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Assessing the business case for rural solar microgrids in India: a case study approach

Final report

Prepared for Azure Power

October 30, 2014

Energy+Environmental Economics

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Abbreviations

BPL: below poverty level

CREDA: Chhattisgarh Renewable Energy Development Agency

CAPEX: capital expenditure

DISCOM: state electricity distribution utility

FiT: Feed in tariff

FOR: Forum of Regulators

INR: Indian national rupee

IREDA: Indian Renewable Energy Development Agency

JNNSM or NSM: Jawaharlal Nehru National Solar Mission

kWh: kilowatt-hour

kWp: kilowatts peak

MNRE: Ministry of New and Renewable Energy

O&M: operation and maintenance

ODGBDF: off-grid distributed generation based distribution franchisee

OPEX: operating expenditure

PV: photovoltaic

REC: renewable energy certificate *or* Rural Electrification Corporation Limited

RGGVY: Rajiv Gandhi Grameen Vidyutikaran Yojana

RPO: Renewable Portfolio (or Purchase) Obligation

RVE: Rural Village Electrification programme

SERC: State Energy Regulatory Commission

UPNEDA: Uttar Pradesh New and Renewable Energy Development Agency (also called NEDA)

USTDA: United States Trade and Development Agency

USD: United States dollar

VAT: value-added tax

WIP: willingness to pay

Wp: Watts peak

Table of Contents

Abstract

We studied the feasibility of rural solar based microgrids in the Indian context using a case study approach in which solar microgrids were designed and evaluated for two villages in India (Bar Village in Chhattisgarh and Devari Bharat in Uttar Pradesh). We conducted detailed site assessments, including door to door surveys and community gatherings to assess the desire and interest in electricity and electricity services, demand, willingness and ability to pay for these services. The appetite for electricity and willingness to pay is relatively robust with a strong desire for a tariff that reflects actual consumption (rather than a flat tariff), although the willingness to pay (WTP) and ability to pay varied between the villages and was correlated with the socio-economics of each village. The WTP on an absolute basis ranged from INR 50-200 per month for essential services, to INR 100-500 for additional services. On a unit basis, these translate to ~ INR 4/kWh to INR 40/kWh. A spoiling effect was found in one village due to the fact that some of the residents have access to utility service at subsidized rates. Using the survey results, we developed demand profiles and used these as inputs to an integrated design approach.

Several AC-based microgrid designs were evaluated, consisting of solar PV arrays, inverters, batteries and backup diesel generation. An investment grade economic model was developed that determined the tariffs to be charged the villagers, given a set of financing criteria. The microgrid's economic feasibility was significantly better for the village in which a higher demand was estimated. We found that for higher demands (~ 400 kWh daily summer load), with favorable financing criteria, the microgrid is economically feasible. However, we found that for lower demands, as was the case with the village with poorer socio-economics the cost of the system was dominated by fixed costs (distribution network, site preparation, etc.) and we were unable to establish a tariff within the willingness to pay.

More broadly, economic and regulatory barriers may prevent widespread developer investment in microgrids of the type we evaluated. There is a significant risk of stranded asset to the developer in the event the grid reaches the village and villagers switch to utility service, even if the quality of service is superior from the microgrid. A significant gap exists between the tariff at which microgrid service can be offered and the WTP for smaller villages with lower loads, where fixed costs will dominate. In these cases, assuming the Indian government has a long term plan to provide grid access, more cost-effective intermediate measures may be better suited, such as solar home systems or DC-based "skinny" grids.

1 Executive summary

This report summarizes the findings of a 21 month study, supported by a grant through the United States Trade and Development Agency (USTDA) to develop the business model for rural solar PV microgrids in India. The grantee of the USTDA grant is Azure Power, a solar developer based in India. The project team was led by Energy and Environmental Economics (E3), a US based consulting firm, in collaboration with Black and Veatch, Schatz Energy Research Center, Varesh Energy, Chris Greacen, Christopher Freitas and Ranjit Deshmukh.

In this study, the E3 Team evaluated the feasibility for two specific villages in India; Bar in the eastern state of Chhattisgarh and Devari Bharat in the northern state of Uttar Pradesh.

The scope of this study was to address the feasibility of Alternating Current (AC) based solar PV microgrids, and hybrid solar PV-diesel microgrids, that could be interconnected into the utility grid at some point in the future. A variety of other rural electricity solutions exist, such as such as solar home systems, solar water pumps, DC-based microgrids or “skinny grids”. However, these were outside of the scope of this study.

Site characteristics

The villages we surveyed represented diverse social-economic demographics, awareness of electricity and solar energy, electricity access. Both villagers showed a strong appetite for electricity and a preference for a metered tariff or consumption based tariff. Overall, both villages showed promise in terms of willingness to pay (WTP) and stronger willingness to pay (WTP) for essential services (lighting, fans, mobile charging) with the following distinctions:

+ Bar: WTP for essential services ranges from ~ INR 100-200 ($1.6-$3.3) per month; for higher service, generally between INR 300-500 per month (~$5-$8). These values translate to unit prices of INR 8-42/kWh ($0.13-$0.70/kWh) with a median INR 19/kWh ($0.32/kWh).
+ Devari Bharat: WTP for essential services ranges from ~ INR 50-150 (~$1-$2.5) per month; for higher service, generally between INR 100-300 per month (~$1.6-$5). These values translate to a unit price of INR 4/kWh to INR 10/kWh ($0.07/kWh to $0.16/kWh).

The villages differ in terms of solar energy awareness and electricity access. Several residents in Bar Village have household solar systems and are familiar with solar energy because of the efforts by the

Chhattisgarh Renewable Development Agency (CREDA). Due to its proximity to a national forest, the electricity grid is unlikely to reach Bar in the near future. By contrast, Devari Bharat Village has partial access in which about 30% of residents have either legal or illegal connections. The utility electricity tariffs are low, and widely acknowledged to be below the cost of service, creating a "spoiling effect" whereby the un-electrified majority is reluctant to pay more than subsidized retail service.

We conducted individual surveys to identify the services desired by households and when these services are desired. Using this data, we constructed demand profiles for input to the design process. The demand was dominated evening consumption for lights and fan. This is expected, given that the economic activities for both villages are agriculturally dominated. A small number of customers desired daytime usage, such as medical facilities and shops; however, these are relatively small in number. We developed a few sensitivities, with the base case daily summer demand for Bar Village of 400 kWh per day and 160 kWh per day for Devari Bharat.

Approach

A key goal of this project was to develop a microgrid design and implementation strategy that meets the needs of the community. In contrast to utility scale generation projects, microgrids require greater attention towards the demand side of the equation. What electricity services are desired, when is electricity needed, and how much, are key considerations. We applied an integrated and iterative design approach that consisted of the following elements:

+ Needs based design approach, beginning with the electricity services desired by the village
+ Optimized for affordability and scalability
+ Integrated design approach in which economic, technical and implementation aspects were considered collectively and iteratively

Figure 1 illustrates the project flow of an integrated design approach. Beginning with the needs of the community, the technical design is iterated to achieve a design that is affordable and attractive from a business perspective.

Figure 1: Integrated design approach

An integrated design that begins with the needs of the community, and simultaneously addresses economics and technical design simultaneously, is essential to achieve an optimally designed solution. Unlike utility scale solar power design, microgrids have to continually achieve balance between supply and demand, without the 'storage' capacity of the grid.

