approach for developing microgrid designs for other parts of the world, the input values should be modified to reflect the local conditions.

Solar PV price sensitivity

To demonstrate that there is merit in accelerating the adoption of solar PV systems and reach lower unit prices through economies of scale (Figure 11), the optimal system design based on global solar PV prices were calculated in addition to the currently applicable prices in India. This case demonstrates that with lower unit prices achieved from incorporation of higher volumes of solar PV projects, overall system costs can be

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[32] For details, check the Bihar State Hydroelectric Power Corporation website: http://www.bshpcltd.com/

[33] The reports can be accessed from the Alternate Hydro Energy Centre webpage: http://www.ahec.org.in/publ/model/model%20dprs.html

brought down. Therefore governments should encourage policies that accelerate the adoption of solar PV power such as those seen in countries like Germany.

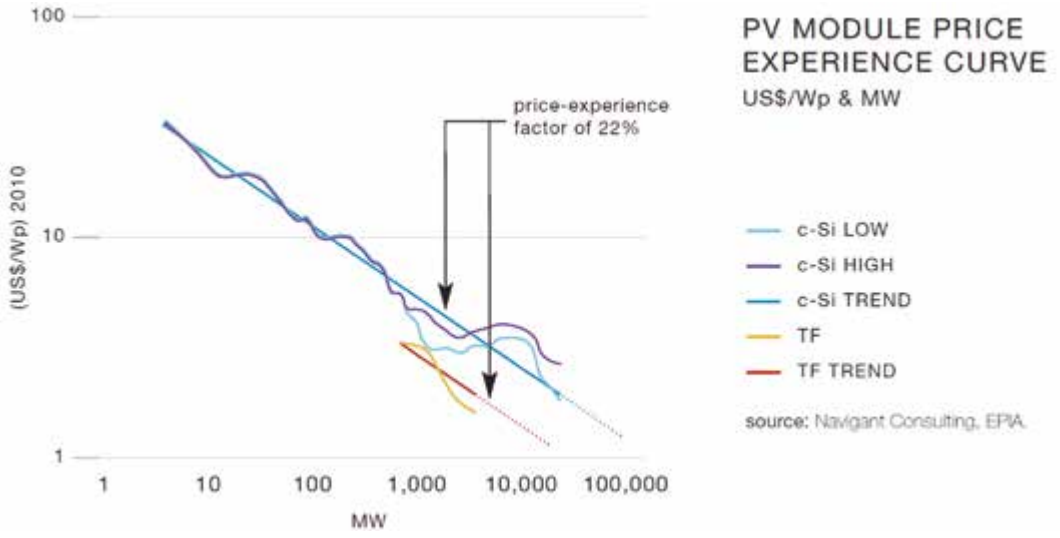

Figure 11: PV module price experience curve. Source: Greenpeace[34]

Another fact to consider is that prices for PV modules have dropped considerably in recent years, and are likely to drop further in the future. To consider the wide range of prices possible in a study that aims to project its results into the future as far as at least one decade, three prices for solar modules in US-Dollar per Kilowatt have been used:

- High PV cost scenario: 190,000 INR/Kilowatt (4200 USD/Kilowatt) – this reflects prices used for similar studies as recent as one year ago.
- Medium PV cost scenario: 114,000 INR/Kilowatt (2520 USD/Kilowatt) – after a heavy price drop over the last months, this represents a more realistic price assumption as of today.
- Low PV cost scenario: 57,000 INR/Kilowatt (1260 USD/Kilowatt) – this is a hypothetical price that extrapolates the recent price development only a few years into the future.

HOMER Simulation Results

Bihar microgrid with and without hydropower

The following tables show the optimal generation capacities for a microgrid in Bihar with (Table 13) and without (Table 12) access to suitable hydro power resources.

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34 http://www.greenpeace.org/international/Global/international/publications/climate/2011/Final%20SolarGeneration%20VI%20full%20report%20lr.pdf, Page 30

Table 12: Optimal generation capacities for Bihar microgrid without hydropower. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Storage Capacity (Ah)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	4000	0.48
Scenario 2 (100 kW)	6	100	4000	0.38
Scenario 3 (270 kW)	25	240	16000	0.48
Scenario 4 (554 kW)	600	200	140000	0.50

Table 13: Optimal generation capacities for Bihar microgrid with hydropower. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Hydro (kW)	Storage Capacity (Ah)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	0	4000	0.48
Scenario 2 (100 kW)	6	40	100	4000	0.22
Scenario 3 (270 kW)	25	180	250	10000	0.26
Scenario 4 (554 kW)	400	200	250	40000	0.34

The consumption in scenarios 1 to 3 is limited to certain hours of the day, even though most of the generation capacity is available for production the whole day. The more energy is produced by the unit, the lower the cost per kilowatt-hour will become. This system is designed to provide a total capacity of only 30 watts per household, which is not enough to power many appliances apart from CFL lighting and cell phone charging. Since the goal of smart energy access is to move beyond this absolute basic scenario, it would not make sense to base the microgrid design on this system design.

Ignoring demand scenario 1, which is the absolute minimum and unrealistic for a microgrid, the cost of energy (CoE) resulting from the optimal system design ranges from 0.38 USD to 0.50 USD per kilowatt-hour (19-25 INR/kWh) for systems without hydro, and between 0.22 USD and 0.34 USD per kilowatt-hour (11-17 INR/kWh) for systems with hydropower. These figures are in range with the service provided by Husk Power System (18 INR/kWh, corresponding to 0.36 USD/kWh), but is much higher compared to the electricity price offered by the grid at 3 INR/kWh (0.07 USD/kWh).

Therefore in areas where there is no access to the grid, these designs offer a cost-competitive power supply option. Even in areas where there is access to the grid, the reliability and quality of service provided by the grid is likely to be much worse than what can be provided by local generation. With the above system designs, all microgrid loads can be served except for some instances in demand scenarios 3 and 4, which amount to less than 1% of the total annual consumption. This is because the system is designed with a 99% supply reliability standard.

Microgrids with wind power

The following table shows the optimal generation capacities for a microgrid in a region with reasonable wind power resources.

Table 14: Optimal generation capacities for microgrids with wind power. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Wind (kW)	Storage Capacity (Ah)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	0	4000	0.48
Scenario 2 (100 kW)	6	100	100	4000	0.38
Scenario 3 (270 kW)	25	240	250	12000	0.48
Scenario 4 (554 kW)	200	300	250	40000	0.46

Ignoring demand scenario 1, which is the absolute minimum and unrealistic for a microgrid, the cost of electricity resulting from the optimal system design for a microgrid in Bihar with access to hydro power ranges from 0.38 USD to 0.48 USD per kilowatt-hour (19-24 INR/kWh). Although this is higher compared to the electricity price offered by the grid at 0.07 USD/kWh (3 INR/kWh), it is still somewhat in range with the service provided by Husk Power System (18 INR/kWh, corresponding to 0.36 USD/kWh).

Effect of PV price reduction

To consider the effect of a 40% price reduction within a only a few years as currently seen on the world-wide module markets, HOMER simulations were performed with lower solar PV prices for microgrids in Bihar with and without hydropower, and with and without wind power. The following tables show the optimal generation capacities for the corresponding combinations of resources.

Table 15: Optimal generation capacities for Bihar microgrid without hydropower and reduced solar PV price. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Storage Capacity (Ah)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	4000	0.47
Scenario 2 (100 kW)	6	100	4000	0.37
Scenario 3 (270 kW)	25	240	16000	0.47
Scenario 4 (554 kW)	600	200	160000	0.37

Table 16: Optimal generation capacities for Bihar microgrid with hydropower and reduced solar PV price. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Hydro (kW)	Diesel (kW)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	0	4000	0.47
Scenario 2 (100 kW)	6	40	100	4000	0.22
Scenario 3 (270 kW)	25	180	250	10000	0.24
Scenario 4 (554 kW)	400	200	250	60000	0.26

Table 17: Optimal generation capacities for microgrids with wind power and reduced solar PV price. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Wind (kW)	Storage Capacity (Ah)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	0	4000	0.46
Scenario 2 (100 kW)	6	100	0	4000	0.27
Scenario 3 (270 kW)	25	240	0	16000	0.30
Scenario 4 (554 kW)	400	300	100	80000	0.28

As can be seen, the results for the microgrids with and without hydropower hardly change at all in comparison to the base assumptions. Due to the relatively small amount of PV, the PV price reduction does not have a very big impact on the cost of energy.

One difference can be seen in the scenario with wind, where the PV price reduction now favours more PV with storage over the wind power contribution.

Effect of accelerated solar PV price reduction

If government policies were designed to encourage the adoption of solar PV power, it is expected that the installation cost for solar PV systems will fall by up to 70% due to economies of scale. To demonstrate this effect, HOMER simulations were performed with lower solar PV prices for microgrids in Bihar with and without hydropower, and with and without wind power. The following tables show the optimal generation capacities for the corresponding combinations of resources.