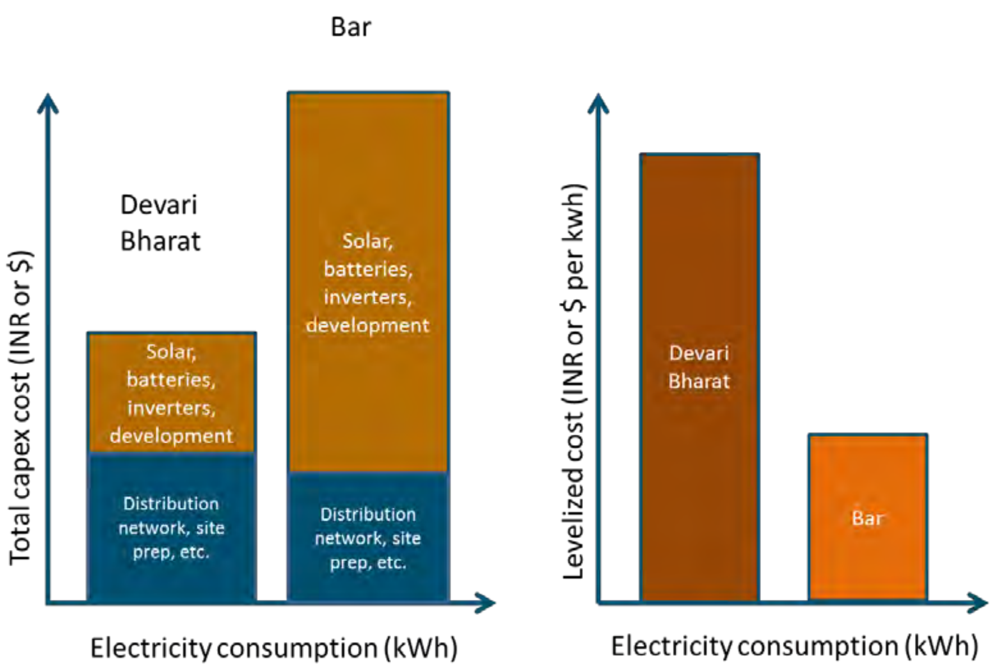
Our team utilized a combination of tools. The HOMER microgrid software tool was used to evaluate various microgrid configurations —sizing of the PV array, battery, diesel generator. HOMER converts future costs to a present cost using a discount rate, and reports this present cost of the various configurations. We selected the top configurations identified by HOMER, conducted more refined analysis for engineering details not considered in HOMER, and developed a detailed engineering cost estimate in which all components were priced, including the fixed cost components, such as meters, distribution network and site preparation. The total system cost over the lifetime of the system was then exercised through a detailed economic model that solves for the revenue requirement and tariff that would be charged to the customers, given a set of financing criteria — debt/equity share, cost, terms. Several financing scenarios and tariff designs were evaluated. At the final assessment, the tariff and monthly bills are compared to willingness to pay to assess feasibility. In our project execution, we repeated the whole cycle several times to improve the feasibility.

Feasibility results

In the case of both villages, the demand profile is not coincident with the solar shape. As a result, in order to meet the demand requirements, either battery backup or diesel generation is required. Both batteries and diesel fuel are expensive. By using HOMER, we were able to identify the optimal combination of solar, battery and diesel generation to meet the demand requirements of the villages. This process resulted in a solar-diesel system of 75 kWac for Bar and 15 kWac for Devari Bharat.

The base case lifecycle cost was INR 30/kWh for Bar Village and INR 80/kWh for Devari Bharat Village. The cost on a Watt basis was INR 285/Wac for Bar and INR 830/Wac for Devari Bharat. A number of sensitivities were performed that are described in the main report. To put the lifecycle costs in perspective, the capex cost for the Devari Bharat system is INR 1.3 Cr (INR 13 Million) or $210,000; for Bar INR 2.1 Cr (INR 22 Million) or $365,000[1]. The solar, battery, inverters and development costs, which are the key capacity-dependent costs constituted ~65% costs for the Bar design and ~30% for the Devari Bharat system. In other words, those costs which are unavoidable regardless of the capacity of the microgrid, such as the distribution system, meters, site preparation, drive up the unit cost of the electricity, as shown in Figure 2.

Figure 2: Relationship between fixed, capacity-dependent costs, lifecycle cost and consumption



As electricity demand is more coincident with the availability of solar, the cost of the microgrid decreases, since the battery size can be reduced. This was found to be a challenging factor in the two

[1] The panel cost of solar was assumed at $0.66/W or INR 41/W; BOS of the PV plant at $0.43/W or INR 27/W; batteries at $156/kWh or INR 9760/kWh, PV inverter at $0.3/Watt or INR 17/Watt; battery inverter at $0.66/W or INR 42/W; and development costs of 10% total capex.

villages we studied since most villagers are outside doing agricultural work during the day and require services mainly at night.

Inclusion of an anchor tenant load is beneficial. At one point, a Forest Department resort was a potential customer. We do not emphasize the results including the anchor tenant load in the executive summary as they are no longer a viable customer. However, we note that including their load had significant benefits towards project feasibility. Including the Forest Dept resort load in the design reduced the overall lifecycle cost by INR 6/kWh (~20%) and the village customer tariff by INR 7/kWh (25%).

We encountered very few technical challenges in the feasibility assessment. However, we faced one noteworthy obstacle in the design process. It was challenging to find a suitable meter. Our criteria includes an AC-based prepaid meter; one that is cost-effective (we were targeting $30-50 a meter); one that could support a consumption-based tariff with a minimum monthly payment; and one that does not require internet access for recharging. We eventually found two suppliers that would qualify, one US-based and one Indian-based, however, a majority of the prepaid meters available and used in microgrids are DC based and most of the qualifying AC-based meters are very expensive.

Regulatory barriers and scalability

There are a number of barriers that need to be addressed in order to achieve scalability. Although the overall market potential is large, given the lack of access in India, the risks to the developer are significant. If the grid eventually reaches the village, then the microgrid runs the risk of becoming a stranded asset. The 2003 Electricity Act also calls for regulation of the microgrid sector. Although model regulations for microgrids have been adopted by the Forum of Regulators, state regulatory commissions have not taken action. The model regulations provide some protection to the developer as they require the utility to use the microgrid's distribution system and compensate the developer for the distribution system book value, should the grid be extended to the village.

Scalability of AC-based solar-PV microgrid is challenging. The larger village, Bar, is an ideal candidate for microgrid deployment, particularly if the anchor tenant load had become viable. The village is unlikely to receive the utility grid soon because of its proximity to the national forest, the villagers are familiar with electricity (from a prior microgrid) and solar energy, and have strong willingness to pay. It's possible to work with the Forest Department to identify similar villages across the country. We found the second village, Devari Bharat to be a challenging case. Although the willingness to pay is higher than typical utility tariffs, a spoiling effect is present because some villagers have access to highly subsidized grid electricity. The overall load was estimated to be relatively small, and as a result, the fixed costs of the microgrid dominated the overall cost. This scenario is potentially a common condition, since there are a number of villages in India with partial access (some classified as electrified, some classified as unelectrified).

To the developer, assuming the grid will be extended eventually to the village, microgrid approaches or rural electricity approaches that serve as transition or “stop-gap” solutions may be more attractive to the developer. Solar home systems or DC-based “skinny” grids that focus on essential services and are easy to dismantle are more likely to provide the basic services below the willingness to pay threshold (i.e., 100-200 INR per month). The AC-based solar microgrid can be part of a long-term solution since all the microgrid components can be utilized in a grid-connected arrangement—though some are less valuable with grid connectivity. A franchisee arrangement with utilities that compensates the developer for the value of their assets can help ensure that the AC-based solar microgrid becomes a part of a long-term path towards electrification.

2 Introduction

2.1 Background

The U.S. Trade and Development Agency (USTDA) has awarded Azure Power (hereafter referred to as Azure) a grant to assess the feasibility of providing electricity in the form of solar photovoltaic (PV) microgrids for rural communities in India that currently do not have access to electricity. A team led by Dr. Priya Sreedharan of Energy and Environmental Economics, Inc. (E3) was selected to execute the study. E3 collaborated with the following organizations and individuals to complete the study ("E3 Team"): Black & Veatch (USA and India), Humboldt State University's Schatz Energy Research Center, led by Professor Arne Jacobson, Varesh Energy of India, Dr. Chris Greacen of Palang Thai, Christopher Freitas of SunEnergy Power International, and Ranjit Deshmukh, formerly of Prayas Energy Group.

The project takes a case study approach by examining the feasibility of solar microgrids for two villages in the Indian states of Chhattisgarh and Uttar Pradesh. The intent is that the feasibility assessment of the two specific sites can be used to attract investors for project implementation and microgrid development. Through the initial pilot project of two sites, Azure aspires to demonstrate the technical and economic feasibility of meeting rural electricity demands via a microgrid.

The broad objective of the study is to motivate investment in the microgrid sector and to provide electricity to rural communities that currently have little or no connectivity to the electrical grid. Azure, with support from the E3 team, aims to set up over 100 microgrid solar systems in rural areas. An additional goal of the study is to identify opportunities for specialized U.S. solar exports to establish a foothold in the growing Indian solar market.

2.2 Project scope

This project was structured in the form of sixteen individual tasks (excluding the final report task), beginning with the site assessment and concluding with the development impact analysis. Because each of these tasks resulted in a detailed deliverable, we have included these as appendices to the final report. The results of each of these individual tasks were used as the basis for this final report.

Table 1: Project scope and individual task descriptions

Task no.	Task description
1	Site assessment & project planning
2	Review solar microgrid models in other countries
3	Regulatory review and policy recommendations
4	Demand analysis and willingness to pay
5	Solar irradiation study
6	Solar plant technical feasibility analysis
7	Interconnection, distribution and metering study
8	Conceptual design
9	Economic Analysis
10	Development of business plans
11	Establish financing plan
12	Procurement and logistics
13	Construction and O&M planning
14	Metering, billing and collection assistance
15	Preliminary environmental impact assessment
16	Developmental impact assessment
17	Final report

We organized the final report differently from the original sixteen tasks to facilitate readability. Where applicable, we direct the reader to specific sections of the original tasks contained in the appendices.

2.3 Review of microgrids

The field of microgrids for rural electrification is evolving rapidly with constant innovation in power electronics and telecommunications that enable higher system efficiency; greater reliability; and remote monitoring, control, and payment. For solar powered microgrids, the major recent drop in the cost of solar modules has further pushed the boundaries of what is economically and technically feasible.

Microgrid developers must address several important questions in choosing a system design and business model appropriate to their intended customers:

+ How can the developer reconcile community energy demand with local willingness to pay?
+ Will the project rely on subsidies or be entirely market-driven?
+ What mix of generating resources will be employed?
+ What level of service will be provided? Basic household lighting only, or support for income generating activities?

- What is the best balance between high product quality and minimal capital cost?
- Will energy use be metered or sold at a flat rate?
- How will the system be configured with respect to AC and DC power?
- Will the developer aim to provide 24-hour power?

The developer must address a number of challenges. The key ones include the following.

- How will the microgrid be financed?
- How can power theft be mitigated?
- How can risk of non-payment be minimized?
- How can the microgrid be sized appropriately?
- How can the implementation leverage local technical capacity?

We reviewed several microgrid case studies from around the world, including India. These findings are described in the **Task 2** contained in the **Appendix 2**. We summarize the key lessons.

Business model considerations

- Electricity theft by non-customers and non-payment by legitimate customers can cripple a microgrid. Companies including Mera Gao and Gram Power have developed innovative meters and monitoring devices that are resistant to customer tampering. Pre-payment for energy avoids the non-payment problem and is an easy sell to rural customers, as they are already familiar with prepaid mobile phones and benefit by not unwittingly running up large bills they are then unable to pay. Social measures that create peer pressure within the community can be used to deter energy theft. Technical measures like circuit-level metering and reconciliation, or use of coaxial power cables can also help.
- Flat monthly rates for energy are widely used in the case studies. These tariffs can work, provided they are coupled with load limiting devices or other measures to deter over-use of energy. For larger scale systems designed to support income-generating activities, for which energy use may vary greatly over time, metering is a general practice.
- Demand side management (DSM) is an essential component of a successful microgrid project. DSM can take many forms, including promotion of energy-efficient loads, tariff structures designed to limit energy use, or encourage shifting of usage to off-peak periods, prepayment schemes, and electronic load-limiting devices at customer locations.

- All of the projects surveyed depended to some degree on subsidies or other sources of funding in addition to or instead of revenues collected from customers. Microgrid projects that rely on subsidies may fail if the subsidies are ended or significantly reduced.
- Microgrid developers working in remote communities should consider the possibility that main grid power may become available during the microgrid's working lifespan. There are a number of options available if this does occur, including continuing to operate the local generation as a distributed generator feeding the main grid, using the local power source only for backup during grid outages, or abandoning local generation altogether. Likewise, the local distribution system can be integrated with the main grid, operated separately in parallel, or decommissioned. The developer can profit from having a sound plan for grid connection in place from the outset.

Technical considerations

- Microgrids require varying degrees of skilled operation and maintenance. Successful developers of biomass gasifier-based projects, including Husk Power and VESP, have implemented extensive training programs to give local technicians the skills needed to operate and maintain the plants. The ILZO/RAPS diesel/solar and Devergy projects employed an alternative approach, relying instead on remote monitoring to troubleshoot its systems. It is not known how successful this approach has proven over the long term.
- Many developers are building DC-only microgrids. Such designs can offer cost advantages when built at very small scales. For electrical safety reasons, such microgrids should be limited to very low voltage (48V or less), which effectively limits the distribution distance from the power plant to 50 m or less.
- DC coupling was more commonly employed than AC coupling among the systems reviewed. AC coupling simplifies the future addition of new power sources to the microgrid. However, AC coupling slightly reduces overall system efficiency due to the need for extra power conversions and adds to capital cost since more inverters are required.
- Small-scale microgrids that support only basic energy services such as household lighting may be popular with government agencies, as they allow officials to claim success in rural electrification with minimal investment per household. These systems provide very valuable services such as lighting and mobile charging, however, such 'skinny grids' are unable to support the productive uses of energy that are necessary to achieve real economic development in the countryside.

We found that few models exist that emulate the goals of this project which is to build a scalable solar based microgrid suitable for future grid interconnection that is suitable for private sector investment. However, what is clear from all case studies is that to have a successful project, an integrated approach towards design, implementation and operation, that considers technical and social aspects of the microgrid is essential.

3 Policy context

Roughly 300 million people in India lack access to electricity (IEA, 2011)[2]. The benefits of electricity to economic and social development are understood. The Government of India (GoI) has made a significant push towards electrification by extending the electricity grid through the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) program. This program includes providing microgrids for certain communities where grid extension is determined to be difficult or impossible, such as for very remote villages. Microgrids can provide electricity to communities without access in the interim period, or to villages that may never receive the grid. Alternatively, given the challenges that India's power sector faces over all — financial losses of the utilities, domestic coal supply shortages, increased dependence on imported fuels— microgrids may help improve the reliability of service.

To support this feasibility study, we reviewed the central and state government policies and regulations relevant to solar photovoltaic microgrids for rural electrification in India, focusing on those aspects that are most relevant from the developer perspective. We identify key institutions and discuss policies and regulations at the central and state (Chhattisgarh and Uttar Pradesh) levels, including incentive programs, taxes, permitting, tariff regulation, and investor friendliness, focusing on the critical pieces of information for solar microgrid project development.