Table 18: Optimal generation capacities for Bihar microgrid without hydropower and further reduced solar PV price. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Storage Capacity (Ah)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	4000	0.46
Scenario 2 (100 kW)	6	100	8000	0.36
Scenario 3 (270 kW)	150	180	16000	0.43
Scenario 4 (554 kW)	700	200	160000	0.27

Table 19: Optimal generation capacities for Bihar microgrid with hydropower and further reduced solar PV price. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Hydro (kW)	Storage Capacity (Ah)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	0	4000	0.46
Scenario 2 (100 kW)	6	100	80	4000	0.21
Scenario 3 (270 kW)	25	240	250	10000	0.24
Scenario 4 (554 kW)	400	200	250	80000	0.19

Table 20: Optimal generation capacities for microgrids with wind power and further reduced solar PV price. Source: energynautics.

Demand scenario (system peak demand)	Solar PV (kW)	Biomass (kW)	Wind (kW)	Storage Capacity (Ah)	CoE (USD/kWh)
Scenario 1 (20 kW)	1.5	30	0	4000	0.46
Scenario 2 (100 kW)	6	100	0	4000	0.36
Scenario 3 (270 kW)	150	240	0	16000	0.43
Scenario 4 (554 kW)	700	200	0	160000	0.27

It can be seen the further reduced PV price now eliminates the use of wind power even in regions with good wind potential. In comparison to the previous scenarios with higher solar prices, the energy prices only drop significantly in load scenario 4. The reason is that the assumed load profile in this scenario has a higher correlation with solar irradiation, which leads to a naturally higher share of PV in the energy mix. With lower prices for PV modules this directly influences the cost of energy.

Conclusions from this section

The HOMER study allowed us to find the optimal installation capacities of a combination of generation resources for each demand scenario. The first scenario represents the absolute minimum level of electricity service, while the second is the basic level of service expected to be provided in a rural village in India. The third and fourth scenarios reflect future situations when the demand level grows as the economic standard improves.

If a hydro resource is available, this causes the system cost to drop. This would be suitable for areas where canals already exist, such as villages adjacent to the Sole, Gandak, or Kosi river canals. As a matter of fact, several hydro power plants already exist, and micro hydro schemes are planned for canals stemming from the Sole in the southwest of the state already. Although it is an economic and easily exploitable resource depending on the location, due to the stigma with hydro schemes there are not many plans along the Kosi and Gandak rivers to build hydro power plants. Also, even if a village is close to a river, a bypass canal needs to be created which can be costly. Therefore it is recommended that this resource be exploited in areas where the canals already exist. Another issue with hydro is that the main use of the canals is for irrigation. Therefore the available resource and flow rate varies significantly depending on the time of the year. In some cases the hydro power plant is taken out of operation for 4 months because of irrigation[35]. Therefore it must be paired with another form of power generation such as biomass or diesel. Wind resources in the state of Bihar are not optimal for economic operation of wind power plants. Even if the wind speed were

[35] According to Natwar S.H. P. Salient Features provided by Bihar State Hydroelectric Power Corporation.

higher, the initial investment required in comparison to biomass, hydro and PV is such that it does not feature highly.

Similarly, although being an abundant source, solar power also, take a high share in the optimal generation mix due to the relatively high capital costs. This is the case even if the photovoltaic price is assumed to fall by 40% compared to the current prices in India, bringing it in line with global prices.

STEP 3: TECHNICAL FEASIBILITY CHECK

To ensure that the generated electricity can be delivered safely to the customers, power system modelling and simulation software called PowerFactory[36] was used to model the operation of the distribution grid. The network layout for the village of Manjharia in Bihar was modelled, and the behaviour of the electrical system under different operating conditions was observed. For this case study, the optimal topology of the network, required cable sizes, voltage control and location of generation assets were determined based on steady-state power flow studies.

The design of the distribution network aims to fulfil the following objectives:

- The lines and transformer must be capable of safely supplying any peak load situation from any of the load scenarios:
    a. Lines and transformers must not reach their thermal operating limits at peak load.
    b. The voltage at any consumer shall not exceed the commonly used tolerances around the nominal voltage of ± 10%.
- The network of the analysed case study must be self-contained in that it does not necessarily require connection to further outside networks for economic installation and operation.

Allowing voltages outside the ±10% tolerances must be avoided because electric equipment may not operate correctly when the voltage is too high or too low, which can result in equipment damage or even danger to life.

Load-Related Assumptions and Network Design

The case of the Manjharia system can build upon existing structures, as there is already a rice-husk based biomass power generator supplying consumers in the vicinity. A sketch of the existing system is shown in table 21.
The general structure of this system is kept; however lines and configuration must be upgraded to be able to supply even the peak load from demand scenario 4.

[36] PowerFactory is a power system simulation software for designing and analysing power systems. It is a licensed product developed by DIgSILENT

Radial Design – Ease of operation

The network is laid out as a radial distribution structure. This is the natural choice for the given case study since the existing generation assets are located in the geographical centre of the village cluster. Besides, radial structures are the easiest to operate.

Location of generation assets

For practical reasons it is assumed that additional generation assets as determined in the HOMER study are installed close to the existing biomass power generator and can thus be connected to the same central node. A connection to a hypothetical transmission system with higher voltage through a transformer is also expected to be located in the same area. The benefit of this choice is that power flows will then be similar in off-grid and grid connected operation, and the lines and fault protection equipment can be picked and parameterized identically.

Line lengths and initial topology

The village clusters were assigned three-letter abbreviations to obtain the names for the nodes in the network model. The distances between the villages were measured in Google Earth and used as the lengths of the lines connecting the villages.

Table 21: Inter-cluster line topology and line lengths

Name	Node 1	Node 2	Length in km
BAZ-BHA	BAZ	BHA	0.430
BAZ-SIT	BAZ	SIT	0.364
C-BAZ	PLANT	BAZ	0.750
C-RAB	PLANT	RAB	0.248
C-RAM1	PLANT	RAM1	0.100
CHA-GOB	CHA	GOB	0.472
DHU-CHA	DHU	CHA	0.259
MAN1-MAN2	MAN1	MAN2	0.830
MAN1-PIP	MAN1	PIP	0.269
RAB-DHU	RAB	DHU	0.575
RAM1-MAN1	RAM1	MAN1	0.300
RAM1-RAM2	RAM1	RAM2	0.120
SIT-BAR	SIT	BAR	0.548
SIT-SIS	SIT	SIS	0.315

Within each cluster there are additional lines connecting the actual consumers (institutions, households, lighting) to the main point of connection of the cluster. Due to the small size of the clusters, these lines are considered to be short in comparison to the inter-cluster lines and are neglected in the calculations.

Choosing cable cross-section

An initial estimation of the required cable/line cross-section was made based on a few simple assumptions:

- For reasons of simplicity, the same cable cross-section would be selected for all inter-cluster lines. I.e., individual lines are not adapted according to the load expected for them.
- For each load scenario, the load would be split equally between the three feeders connecting the clusters to the central node.
- The maximum current in each feeder is determined from the nominal voltage, the maximum load on the feeder, and the number of conductors involved (number of phases).
- The minimum cross-section needed to withstand this current without overheating was determined from tables in [18].
- Taking the longest (line) distance between a cluster node and the central node and assuming a power factory of 0.9 (inductive), the voltage drop was analysed. This implies an unrealistic worst-case consideration in that the entire load does not normally have to be transmitted over the full line length.

The calculations based on these considerations led to the following conclusions:

- The thermal limits of the lines are not a problem, compared to the necessity of limiting the voltage drop across the lines.
- Only the biggest cross-sections within the range of standard distribution cable types may be sufficient in order to limit the voltage drop.

Standard cross-sections of distribution cables are in the range of 70-300 mm² per conductor. For the simulation model, a cross-section of 240 mm² per conductor in a 4-conductor cable (three phases plus neutral) was chosen. Power flow calculations would then show whether the voltage variation at the loads can be kept within a few per cent, see further below.

Exact cable types chosen are NYBY 2x240sm 0.6/1kV for scenario 1 and NYBY 4x240sm 0.6/1kV for scenarios 2-4. Conductor material is copper[37].

Load distribution

For the HOMER study the total load was composed of separate profiles generated for Administration, School, Health Station, Public Lighting, and households. For the power flow study these profiles must be disaggregated and assigned to locations in the grid.

Administration, School, Health Station

The administration is usually located in the biggest cluster in the vicinity. In this case the Manjharia village; hence the administrative load profile is assigned to a load element at the node named MAN. Similar arguments can be made for the location of the School and the health station, therefore they are also assumed to be located at the MAN node.

[37] For a practical realisation it is likely that aluminium cables will be chosen instead, because they are cheaper. However, since aluminium has slightly lower conductivity than copper, even higher cable cross-sections will be needed.

Public Lighting

Public lighting is not only required in the biggest village, but essentially in all clusters alike. The total public lighting demand as assumed in the HOMER study is therefore distributed to equal parts among the 12 clusters.