Central programs and National Solar Mission

There are three noteworthy central level microgrid programs: Jawaharlal Nehru National Solar Mission (JNNSM or NSM) and Remote Village Electrification (RVE) schemes, both operated by the Ministry of New and Renewable Energy (MNRE), and the Decentralized Distributed Generation (DDG) scheme under the Ministry of Power. Of these, the NSM is the program most utilized by developers and is the only program that allows a private developer to select its own villages for implementation and provides full flexibility in terms of ownership model and tariff setting. The RVE and DDG are less relevant; the RVE program is being subsumed into the NSM and the DDG is deemed unattractive by developers and is effectively inactive (nodal agencies and Rural Electrification Corporation select the villages; a build-own-maintain-transfer model is mandatory, and tariffs must be comparable to neighboring utilities' tariffs).

[2] International Energy Agency, 2011, Energy for All. Financing access for the poor. **http://www.iea.org/papers/2011/weo2011_energy_for_all.pdf**

Under the NSM, developers can receive a subsidy of 30% of the benchmark capital cost of a project and a soft loan at 5% annual interest to cover the balance of the project cost, provided the developer contributes 20% of the project cost as equity. The current benchmark price is INR 300 per Watt solar, equating to a capex subsidy of INR 90/W. At the time our study began, there was some uncertainty regarding whether the MNRE incentive would be increased from 30% (phase 1) to a 90% capital subsidy (phase 2 proposed incentive) for solar off-grid systems. However, the incentive remains at 30% of the benchmark price of INR 300/W. See the MNRE Amendment in the benchmark cost for "off-grid and decentralized solar applications programme"[3] This topic was confirmed with the MNRE[4].

The central government has delegated much of the responsibility for implementation of rural electrification to the state governments, including the dissemination of incentives. For renewable energy projects, both on- and off-grid, states have set up their own renewable energy development agencies, state-level analogues to the central government's MNRE. These nodal agencies act as program administrators, one of several "channel partner" roles established by MNRE for implementation of the NSM. The state-level discussions in this report call attention to special policies or conditions identified in Chhattisgarh and Uttar Pradesh that could affect microgrid development in these states. In some cases, state nodal agencies offer their own funding or services in addition to the pass-through central government funding they are charged with administering. The Chhattisgarh Renewable Energy Development Agency (CREDA) is especially enthusiastic to partner with Azure Power and help with access to incentives and permitting processes.

Regulation of the microgrid sector

We review electric tariff regulations where these have bearing on a stand-alone microgrid. Each of the central government programs addresses tariffs with varying degrees of latitude for developers. However, under the NSM program, there are no limitations on how the developer may set tariffs. This was validated through conversations with state nodal agencies.

An important regulatory change currently in process is the introduction of tariff regulations pertaining to off-grid microgrids. The Electricity Act requires that state regulatory commissions develop regulations

[3] MNRE Amendment in the benchmark cost for "off-grid and decentralized solar applications programme" implemented under the Jawaharlal Nehru National Solar Mission (JNNSM) during 2013-14 **http://mnre.gov.in/file-manager/UserFiles/amendmends-benchmarkcost-aa-jnnsm-2013-14.pdf**
4 Per discussion in July 2014 with Dr. Tiwari, manager of solar programs at MNRE.

for the microgrid sector. It is anticipated that projects established before tariff regulations are adopted will be exempt and that regulation may apply only if the microgrid has received subsidies.

The Forum of Regulators (FOR) has issued "model" regulations[5], however each individual state must adopt these through its regulator. As of now, these regulations have not been adopted by the individual state commissions. We list key elements of the FOR Model Draft Regulations.

- There are two model guidelines adopted by the FOR:
    - (1) Off-grid distributed generation and supply framework. Developer sets up a franchisee agreement with the DISCOM and receives payment from the DISCOM in the form of a Feed in Tariff and simultaneously receives revenue from consumers; the Feed in Tariff is to be based on a cost-plus basis; the intent of this business model is that the tariff be set to a comparable level that grid-connected consumers of the DISCOM see. Procedurally, Each electricity distribution company (DISCOM) would submit a petition to SERC for determination of the appropriate FiT. This generic step would be performed for each technology in each state and not for each individual project. In order for the developer to recover costs, it may need to ask the SERC for a custom FiT and/or flexibility in tariff setting, in order for the sum of the FiT and applicable incentives to cover all solar microgrid costs, given how low the benchmark utility rates are.
    - (2) The REC based model. Developer receives revenue for the renewable generation by receiving credit in the form of RECs through engagement with the Power Exchange; Developer receives direct revenue from consumers through tariffs. The intent in this model, also, is that the tariff be set to a comparable level that the grid-connected consumers of the DISCOM see. We express doubts that the revenues from the RECs would be sufficient to make this model viable for all renewable energy technologies.
- Although the intent is for the Developer (or rural system operator as they refer to it) to apply tariffs that grid-connected customers see, the Developer can charge either commission approved tariffs (i.e., utility/DISCOM tariffs) or a tariff mutually approved between consumers and developer. Hence, the developer is not required to charge the utility tariffs, which are generally low compared to the tariffs that would enable cost recovery.

5 See the following documents describing the Forum of Regulators activity regarding rural off-grid systems.
Minutes of Thirtieth meeting of Forum of Regulators; 6th of June 2012. **http://shaktifoundation.in/wp-content/uploads/2014/02/for-endoresement_off-grid-model.pdf**
Model draft regulations for off-grid RECs for community level off-grid projects. **http://www.forumofregulators.gov.in/data/homepage/2.pdf**
Model draft guidelines for off-grid distributed generation and supply framework. **http://www.forumofregulators.gov.in/Data/HomePage/5.pdf**

+ If the grid is extended to the village, the DISCOM must utilize the distribution network developed for the microgrid and provide payment to the DISCOM for the book value of the distribution network. The DISCOM can continue to provide payment to the Developer for the renewable power generation (through the FIT, for example).

The intent of the FOR guidelines is to provide business model options to the Developer. However, if the Developer prefers to develop the microgrid applying their own business model, that is acceptable. The most noteworthy aspect of the guidelines from a developer perspective, is that they provide some protection to the Developer against stranded assets. This is a key risk that any microgrid developer takes on, since currently, there is no protection to the developer from consumers opting to purchase power from a DISCOM when the grid is extended to the village.

Tax policies and permitting

There are a number of important tax policies that influence the feasibility of microgrids. Solar PV systems receive significant discounts on customs and excise duties. These exemptions have been challenged by domestic PV manufacturers; it is possible the exemptions may be unavailable in the future. Chhattisgarh exempts solar microgrids from the Value-Added-Tax (VAT), which applies to goods purchased within the state; Uttar Pradesh does not provide this exemption and the VAT can be as high as 14.5%. Finally infrastructure projects, such as solar projects, receive a 10 year income tax holiday; however, the Minimum Alternative Tax still applies. Finally the central level service tax is significant at 12.36% for which there are no specific microgrid related exemptions.

The required permits and regulations are unlikely to present major hurdles to a private microgrid. Multiple agencies have permitting requirements, but fortunately both the state renewable energy nodal agencies and state industrial development agencies in Chhattisgarh and Uttar Pradesh are authorized in their charters to provide “single window clearance” to assist developers with compliance.

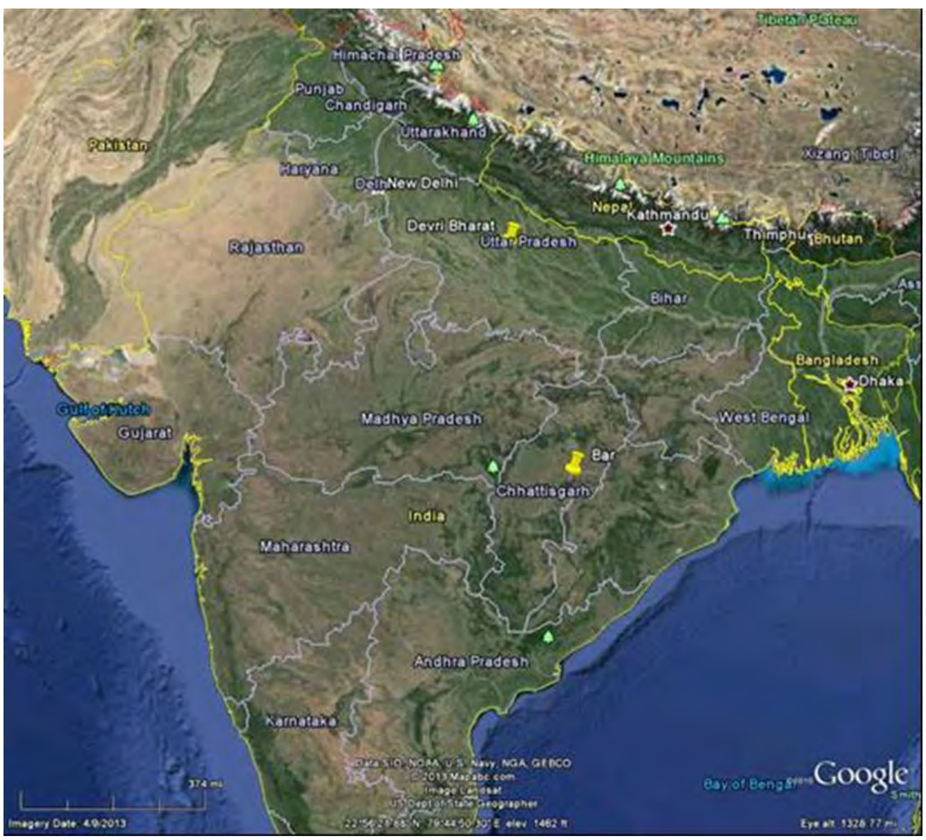
Additional details on the above subjects, and additional subjects, such as carbon financing, specific programs in Chhattisgarh and Uttar Pradesh, REC and RPO policies are discussed in the **Task 3** report included as **Appendix 3**.

4 Village descriptions

The original RFP issued by Azure and USTDA identified the districts of Raipur in the eastern state of Chhattisgarh and Sabarkantha in the western state of Gujarat. The district in Gujarat was later replaced, by Azure, with the Lucknow District in Uttar Pradesh (U.P.). The village in Chhattisgarh is Bar Village. For Uttar Pradesh, we investigated three nearby villages: Devari Bharat, Gumsena and Bakshi Kheda. Through the investigation we selected Devari Bharat among the three potential villages as the most promising site for the microgrid. Thus, the report focuses on Devari Bharat. Additional details for the other villages are presented in the **Task 1** and **Task 4** reports (**Appendix 1** and **Appendix 4**).

The locations of the villages are shown in the figure below.

Figure 3: Site locations for Bar, Chhattisgarh and Devari Bharat, Uttar Pradesh



We conducted detailed civil site assessments to identify locations for the solar microgrid and conducted detailed surveys to estimate the demand and willingness to pay.

4.1 Key characteristics

We conducted two sets of site visits. In the first, the overall site characteristics were explored. Maps of the village were developed, number of households assessed, and potential locations for the microgrid were identified. The concept of the microgrid was introduced and socialized to the community, working closing with the village Panchayat or governing council. Prior to visiting the sites, we conducted interviews with the MNRE nodal agencies, the Chhattisgarh Renewable Energy Development Agency (CREDA) and Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA), to gain their understanding and knowledge of each village.

The key attributes of each village is described in the tables below.

Table 2: Summary of village demographics

Attribute	Bar Village	Devari Bharat Village
Location (Latitude and Longitude)	21°24.309'N Latitude and 82°25.515'E Longitude	27°3.075'N; 80°47.636'E
Number of buildings/households	194	221 if connected customers included 153 if unconnected customers included
Population	1200-1500	1500-2000
Electrification status & transmission grid availability	Village is unelectrified and does not have access to the grid	Partially Electrified
Experience with electricity	Previously had a solar microgrid but it was removed; ~ 30% of villagers have small solar home systems	Roughly 25% of villagers have legal or illegal connections to the grid
Potential anchor tenant	At one time, Forest department resort might have been an anchor customer	None since industrial loads currently have utility service
Agricultural activity	Rice farming	Mango farming
Additional commercial activities	Forest Resort, shops and hospital	2 flour mills and some small shops
Number of plots and area available	2 plots (2 and 1.3 acres)	5 plots (0.12, 0.18, 0.06, 1.2 and 0.8 acres)
Key characteristics of plot	Panchayat owned	Private and Panchayat owned
Road access	Available by unpaved road; access for heavy vehicles in the monsoon period may be difficult	Available by unpaved road; close proximity to highways

Bar has approximately 200 houses and buildings, including small shops, clinics, a hospital, school facilities etc. Most of the shops and clinics are located in the center of the village. The forest service also has a significant presence in the village, with several homes and offices located in the village in addition to the forest guest house. The Barnawapara Wildlife Sanctuary has multiple villages scattered throughout with Bar located in the center. Bar has the most economic development among the nearby villages as it has served as the main commercial center for villages in the sanctuary. Residents of the other villages come to Bar to acquire goods and services.

Devari Bharat has approximately 236 houses, including small shops, school, flour mills and other facilities scattered around the village. One or multiple families may be living in one house based on their requirements. have mixed population of above poverty line (APL) and below poverty line (BPL).

Bar village summary

We list the qualitative aspects of Bar village that pertain to feasibility of the solar microgrid.

- Unelectrified village in middle of wildlife sanctuary with no potential for future electrification; this reduces the risk of stranded assets due to grid extension, but also underscores that Bar is a unique case study
- At one time, the Forest Department Resort was a potential anchor tenant customer (since our visit, the Forest Dept Resort constructed its own microgrid using government funds)
- Village was previously electrified by a small solar microgrid; customers are familiar with electricity and solar, and are primed for load growth
- CREDA is an enthusiastic partner and can facilitate acquiring the NSM incentive, provide additional incentives if needed, and obtain all necessary permits
- Two large sites available for the power plant
- The sites are close to village, on Panchayat land and available without cost

Overall, Bar Village is an excellent candidate for private sector electrification.

Bar electrification status and history

We elaborate on the electrification status and history. CREDA briefed the E3 Team about the present electrification status in and around Bar[6]. Bar does not have electrification except in the state-run Forest Dept resort and a few households that have individual solar home systems (purchased using a subsidy provided by CREDA). Under an initiative by CREDA, Bar was previously electrified. That system was sized to provide very basic needs such as lighting for a limited number of hours in the morning and at night.

[6] The E3 Team met with Mr. Sanjeev Jain, Mr. Rajeev Gyani and Mr. Nikhil Garg of CREDA thrice between May and July of 2013.

Residents paid a fixed monthly fee for the service of INR 5; an additional INR 20 is provided to the O&M contractor by CREDA. Though most of the systems installed by CREDA elsewhere in the state are still under operation, the system in Bar was only online for a short period of time. The power plant became non-functional due to multiple reasons, including increased demand by the community that had not been accounted for in the sizing of the system and potential theft of power and microgrid components. The plant was officially decommissioned and the equipment (panels, inverters and batteries) was relocated to a neighboring village to increase that village's capacity.

Local generation is the only option for villages in and around the Barnawapara Wildlife Sanctuary because it is located in a protected natural area. Transmission lines cannot be installed, thus transmitting conventional power is not feasible. One village in the sanctuary does have power from the grid because it was installed prior to the sanctuary being declared a protected area.

Devari Bharat summary

We list the qualitative aspects of Devari Bharat that affect project feasibility.