Households

The HOMER study is based on the number of 600 households. These 600 are distributed across the 12 clusters for the PowerFactory study as follows:

Cluster Number	Cluster	Number of Households
1	RAM	41
2	PIP	48
3	MAN	102
4	BAZ	94
5	BHA	32
6	SIT	42
7	SIS	40
8	BAR	32
9	RAB	29
10	GOB	66
11	DHU	56
12	CHA	18

This distribution key is an estimate based on the "area" of each cluster, obtained from the polygon area as drawn in Google Earth.

Reactive Power Demand

While the reactive power demand does not have considerable impact on the active power demand, it has a big impact on the voltage drop across the distribution lines.

Table 22: Assumed Consumer Power Factors

Consumer Type	Power Factor (SL1)	Power Factor (SL2, SL3, SL4)
Administration	0.90 capacitive	0.90 inductive
Health Station	0.95 inductive	0.95 inductive
School	0.95 inductive	0.95 inductive
Public Lighting	0.80 capacitive	0.95 inductive
Households	0.80 capacitive	0.95 inductive

Inductive loads lead to a higher voltage drop across distribution lines and therefore require higher cross-sections in order to limit the voltage drop for the same active power consumption. The consumption in the minimum load scenario (SL1) is dominated by CFL lighting, which behaves more capacitive than other types of equipment. The other load scenarios also include other types of consumer devices and are therefore assumed to have a more inductive character.

Power Flow Analysis

The same load profiles as used as the input data for HOMER are used for the consumption patterns, as described above. All data is provided as hourly data for one year. Power Flow analysis in each scenario is run for all hours of the year to obtain the minimum and maximum voltages as well as losses and required energy import/export (due to HOMER allowing a certain amount of non-delivered energy and the need to compensate the grid losses).

The main criterion for a valid configuration is that the voltage range not exceeds much more than 5% between the lowest and highest voltage at any low-voltage node. While in practice a voltage deviation of +-10% around the nominal voltage is allowed, we have to take into account that the voltage at the central node may also fluctuate due to voltage regulation issues at the generation assets or due to voltage variations in the (medium voltage) transmission grid. Only allowing a delta of 5% within the low-voltage system should provide the required safety margin.

Initial one-phase per feeder configuration

```
Study Case        SR1-BD-(Base)
Iterated over     8760 hours

Energy Import   =      9101.96 kWh
Energy Export   =      1776.68 kWh
Grid Losses     =      1072.68 kWh

Max P Export:           1.0979 kW   at hour: 7524
Max P Import:           3.3750 kW   at hour:   44
Max P Load:            24.5686 kW   at hour:   44
Min P Load:             0.0000 kW   at hour:    6
Max P Generation:      21.5000 kW   at hour:   44
Min P Generation:      -0.0000 kW   at hour:    4
Max P Loss:             0.6823 kW   at hour:   44
Min P Loss:             0.0000 kW   at hour: 2986

Max Q Import:           0.0559 kvar at hour: 7857
Min Q Import:         -17.6351 kvar at hour: 2229
Max Q Load:             0.1555 kvar at hour:   31
Min Q Load:           -17.8454 kvar at hour: 2229

Max Voltage LV:   1.0500 p.u. at hour:    6 at node: BAR
Min Voltage LV:   1.0432 p.u. at hour:   44 at node: BAR
Max Voltage MV:   1.0238 p.u. at hour: 7857 at node: MV_BUS
Min Voltage MV:   1.0228 p.u. at hour: 2229 at node: MV_BUS
```

Extension to three-phase

To cope with the demand in scenarios 2 and 3, it is necessary to upgrade the lines from single phase to three-phase. This increases the number of conductors from 2 to 4, but reduces the voltage drop significantly. To make this work in practice, it will require that consumers will be connected in similar patterns to each of the three phases.

Load Scenario 2:

```
Study Case        SR2-PBD
Energy Import   =     10593.37 kWh
Energy Export   =      1275.85 kWh
Grid Losses     =      1462.97 kWh

Max P Export:           8.5612 kW   at hour: 7711
Max P Import:           3.3598 kW   at hour: 2204
Max P Load:            79.3888 kW   at hour: 2228
Min P Load:             0.1120 kW   at hour:   10
Max P Generation:      76.9178 kW   at hour: 2228
Min P Generation:       0.0000 kW   at hour:    0
Max P Loss:             0.8086 kW   at hour: 2228
Min P Loss:             0.0000 kW   at hour:   82

Max Q Import:          26.5813 kvar at hour: 2228
Min Q Import:          -0.2631 kvar at hour: 8072
Max Q Load:            26.0938 kvar at hour: 2228
Min Q Load:             0.0368 kvar at hour:  231

Max Voltage LV:   1.0500 p.u. at hour:  613 at node: BAR
Min Voltage LV:   1.0307 p.u. at hour: 2204 at node: BAR
Max Voltage MV:   1.0252 p.u. at hour: 2228 at node: MV_BUS
Min Voltage MV:   1.0237 p.u. at hour: 8072 at node: MV_BUS
```

Load Scenario 3:

```
Study Case        SR3-BD
Iterated over     8760 hours

Energy Import   =     24798.98 kWh
Energy Export   =     16074.12 kWh
Grid Losses     =      8012.41 kWh

Max P Export:          23.0543 kW   at hour:   31
Max P Import:          26.5030 kW   at hour: 7315
Max P Load:           223.3663 kW   at hour: 2226
Min P Load:             0.1120 kW   at hour:    7
Max P Generation:     223.3624 kW   at hour: 2226
Min P Generation:       0.0000 kW   at hour:    0
Max P Loss:             6.7994 kW   at hour: 2226
Min P Loss:             0.0000 kW   at hour:    7

Max Q Import:          79.7724 kvar at hour: 2226
Min Q Import:          -0.2631 kvar at hour:    7
Max Q Load:            73.4758 kvar at hour: 2226
Min Q Load:             0.0368 kvar at hour:    7

Max Voltage LV:   1.0500 p.u. at hour:    4 at node: BAR
Min Voltage LV:   0.9931 p.u. at hour: 2202 at node: BAR
Max Voltage MV:   1.0282 p.u. at hour: 2226 at node: MV_BUS
Min Voltage MV:   1.0237 p.u. at hour:    7 at node: MV_BUS
```

As can be seen from the voltage range at low voltage (LV) nodes, the voltage range already exceeds 5%. This indicates that for higher consumption it will be necessary to upgrade the grid again.

Extensions to accommodate peak load in the maximum load scenario

Keeping the voltage range below 5% even in load scenario 4 can be achieved by taking the following measures:

- Two additional feeders, connecting clusters BAR and GOB directly to the central power plant via new lines: C-BAR (0.82 km), and C-GOB (0.97 km).
- Installing parallel cables in a few sections: C-RAM1-MAN1-MAN2 and BAZ-SIT would need a second cable, on section C-BAZ the number of parallel cables must be increased to three.
- The lines SIT-BAR and CHA-GOB are opened to retain a radial structure.

Other alternatives would be to install additional connection points to the (as of yet hypothetical) medium-voltage system, which would make operating the system in island significantly more complex.

Upgrading the system as described above leads to the following results:

```
Study Case        SR4-BD-inductive-ExtGrd
Iterated over     8760 hours

Energy Import   =     20855.44 kWh
Energy Export   =       235.44 kWh
Grid Losses     =     16992.59 kWh

Max P Export:           8.8551 kW   at hour: 3366
Max P Import:         251.9587 kW   at hour: 2493
Max P Load:           557.5181 kW   at hour: 2493
Min P Load:            43.6442 kW   at hour: 3366
Max P Generation:     325.0008 kW   at hour: 2493
Min P Generation:      52.4568 kW   at hour: 5632
Max P Loss:            19.5040 kW   at hour: 2493
Min P Loss:             0.1077 kW   at hour: 3366

Max Q Import:         203.2997 kvar at hour: 2493
Min Q Import:          13.7857 kvar at hour: 3366
Max Q Load:           183.2439 kvar at hour: 2493
Min Q Load:            14.3449 kvar at hour: 3366

Max Voltage LV:   1.0492 p.u. at hour: 3366 at node: PLANT
Min Voltage LV:   0.9836 p.u. at hour: 2493 at node: SIS
Max Voltage MV:   1.0500 p.u. at hour:    0 at node: MV_BUS
Min Voltage MV:   1.0500 p.u. at hour:    0 at node: MV_BUS
```