+ Partially electrified village; roughly 30% of households have either legal or illegal connections
+ Most customers will be lower income off-grid customers; the wealthier customers have access
+ No apparent anchor tenant customer; the industrial loads are connected the grid and have very low tariffs and in some cases, flat tariffs (e.g., pump tariffs)
+ 5 sites were evaluated for power plant
+ Best candidate is site 4 which is currently unused and without any nearby structures; this site is mostly barren and will require some fill as it has some low lying areas.
+ Gram Pradhan indicated that it can be made available without cost to developer for mini-grid

Although the village has partial electrification, 70% of the households do not have access. More broadly, the under-electrified village (rather than completely off-grid) may represent an even larger market opportunity in India. Thus, if the business case can be made for this application, it might provide a path to a large market opportunity.

Devari Bharat electrification status and history

The Team met with UPNEDA on two occasions to discuss electrification status in and around Devari Bharat and to understand UPNEDA's microgrid activities. [7] Grid power is available in some parts of Devari Bharat. However, availability and reliability of grid power is very poor. Villages get 6 to 8 hours of power daily under a special agreement, but the power quality and the hours during which power is made available vary significantly from day to day. Some of the houses/shops in Devari Bharat have installed their own unauthorized connections from the grid line. However, 70% of the houses in these villages are without connections. In 2010, the Gram Pradhan (Mayor) had submitted an application to NEDA to build a microgrid in Devari Bharat. In the updated model, UPNEDA has invited private developers to install solar PV microgrid plants and localized distribution networks at villages located in U.P.

4.2 Demand and willingness to pay

We assessed electricity demand and willingness to pay for electricity in the villages using a survey approach. Reliable estimation of willingness to pay (WTP) requires more than simply asking residents what they consider to be a fair price for electric power. Residents may have no point of reference, or they may expect off-grid power to be available at the same artificially low prices their urban relatives pay for grid service. A thorough WTP study should assess household income and expenses, including current expenditures on energy, and present villagers with realistic scenarios of energy service and cost they can respond to. Recent studies of WTP in rural India suggest developers should aim to provide service that allows lower income customers to pay no more than about INR 150 per month for basic service including lighting and mobile phone charging. For purposes of our surveys and focus group discussions, we used an assumed tariff of INR 27.50 per kWh when presenting cost scenarios to participants. This tariff results in a monthly bill similar to the INR 150 figure for the minimum service level scenario.

We conducted a field study in the project sites, using the following tools:

- Direct observation of living conditions and existing infrastructure in each village
- Questionnaires used to interview residents, small business owners, and other community stakeholders

[7] The Team met with Mr. Y.K. Arora, program officer for the districts, and Mr. Ashok Srivastava, off-grid program officer of UPNEDA twice between May and July 2013.

- Focus group discussions where small numbers of villagers gathered to discuss their energy needs and willingness to pay
- Informal discussions with community leaders and other stakeholders such as state and central government officials familiar with the villages

We summarize the key points and highlights from this evaluation. Additional details of our approach and results are presented in the Task 4, Appendix 4 of this report.

Summary results

The villages we surveyed represented diverse social-economic demographics, awareness of electricity and solar energy, electricity access. Both villagers showed a strong appetite for electricity and a preference for a metered tariff or consumption based tariff. Overall, both villages showed promise in terms of willingness to pay (WTP) and stronger willingness to pay (WTP) for essential services (lighting, fans, mobile charging) with the following distinctions:

- Bar: WTP for essential services ranges from ~ INR 100-200 ($1.6-$3.3) per month; for higher service, generally between INR 300-500 per month (~$5-$8). These values translate to unit prices of INR 8-42/kWh ($0.13-$0.70/kWh) with a median INR 19/kWh ($0.32/kWh).
- Devari Bharat: WTP for essential services ranges from ~ INR 50-150 (~$1-$2.5) per month; for higher service, generally between INR 100-300 per month (~$1.6-$5). These values translate to a unit price of INR 4/kWh to INR 10/kWh ($0.07/kWh to $0.16/kWh).

The awareness of solar energy and electricity access differ between the villages. Several residents in Bar Village have household solar systems, and are familiar with solar energy in general, largely because of the efforts by the Chhattisgarh Renewable Development Agency (CREDA). Due to its proximity to a national forest, the electricity grid is unlikely to reach Bar. Devari Bharat Village has partial access in which about 30% of residents have either legal or illegal connections. The utility electricity tariffs are low, creating a “spoiling effect”.

We conducted individual surveys to identify the services desired by households and when these services are desired. Using this data, we constructed demand profiles for input to the design process. The demand was dominated evening consumption for lights and fan. This is expected, given that the economic activities for both villages are agriculturally dominated. A small number of customers desired daytime usage, such as medical facilities and shops; however, these are relatively small in number. We developed a few sensitivities, with the base case daily summer demand for Bar Village of 400 kWh per day and 160 kWh per day for Devari Bharat.

Key findings from Bar

Bar villagers are familiar with electric power because they were previously served by a solar PV microgrid that was installed by CREDA. The microgrid was removed and relocated to another village, in part, because the villagers plugged in additional devices beyond the basic services envisioned by CREDA; thus, Bar residents already own some electrical devices. Some residents have small household PV systems purchased from CREDA at a subsidized price. Almost all residents desire electricity service from the microgrid and many have clear expectations about electric loads they will own and use.

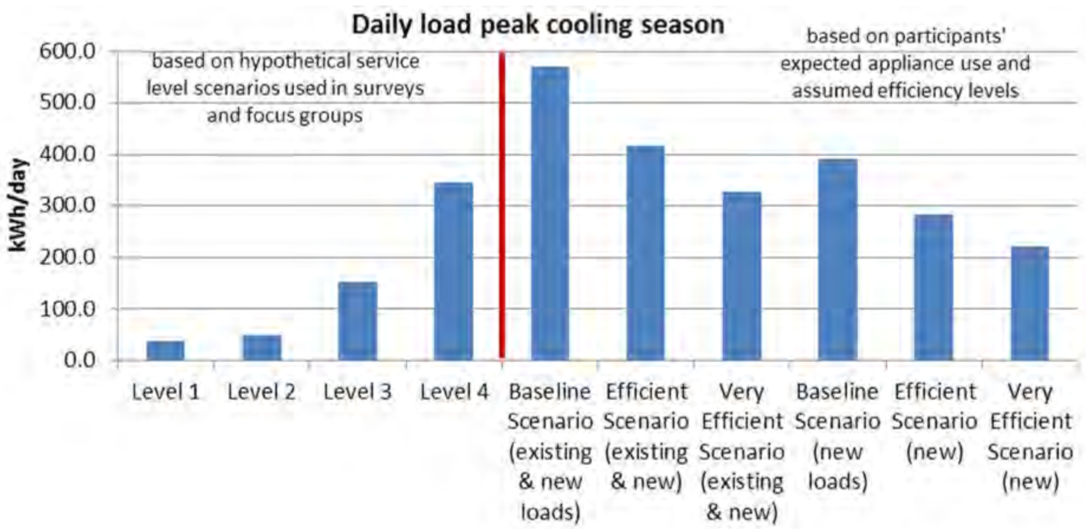
We estimated the demand for several scenarios shown in Figure 4; there are roughly 194 sites (households, businesses, schools, etc.) in Bar. The service level demand scenarios are based on predefined service levels (with estimated monthly use and cost, using INR 27.50/kWh).:

+ **Service level 1:** two lights and mobile charging (~ 6 kWh/month, INR 160/month)
+ **Service level 2:** three lights and mobile charging (~ 8 kWh/month, INR 220/month)
+ **Service level 3:** four lights, TV, fan, mobile charging (~ 24 kWh/month, INR 650/month)
+ **Service level 4:** service level 3 plus refrigerator (~ 54 kWh/month, INR 1500/month)

The baseline, efficient, and highly efficient demand scenarios are calculated using survey data on quantity of appliances and hours of usage of these appliances. In general, lights, fans, TV's, radios, mobile charging, and a small number of refrigerators were selected. [8] It is worth noting the baseline, efficient and highly efficient demand scenarios reflect the expected demand based on inventory of participants' appliances already owned or desired and their self-reported expectations about hours of use of these appliances, independent of any consideration of willingness to pay.