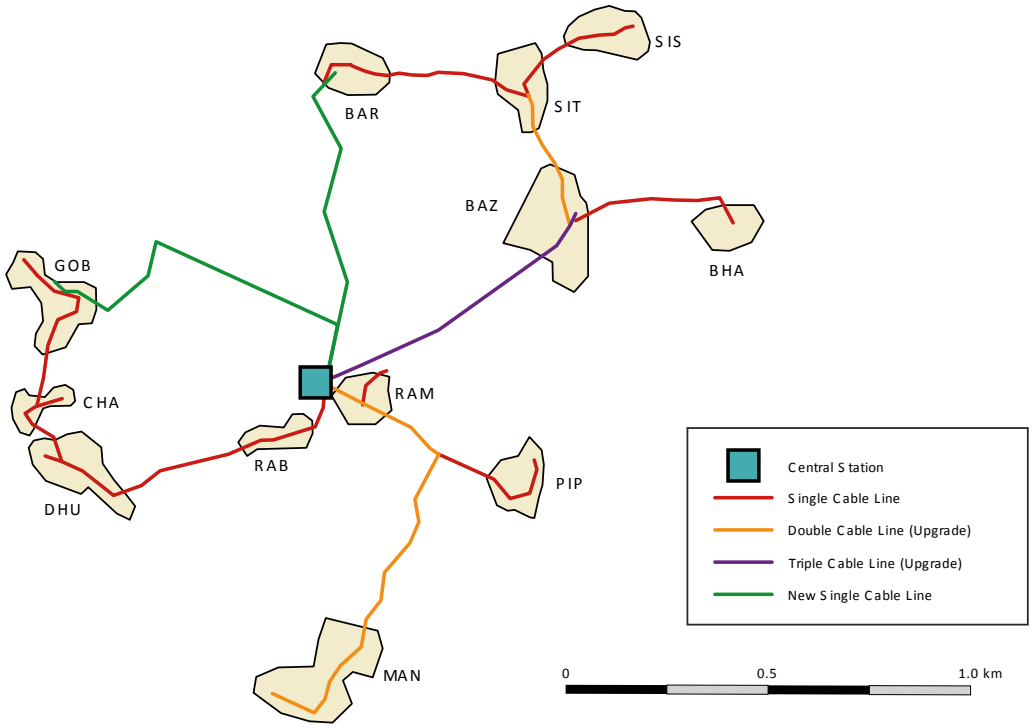

Figure 12: Network with upgrades to accommodate load scenario 4.

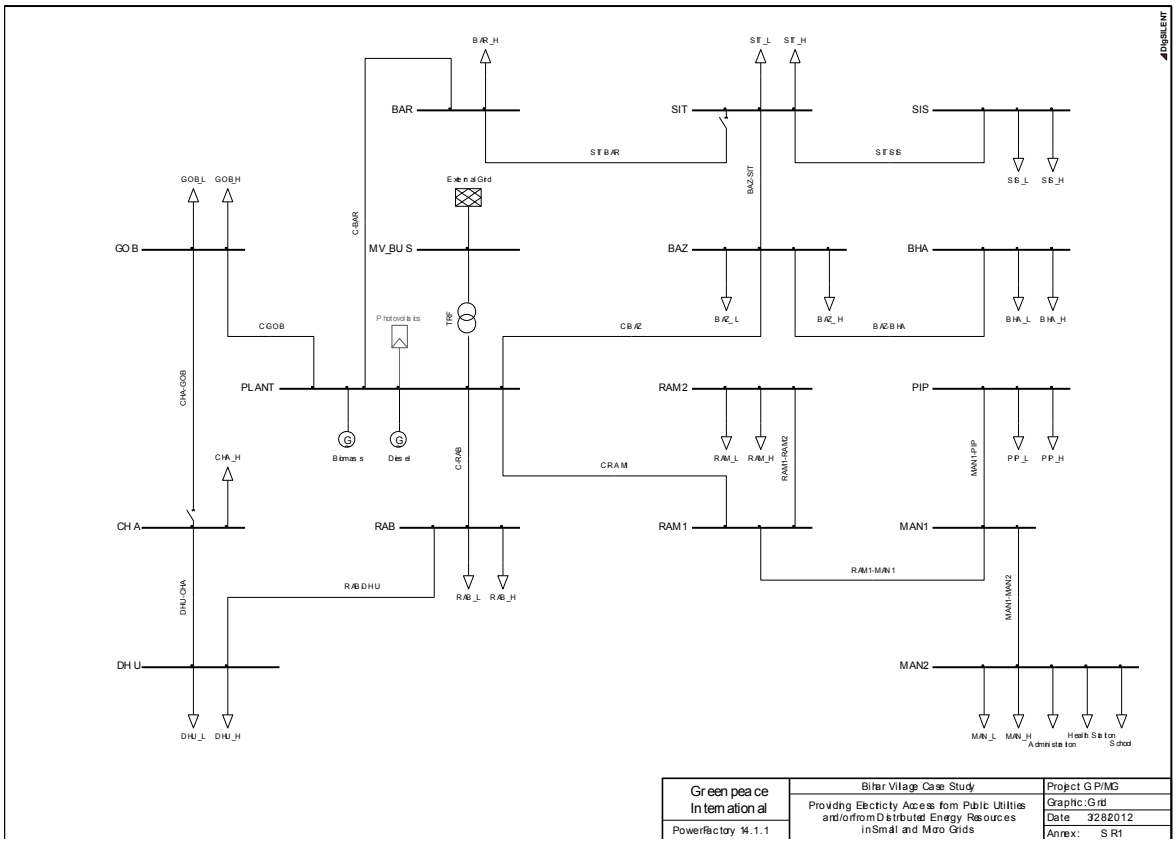

Figure 13: Upgraded grid model

Conclusions from this section

Each load scenario comes with a certain peak load, which is the most important factor in dimensioning the distribution grid. While load scenario 1 can still be supplied using single-phase feeders, all other scenarios already need three-phase feeders with strong cables. In the case of the maximum assumed load, it is even necessary to upgrade individual sections to multiple parallel cables, and new cables have to be put in.

Based on these simulations, a system with the following key features was suggested.

- Radial distribution structure: This is the natural choice for a system with large biomass and diesel generation assets located at the geographical centre of the village. Besides, radial structures are the easiest to operate.
- Standard cross-sections of distribution cables are in the range of 70-300 mm² per conductor. For the simulation model, a cross-section of 240 mm² per conductor in a 4-conductor cable (three phases plus neutral) was chosen.
- Location of generation assets: For practical reasons it is assumed that additional generation assets as determined as appropriate by HOMER will be installed near the central biomass power generator and can thus be connected to the same central node. A connection to a hypothetical transmission system of higher voltage is also expected to be located in the same area. The benefit of this choice is that power flows will then be similar in off-grid and grid connected operation, and the lines and fault protection equipment can be picked and parameterized identically.
- Voltage at central node can be controlled locally when the microgrid is in island mode. However there will still be variations, which depend on the output characteristics of the generators connected to that node. It is vital that the voltage variations stay within limits, particularly at the end of the distribution feeders. Although the actual voltage drop across the feeders depends on the loads, a tolerance of 5% has been assumed between the central node and end of the feeder. The voltage drop observed in the simulations was addressed by reinforcing the distribution network. In grid connected mode voltage control method will depend on the properties of the distribution transformer which forms the connection with the grid.

STEP 4: DEVELOPMENT OF A CONTROL STRATEGY FOR THE SWITCHING OPERATION

The critical feature of what makes a microgrid unique, which is the ability to switch from grid-connected mode to island mode and visa-versa, is discussed in this section. The aim is to suggest system designs that achieve this goal at moderate initial investment costs.

There may be several reasons for a microgrid to switch from grid-connected to island operation mode. For example if there is a blackout on the central grid induced by a fault, if the region is subject to a rotating blackout due to insufficient supply, or if the quality of supply is undesirable for the application in the microgrid.

In connecting and disconnecting a microgrid to and from the grid, however, there are a number of significant technical challenges. These are related to maintaining stable operation during and after the switching event and require a sophisticated control strategy involving monitoring, communication and coordination between generators and system operators.

Depending on the quality of service required by the loads in the microgrid, the regulations stipulated in the grid code for operation practices, and number of grid support features desired, several different designs could be developed. For more details on these designs, check references [19], [20], and [21].

The simple solution

For application in developing countries as a tool to improve energy access however, rather than designing such a complicated and expensive system, it may be sufficient to restrict the switching from grid-connected mode to island mode in the case of supply from the central grid being unavailable for a prolonged period of time (e.g. due to rotating power cuts), and the transition from island mode to grid-connected mode when the grid supply is back.

Such transitions would be handled by manual switching, upon confirmation that there will be a prolonged blackout, and that the central grid is ready to receive the microgrid connection back again. If there were a controller, this transition would be aided with the boosting of local generation to match local load before the microgrid is disconnected, and preparing the voltage, frequency, and phase of the island system to be in synchronization with the grid when re-connecting to the grid. However, without a controller, the manual switching would be accompanied by a brief blackout of the microgrid, followed by a black start operation. Synchronous generators such as diesel gensets and biomass systems fed by biomass gasifiers (like the Husk Power System), as well as some modern solar PV inverters and wind power converters can support system blackstarts, therefore make this solution possible by choosing the right type of components. This system is not exactly the most elegant solution. Without a microgrid controller which can coordinate the outputs of local generation and load, such a switching event would constitute a brief blackout of the microgrid system each time the microgrid is switched to and from grid connected mode to island mode. However, it removes the need for a complicated and expensive control scheme, therefore could be

an economically accessible solution which still provides a more reliable supply compared to a system which relies solely on the grid supply, and a cheaper supply compared to a system which does not have the option to access grid supply.

The advanced solution

As the economic capacity develops, and power system operation capabilities as well as regulations accommodate for it, more sophisticated control strategies may be implemented. This would attempt to make the transitions between grid-connected and island modes smoother, by implementing a control scheme that can coordinate the outputs of the distributed generators with the local demand.

Such a full-fledged system would require a number of different components, costing approximately 5 million INR (100,000 USD) for one microgrid (see table 23) [22].
It should be noted that this price estimation is only indicative; real prices in actual project implementations may differ significantly.
Some components such as circuit breakers, load controllers, and micro generators controllers are already required in the simple solution approach.

Table 23: Investment Costs to Establish the Microgrid. Source: [22], prices converted from EUR to INR

Asset Type	Estimated Cost in Indian Rupees
LV circuit breaker	133200
Protection of MV grid/µG Interface	666100
Flywheel based storage system	832600
Load Controllers	879200
Micro generators Controllers	519500
Micro Grid Central Controller	999100
Communication System	1145700

Control issues

It is essential that a microgrid in island operation mode can maintain voltage and frequency stability in response to demand fluctuations as well as weather induced variations in renewable energy based power generation. Furthermore power quality should be kept within certain standards, and there should be strategies to ensure stable operation during network disturbances.

When the microgrid is switched back to grid-connected mode, it must be made sure that the voltage, frequency, and phase of the microgrid is synchronised with that of the central grid at the point of common coupling. This requires a microgrid controller at the interface with the grid. With such a controller it would also be possible to control the amount of power injected/consumed by the microgrid at the point of common coupling,

therefore giving the possibility for it to be coordinated with the operation of the central grid to offer voltage and frequency control services if needed.

Frequency and voltage control in island mode

When the microgrid is operating in island mode, the common method used to control voltage and frequency is the droop control method. A simple approach is presented in paper [23]. This approach is to implement conventional f/P and V/Q droop control mechanisms to the battery inverter. In this way, expensive systems that require communication and extra cabling for a control node can be avoided. Furthermore, the output frequency can be estimated by measuring the active power output of the inverter and taking the frequency droop into account. This approach presents several advantages as low cost, simple expansion of the system, increased redundancy and simplified supervisory control [24].

Frequency and voltage control in grid-connected mode

When the microgrid is connected to the central grid, the easiest solution is to have the voltage at the connection point controlled by the central grid and not do any active voltage control in the microgrid itself. This allows using simple transformer types without on-load tap changing capability, but requires an effective voltage regulation regime in the central grid where voltages are always kept within a sufficiently small band. Within the microgrid all feeders will experience a voltage drop the further away it gets from the transformer node and the larger the load is connected to the feeder branch. It was found during the power factory simulation part of this study that it is likely that the voltages at the end of the feeders will be too low if the feeders cover a distance of longer than 1 km. To mitigate this problem, the lines would have to be reinforced or the voltage would need to be supported, which could be done by injection of active or reactive power at certain points along the feeder. Another option is to utilize voltage controlling transformers either at the connection to the central grid or even within the same nominal voltage level in long feeders.

Since the microgrid contains generators, it is possible to incite support from generators to maintain an adequate voltage level at the connection point, or to provide support to the central grid. However, such an arrangement would have to be assessed and approved by the central grid operators before put into application to make sure that it does not interfere with control schemes implemented in the central grid.

When the microgrid is connected to the grid, the frequency will be dictated by grid.

Harmonic effects

Harmonic effects are caused by certain types of electronic loads, such as; CFLs, computers, laser printers, stereos, radios, TVs, fax machines and many other electronic devices. It increases the losses in the system, produces noise and vibrations, and decreases the life-time of motors and transformers. As the use of electronic devices ever increasing and are also expected to be in the microgrid, it is an issue that needs to be considered.

According to the IEEE-5 19 recommended limits [26], a rule of thumb assessment can be applied, that if the system capacity is greater than twice the demand, there is minimal voltage distortion and no interference with other electrical equipment caused by harmonics. Applying this rule of thumb, the harmonic effects for different load scenarios for a typical village in Bihar (i.e. Manjharia village from the case study), we can find out whether or not a significant value of harmonic loss is present for each scenario (see Table 24).

Table 24: Demands (Electronic Devices) and mitigation methods for different scenarios

Demand scenario	Demand (corresponding to electronic devices) (kW)	System size (kW)	Harmonic losses significant?	Mitigation Method
Scenario1	22	22	Yes	Load connected, HSS[38]*
Scenario2	27.6	100	No	Not Required
Scenario3	82.8	270	No	Not Required
Scenario4	N.A.	554	No	Transformer Secondary Connected, HSS

Table 24 shows that in scenario 2, scenario 3 and scenario 4 the system capacity (system size) is greater than twice the demand corresponding to electronic devices, so the harmonics or the voltage distortion produced is minimal and can be neglected. No mitigation methods are required but can still be implemented. Whereas, in case of scenario 1, the system capacity (system size) is equal to the demand (for electronic devices), therefore, high values of harmonics are present. This Harmonic loss can be mitigated by the use of load connected Harmonic Suppression Systems (HSS).

Load connected HSS is an effective but tedious harmonic mitigation method. Every load terminal must be fitted with an HSS, which in the case of this microgrid means each CFL unit (of which there are over 1,000). Due to this reason, it is not a practical solution, and there is no other suitable method to mitigate the harmonic problem. However, the system corresponding to demand scenario 1 is not a realistic system for the smart energy access strategy, therefore no further solution is required.

Power flow at point of connection (Grid-connected mode only)

Microgrids should not inject active power into higher voltage networks to the extent that the reverse flows cause a problem (i.e. disrupting PQR). When switching to island/grid mode controller has to balance local supply with load so that power flow at

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[38] HSS: Harmonic Suppression System

PCC is zero. For this, metering and controller is required. If too many communication and control equipment need to be installed, simple would be to momentarily blackout the system. This way during power cuts/rotating blackouts which last a while, can be reduced to a momentary blackout. Of course it is better to avoid all blackouts but it may provide a satisfactory solution at less cost for applications in rural villages.

Conclusions from this section

The general conclusions are that such a system design is feasible, but to achieve smooth transition between grid-connected and island operation modes sophisticated control equipment is required which may not be easily accessible financially. Therefore an alternative system is proposed, where each time a state transition is required the microgrid power supply is black-started. Such as system may be operated manually, and limited to times when a prolonged supply shortage is experienced either in the local generation pool or in the central grid. This may seem a clumsy approach at first; however, in areas where the central grid is often plagued by blackouts and cut off supply to villages in favour of loads in the cities, this delivers far superior energy supply in terms of reliability and quality.

As the local economy grows, thanks to the access to electricity, depending on the needs of the customers in the microgrid, the switching system may be automated and made more sophisticated (so that there is no need to blackout the system for each transition), but this would depend on how prepared are the customers to finance the costs of such a system. For example, this situation may become true if industrial customers that require superior supply quality rise up in the village, or the economic power in the village reaches a certain level that individual households expect a better service quality.

Some of the advanced features a microgrid can offer if a full controller is implemented, is the ability to offer frequency and voltage control services to the central grid, as well as contribute to black starts if the central grid experiences a black out. These are aspects of microgrids that are being investigated as ongoing research in regions like the USA (CERTS), Europe (MORE microgrids), and Japan (Hachinohe).[39]

Ideally, simulations of such operation could also be carried out using power system simulation software such as PowerFactory. However, this requires detailed modelling of the dynamic characteristics of each component in the system, therefore has not been carried out in this case study.

.....

[39] Some advanced features have been recently demonstrated in a utility-scale distribution grid in Denmark, in the Cell Controller Pilot Project run by Energinet.dk. For more information see http://www.energinet.dk/EN/FORSKNING/Nyheder/Sider/Den-ustyrlige-vind-kan-styres.aspx

COST COMPARISON WITH GRID EXTENSION

To determine whether system costs can be a support to justify the bottom-up approach of building a microgrid over extending the grid, it is useful to compare them with grid extension costs. This is done comparing the optimal systems costs calculated by HOMER with the cost of extending the grid, based on the approximation given by Cust et al[40].

It can be seen from Figure 14 that all microgrids have a higher system cost compared to the rates that would be paid by village residents to access grid-connected services. However, the further away from the central grid the village, the costs of extending the grid increases. Therefore at some point the microgrid system cost would be cheaper than accessing grid services by extending the grid. This is known as the *break-even grid distance*.

The costs of electricity produced by the microgrids are plotted against the price of grid-supplied electricity if the grid is extended in Figure 14. It can be seen that the grid-supplied electricity is the cheapest solution when the distance to the grid is less than 5 km. However, depending on whether small hydropower is available in the microgrid and also depending on the prices for solar PV, the break-even grid distance varies between 5 km and 20 km. The currently implemented Husk Power System has a break-even grid distance of around 13 km.