[8] The baseline, efficient and very efficient scenarios are based on numbers of appliances surveyed through the "short surveys" and hours of operation of each device based on the long residential surveys.

Figure 4: Bar electric demand scenarios for entire village, summer load



The baseline scenario demand serving both existing and new loads is approximately two-thirds larger than the service level 4 demand. The very efficient scenario, serving both existing and new loads, which assumes significantly more energy efficient devices, has a demand level nearly equivalent to level 4 but provides a greater level of service that is customized to the specific preferences of the village. The baseline scenario in which the microgrid is assumed to serve only new loads (i.e., existing loads serviced by existing household systems will continue to be served by those household systems) is between the Level 4 service and baseline scenario serving new and existing loads.

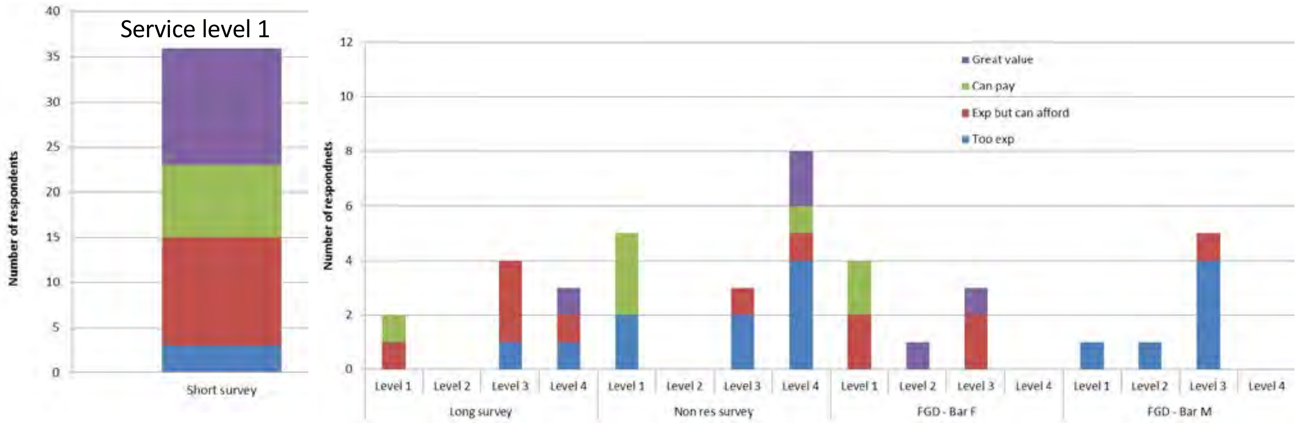
To supplement the appliance audit based demand estimates, we obtained data on village preferences among the predefined service levels. The focus group discussions (FGD) in Bar resulted in the following service level choices:

+ Female preferences: roughly split between service levels 1 and 3
+ Male preferences: roughly 70% selected service level 3 and the rest chose service level 1 or 2.

In addition to the FGD's, we obtained preferences among these service levels through a small set of individual surveys. These surveys yielded results similar to the male FGD results; roughly 30% of respondents selected basic service with the remainder selecting service levels 3 and 4.

We obtained willingness to pay (WTP) for the predefined different levels of service on a categorical/qualitative basis ranging from 'great value' to 'expensive and unaffordable'. The costs of each service level were based on INR 27/kWh.[9] Figure 5 illustrates the results of these categorical assessments of WTP by service level from the different survey methods.

Figure 5: Bar – Service level preferences



Key insights based on the categorical WTP are as follows:

- There is a general willingness to pay at the assumed cost of INR 27/kWh
- For minimal service (service level 1), the short surveys revealed ~ 90% of respondents could afford the service level benchmarked to INR 27/kWh.
- Focus group discussions vary between female and male; the female group indicated a willingness to pay for all service levels, while the male focus group were unwilling to pay the equivalent of INR 27/kWh. The female participants in the FGD spent higher amounts (INR 290) than the male participants (INR 115) on energy and were more willing to spend on electric services.

We collected numeric maximum WTP on an absolute INR basis specifically for respondents that viewed the benchmark service cost of INR 27/kWh as unaffordable. In some cases, the data are specific to service levels and in other cases, respondents merely defined an absolute maximum WTP (INR per month) regardless of service. The tables below show this data on a normalized basis (per unit).

[9] The INR 27/kWh was estimated assuming ~ $7.50/Watt, 22% capacity factor, 11% discount rate, 20 year lifetime, and conversion rate of 55 INR per 1 USD. No incentive is taken into consideration.

Table 3: Bar willingness to pay by level of service (INR per kWh)

Source	Service Level 1	Service Level 2	Service Level 3	Service Level 4
Short survey	25.7 34.3 17.1		12.6 23.1 21.0 21.0 42.0 8.4 21.0 12.6	
FGD Bar M	17.1	19.1	12.6	
FGD Dound				14.8

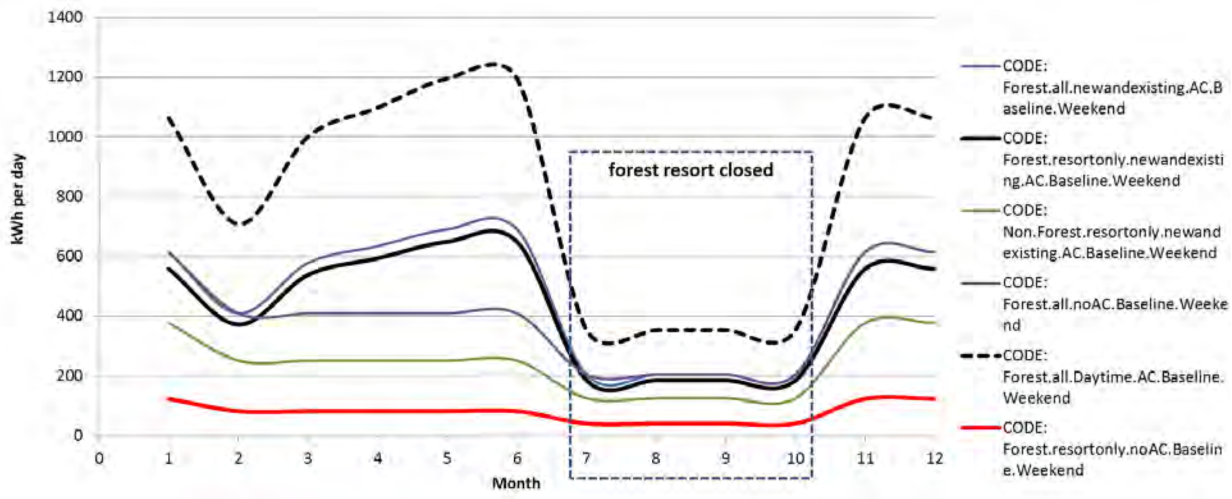
Each entry in the table represents a specific individual respondents' willingness to pay. We show the individual data points rather than statistical summaries to preserve the richness of the data and because there are a limited number of responses.

We also explored the potential of using the Forest Department resort as an anchor tenant load. Although the Forest Department recently[10] constructed its own microgrid using government funds, we present the results of our demand assessment including the Forest Department loads. The Forest Department operates a resort and also has a few small loads, such as offices and employee residences. The resort was previously powered by an 18 KW solar PV system and two diesel generators (40 kW and 15 kW). We conducted energy audits of the current resort load and future load based on ongoing expansion, as well as the ancillary loads (e.g., offices). The audit involved collecting information on drivers such as occupancy rates, air conditioning operation, and generator runtimes. We estimated forest resort demand for several scenarios, shown in Figure 6 for weekend loads. The scenarios show these factors in different combinations:

+ With air conditioning as currently operated (night only), with air conditioning operating day and night, and without any air conditioning
+ All Forest Department loads (forest resort plus offices), non-resort loads only, or forest resort loads only

[10] Surveys were conducted in June, 2013. The Forest Department installed its own mini-grid in early 2014.