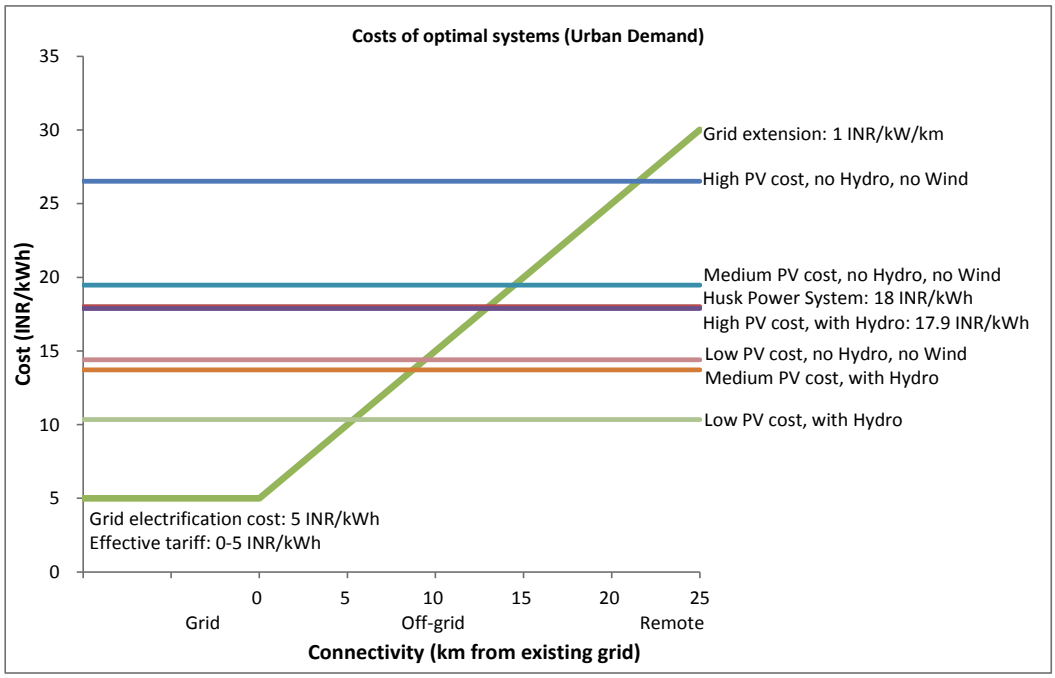


Figure 14: Cost comparison of microgrid systems (with diesel) with grid extension. Modified from [2]

[40] *http://www.eprg.group.cam.ac.uk/wp-content/uploads/2008/11/eprg0730.pdf*

Microgrid scale-up across the state of Bihar

Currently in Bihar, there are over 19,000 un-electrified villages across the state (this is more than half of the total number of villages in Bihar)[41]. Based on a rough geographic assessment of the state, it can be estimated that approximately 3,140 villages lie in the region adjacent to rivers and with access to bypass canals (See Figure 15).

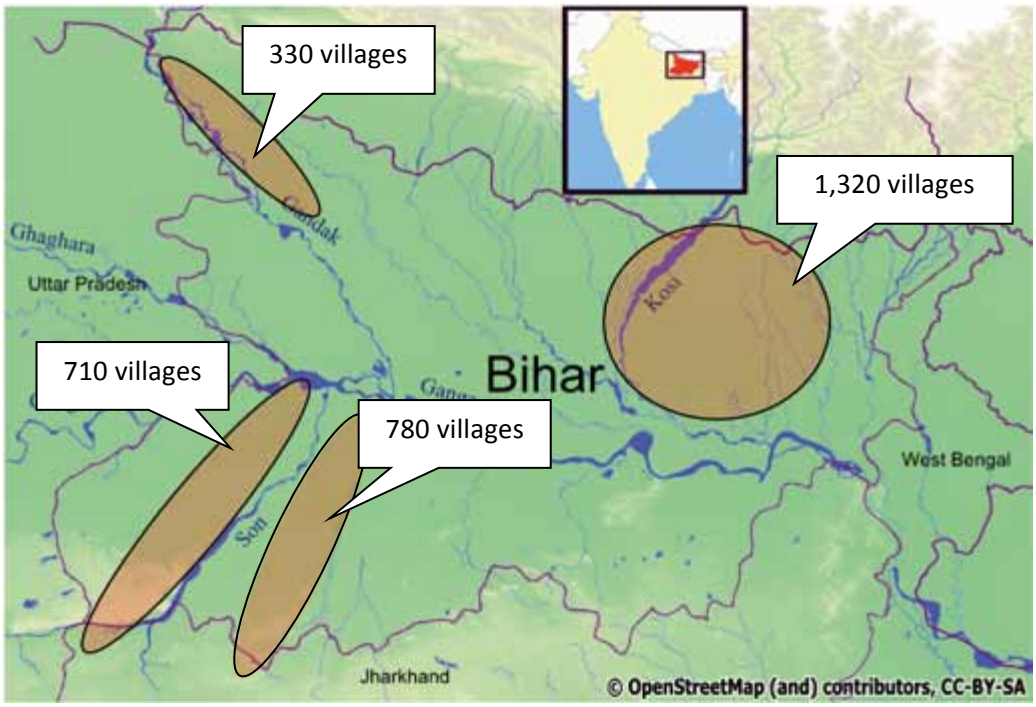


Figure 15: Map of Bihar with regions adjacent to rivers and with access to bypass canals marked in red shading.

If these are powered by microgrids with hydro (Bihar microgrid with hydro optimal system), and the remaining un-electrified villages in the state of Bihar are powered by microgrids without hydro (Manjharia optimal system), at minimum (corresponding to demand scenario D2) approximately 1700 MW of biomass, 314 MW of hydro and 114 MW of PV power installations would be required, at a cost of approximately 20 billion US-Dollar (including generation assets and network equipment cost). At the stage when microgrids are fully integrated with the central grid (corresponding to demand scenario D4), it is expected that at least 4,000 MW of biomass, 785 MW of hydro and 10,000 MW of PV power installations would be required, at a cost of around 64 billion US-Dollar (with medium PV price). This is summarised in Table 25 and Table 26 below.

Table 25: Summary of state-wide expansion of optimal microgrid capacities (MW)

Key Results for E[R] Villagecluster - energy mix options - Bihar State Rural

Scenario		Installed capacity Bihar State Rural				Generation by Technology			
		PV	Wind	Hydro	Bio energy	PV	Wind	Hydro	Bio energy
		[MW]	[MW]	[MW]	[MW]	[GWh/a]	[GWh/a]	[GWh/a]	[GWh/a]
		High PV Cost Scenario							
D1	Absolute Minimum (state-wide)	29	0	0	570	49	0	0	750
D2	Low income demand (state-wide)	114	0	314	1 712	196	0	1 847	5 128
D3	Medium income demand (state-wide)	475	10	785	4 372	818	27	4 185	10 349
D4	Urban households (state-wide)	10 012	570	785	3 990	17 235	1 369	4 185	15 804
		Medium PV Cost Scenario							
D1	Absolute Minimum (state-wide)	29	0	0	570	49	0	0	750
D2	Low income demand (state-wide)	114	0	314	1 712	196	0	1 847	5 128
D3	Medium income demand (state-wide)	475	0	785	4 372	818	0	4 185	10 354
D4	Urban households (state-wide)	10 392	190	785	3 990	17 890	456	4 185	15 673
		Low PV Cost Scenario							
D1	Absolute Minimum (state-wide)	29	0	0	570	49	0	0	750
D2	Low income demand (state-wide)	114	0	251	1 712	196	0	1 478	5 105
D3	Medium income demand (state-wide)	2 458	0	785	4 372	4 231	0	4 185	8 724
D4	Urban households (state-wide)	12 358	0	785	3 800	21 274	0	4 185	14 080

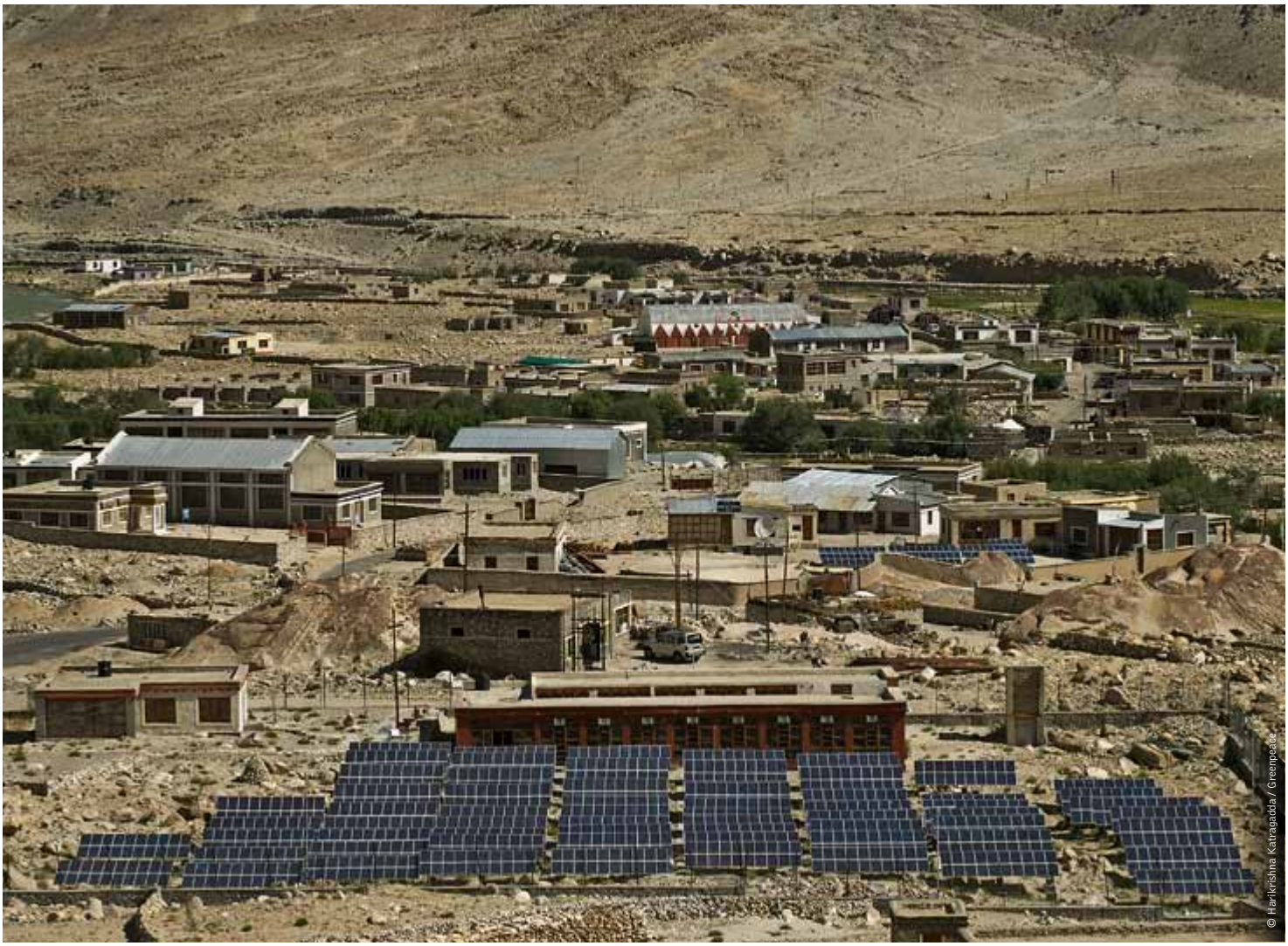
Source: Energy [R]evolution Cluster - Smart Energy Access, energynautics May 2012 and Greenpeace International

Table 26: Investment overview for state-wide expansion in Bihar

Key Results Investment Overview - Rural Bihar

Scenario		Generation and Network Equipment Rural Bihar					
		Investment Power Generation		Investment Network Equipment		Total Investment	
		million US$	billion INR	million US$	billion INR	million US$	billion INR
		High PV Cost Scenario					
D1	Absolute Minimum (state-wide)	1 334	70.1	13 226	694.4	14 560	764.4
D2	Low income demand (state-wide)	4 109	215.7	15 486	813.0	19 595	1 028.8
D3	Medium income demand (state-wide)	10 198	535.4	15 486	813.0	25 684	1 348.4
D4	Urban households (state-wide)	60 257	3 163.5	23 602	1 239.1	83 859	4 402.6
		Medium PV Cost Scenario					
D1	Absolute Minimum (state-wide)	1 286	67.5	13 226	694.4	14 512	761.9
D2	Low income demand (state-wide)	3 819	200.5	15 486	813.0	19 305	1 013.5
D3	Medium income demand (state-wide)	9 384	492.7	15 486	813.0	24 870	1 305.7
D4	Urban households (state-wide)	40 796	2 141.8	23 602	1 239.1	64 397	3 380.9
		Low PV Cost Scenario					
D1	Absolute Minimum (state-wide)	1 250	65.6	13 226	694.4	14 476	760.0
D2	Low income demand (state-wide)	3 665	192.4	16 074	843.9	19 739	1 036.3
D3	Medium income demand (state-wide)	11 461	601.7	16 154	848.1	27 615	1 449.8
D4	Urban households (state-wide)	26 860	1 410.2	23 602	1 239.1	50 462	2 649.3

Source: Energy [R]evolution Cluster - Smart Energy Access, energynautics May 2012 and Greenpeace International



Solar Photovoltaic Power Plant in Tangtse
THE 100 KWP STAND-ALONE SOLAR PHOTOVOLTAIC POWER PLANT AT TANGTSE, DURBUK BLOCK, LADAKH. LOCATED 14,500 FEET AMSL IN THE HIMALAYA, THE PLANT SUPPLIES ELECTRICITY TO A CLINIC, A SCHOOL AND 347 HOUSES IN THIS REMOTE LOCATION, FOR AROUND FIVE HOURS EACH DAY.

3 grid technology + definitions

MACHINES IN SAAP WORKSHOP IN BIHARELECTRICIAN KOSMOS BHAKLA MEASURES THE CHARGING LEVEL OF A BATTERY BANK IN SOLAR ALTERNATIVES AND ASSOCIATED PROGRAMMES (SAAP), A JESUIT-RUN RESEARCH CENTRE PROVIDING SOLAR SOLUTION TO ENERGY NEEDS. THE BATTERIES ARE CHARGED WITH ELECTRICITY GENERATED BY SOLAR PHOTOVOLTAIC PANELS ON THE ROOF. ST. MARY'S COMPOUND, PHULWARIA SHARIF, PATNA, BIHAR.

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3 GRID TECHNOLOGIES AND DEFINITIONS

ENERGY ACCESS OPTIONS

To increase energy access, the central grid can be extended to rural areas where electricity services did not reach before. In this way the central grid can increase its customer base and sell more electricity. However, in cases where there is insufficient supply capacity, or the cost of extending the grid outweighs the benefits gained by selling additional energy, the case for grid extension is not as favourable any longer. Furthermore, to integrate renewable energy supply in the central grid, investments in large-scale RE projects are needed. This is why alternative options are offered as energy access options. These are introduced below.

Energy Homes Systems

Energy home systems are for basic electrification of a single household or building. It consists of a small generator, often solar PV or wind powered, with a battery and a charge controller. This type of system is designed to be connected directly to DC loads of 15-150 Wp, such as lamps, radios, televisions and refrigerators. For AC loads, an inverter would be necessary. The charge controller connects the generator to the battery and controls the state of charge. Often the battery will have 3 to 5 days storage capacity.

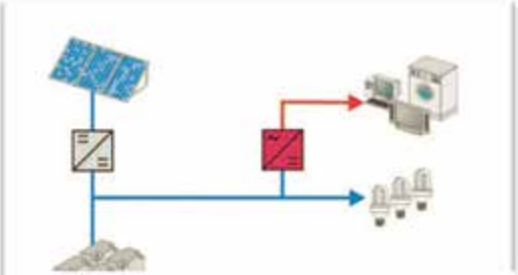


Figure 16: Configuration of a Solar Energy Home System. Source: [33]

Off-grid Distribution Systems

Off-grid distribution systems are essentially a small version of the central grid. It connects several loads with several generation sources and a central controller manages the supply-demand balance. These systems are often used for powering remote communities where the cost of extending the central grid is considered too high. There are many systems in application around the world and it is well suited to exploitation of local renewable energy resources. Due to the seasonal fluctuations and weather dependency of many of these sources however, it is best to use a combination of energy sources in order to have a continuous supply. For example variable sources such as solar, wind and run-of-river hydro should be coupled with batteries, diesel gensets or biomass-based generators that can adapt quickly to fluctuating conditions. These are called hybrid systems and can be designed as DC systems, mixed DC/AC systems or pure AC systems.

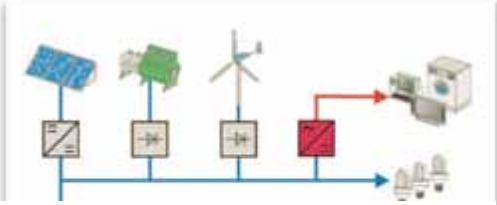


Figure 18: Configuration of a Hybrid System with DC-AC connection. Source: [33]

Figure 17: Configuration of a Hybrid System with AC connection. Source: [33]

Microgrids

Microgrids are distribution systems consisting of loads and generators balanced with a controller, as with the off-grid distribution system, but connected to the grid at a single point of connection (called the point of common coupling). The unique feature of microgrids in this sense is the ability to switch between grid-connected and island operation modes. This allows for flexible operation to access grid supply at times when local demand is high, exceeding the local generation capacity, or when the grid power prices are low, while using local generation when there is a supply shortage in the central grid, or when the grid power prices are high. This increases the reliability of supply to the microgrid customers while simultaneously supporting the central grid by creating a generation/demand block that can controlled to act as a load or a generator and maintain the voltage at the point of common coupling. Additionally, it may be possible for the microgrid to contribute to black starting the central grid.

Distributed Generation Systems

Distributed generation systems are small-scale generators connected to the distribution network of the central grid. Electrically it acts to reduce the distribution load that the central grid sees at the points of common coupling. Since reactive power can also be injected, voltage support can also be offered to a certain extent. Unlike the microgrids however, distributed generation are not made to balance local demand by a central controller, and cannot run disconnected from the central grid.

OBSTACLES TO ENERGY ACCESS PROJECTS

Although there are programs to improve energy access by extending the grid, in many cases the reality is far behind targets. What are the main causes for delayed delivery of energy services? In the report on Africa's power infrastructure by the World Bank [27], European-funded microgrid program in Africa [28] and a report on rural electrification in India [21], the following issues are reported as being barriers to rural electrification.

Financial Project cost too high	Capital cost too high	Lack of financial capacity of: - grid owner - power producer - service user
		Taxes are too high
	O&M cost too high	Fuel price too high
		Transmission and distribution losses too high: - system design - energy theft
	Revenue too low	Village size too small
		Utility fee affordable to consumer is too low
Operational Insufficient system capacity to manage project integration	Supply capacity shortage	Lack of infrastructure
		Energy theft
	Frequent disruption in supply of grid power	The prevalence of backup generators
		Increasing use of leased emergency power
Administrative Project implementation too complex	Inadequate provisions in regulation	Lack of provision for DG, RE, flexible generation
		Lack of provision to manage mismatches between service that can be provided by grid and the service needed by customer
	Inadequate information	No RE potential studies have been done or data available
		Lack of evaluation procedures to identify best practices
		Lack of organisational schemes and well defined procedures for the management and maintenance of electrification projects
	Uncoordinated policies	Slow and complex administrative processes
Social Project not supported by local population	Lack of access to education	Lack of education to develop understanding and acceptance of new energy systems and to cultivate respect to maintain the system, lack of qualified local technicians, etc
	Environmental	Opposition to certain technologies due to aesthetics obstruction, competing land space with agricultural production, etc

STRENGTHS AND WEAKNESSES OF ENERGY ACCESS OPTIONS

Based on the findings in the above table, for the energy access option to be widely adopted in developing countries, it would need the following features:

- Reasonable and affordable capital cost
- Reasonable and affordable O&M cost
- Reasonable and affordable power prices
- Minimal impact on existing regulation and operation practices
- Can be operated and maintained by local communities
- Can be integrated with central grid in the future
- Does not demand additional capacity from central grid when connected

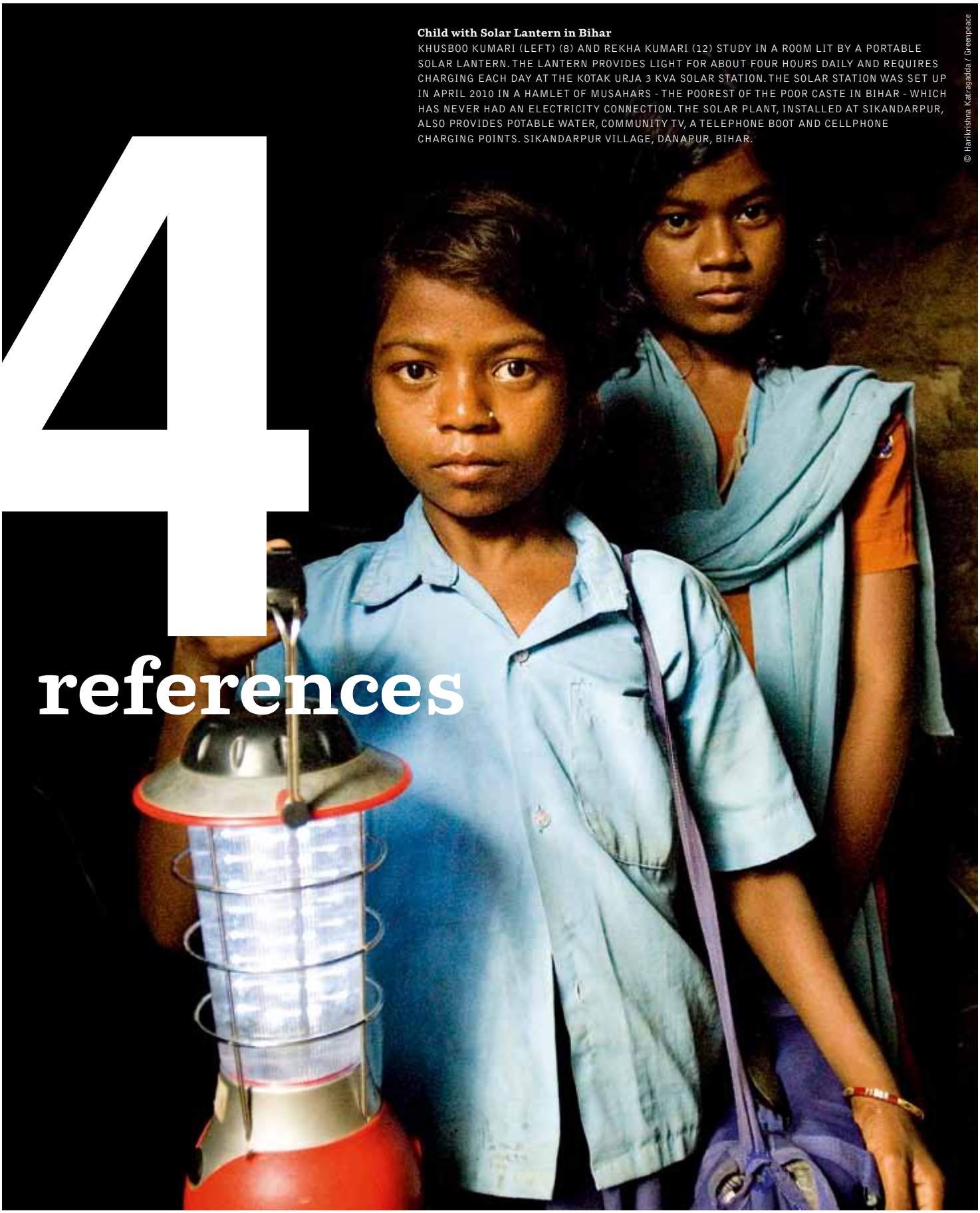
The strengths and weaknesses in addressing the obstacles often seen in developing countries of the application of each of these options in developing countries are given in Table 27. They are compared with grid extension (top-down) and distributed generation.

Table 27: Strengths and weaknesses of different energy access options. Source: energynautics

Energy Access Alternatives	Pros	Cons
Standalone HES (island)	• Lowest capital cost due to small unit size • No transmission or distribution lines need to be built • Fast and simple construction • No change in regulation required • Reliable supply can be sustained when grid is down	• Supply accessible to only one user (No benefit from economy of scale)
Mini-grid system (island)	• No transmission lines need to be built • Supply can be shared between multiple users • No change in regulation required • Reliable supply can be sustained when grid is down	• Distribution lines need to be built • Requires localized balancing control • Effective payment structure needs to be established • Mini-grid operator needs to be established
Microgrid system (island ↔ grid)	• Investment in transmission extension can be delayed until it can be economically justified • Supply can be shared between multiple users • Reliable supply can be sustained when grid is down • Supply from grid can be accessed when energy is cheaper and/or in case of local generation outage • Excess local supply can be fed to grid • Microgrid can support grid voltage and black start operation	• Distribution lines need to be built • Requires localized balancing control • Requires an effective independent payment structure until grid access is available • An operator of the island grid needs to be established until grid access is available • Requires communication and control equipment to switch between operation modes • Requires review of protection equipment and regulation
Grid extension with DG (grid)	• Access to economies of scale • Access to centralized balancing control • No change in regulation required • No new payment structure needs to be developed for consumers	• Transmission and distribution lines need to be built • Reliability of supply is dependent on centralized system (small villages are unlikely to become high priority areas for maintaining delivery of quality and reliability of supply) • Small load on a long feeder is prone to voltage problems

Distributed generation (grid)	• Supply can be shared between multiple users • Access to centralized balancing control • DG can support grid voltage and black start operation • No new payment structure needs to be developed for consumers	• Highest capital cost because transmission and distribution lines need to be built as well as generation units • Reliability of supply is dependent on centralized system (small villages are unlikely to become high priority areas for maintaining delivery of quality and reliability of supply) • Requires review of regulation • Power purchase agreements need to be established

4 references



Child with Solar Lantern in Bihar
KHUSBOO KUMARI (LEFT) (8) AND REKHA KUMARI (12) STUDY IN A ROOM LIT BY A PORTABLE SOLAR LANTERN. THE LANTERN PROVIDES LIGHT FOR ABOUT FOUR HOURS DAILY AND REQUIRES CHARGING EACH DAY AT THE KOTAK URJA 3 KVA SOLAR STATION. THE SOLAR STATION WAS SET UP IN APRIL 2010 IN A HAMLET OF MUSAHARS - THE POOREST OF THE POOR CASTE IN BIHAR - WHICH HAS NEVER HAD AN ELECTRICITY CONNECTION. THE SOLAR PLANT, INSTALLED AT SIKANDARPUR, ALSO PROVIDES POTABLE WATER, COMMUNITY TV, A TELEPHONE BOOT AND CELLPHONE CHARGING POINTS. SIKANDARPUR VILLAGE, DANAPUR, BIHAR.

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"el[r]cluster" for a smart energy access

THE ROLE OF MICROGRIDS IN PROMOTING THE INTEGRATION OF RENEWABLE ENERGY IN INDIA

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