Figure 6: Bar Forest Department electric demand and monthly cooling degree days - weekends



The current resort demand is highly dependent on the operation conditions of the air conditioning units (which are operated at night only); Figure 7 illustrates the daily electric consumption patterns. The daily load for the existing and under construction loads is ~ 1,000 kWh during the peak demand season.

Figure 7: Bar Forest Department peak season daily electric demand pattern

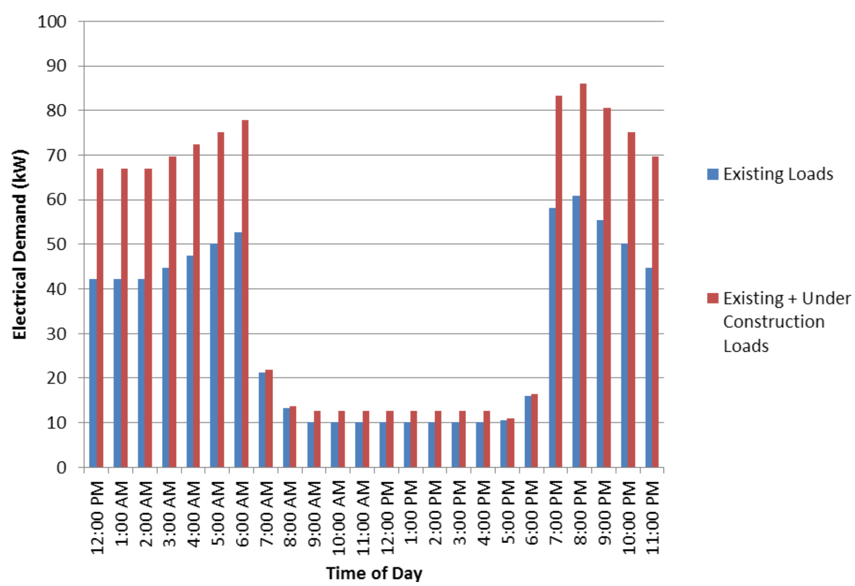
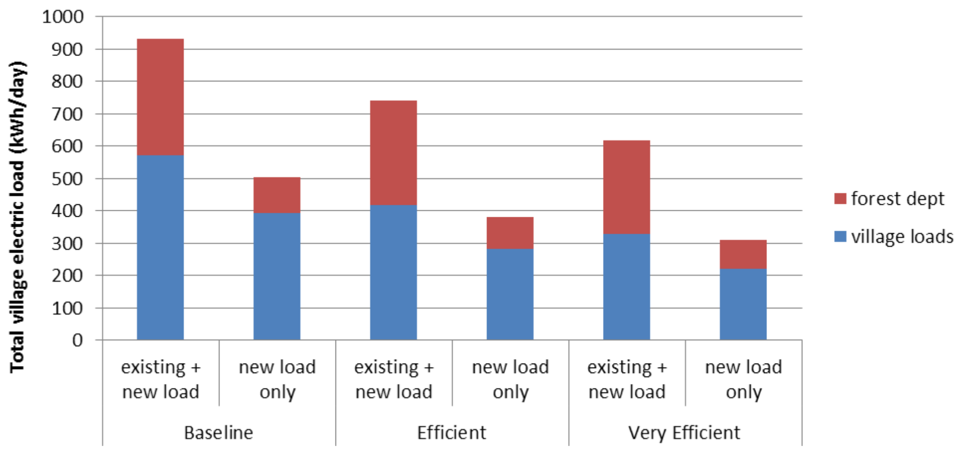


Figure 8 compares the Forest Department load and village load for different scenarios.

Figure 8: Bar Combined forest department resort and village load

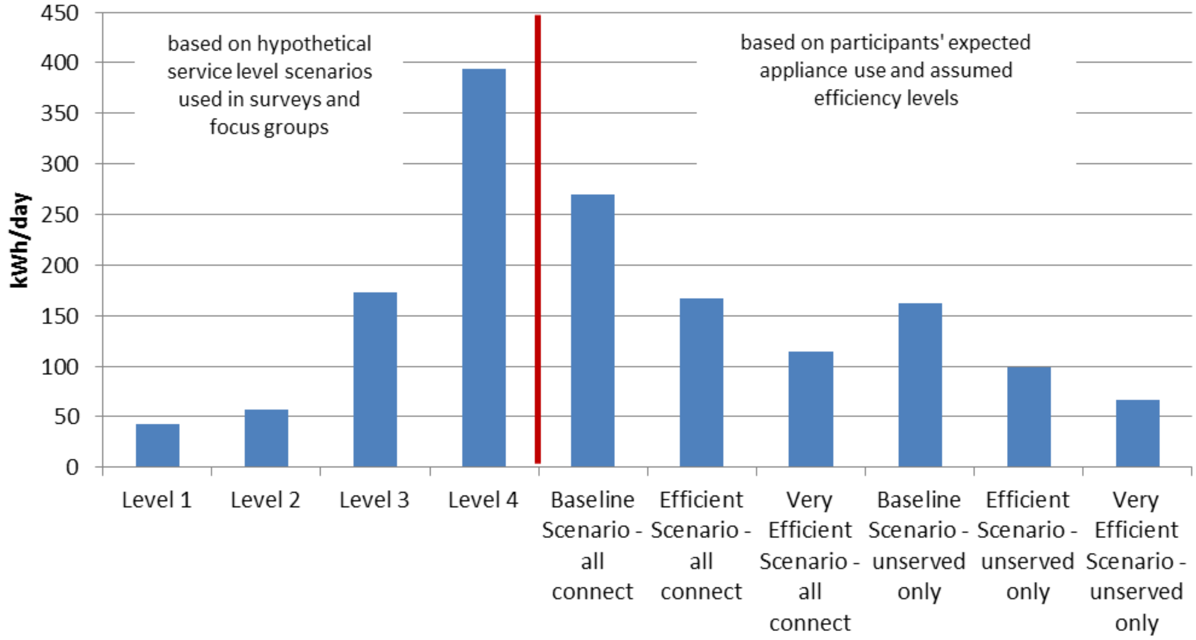


Across these different scenarios, village loads are larger than Forest Department loads, but it is clear the Forest Department would have been a significant anchor tenant customer.

Key findings from Devari Bharat

The team visited Devari Bharat, Gum Sena and Bakshi Keda. Based on survey results, a focus group discussion and informal conversations with community leaders, we determined Devari Bharat to be a more viable site for microgrid development as compared to Bakshi Kheda and Gum Sena. Thus, the discussion focuses on Devari Bharat. Figure 9 shows several scenarios for electric demand based on a) the four service levels proposed in the surveys, and b) six scenarios with varying assumptions about energy efficiency and whether homes currently having grid electric service elect to connect to the microgrid. There are roughly 221 sites in Devari Bharat of which roughly 153 are unelectrified. Devari Bharat is partially electrified with roughly 25% of villagers have utility grid service at very cheap rates. These customers are unlikely to switch to the microgrid service. The demand scenarios present scenarios where all households connect to the microgrid and scenarios where only unelectrified households subscribe for microgrid service.

Figure 9: Devari Bharat - Electric demand scenarios for entire village, summer load



The trends of the demand scenarios are roughly similar to Bar, however, the village-wide electric demand is about half that of Bar for cases where all households are connected to the microgrid. The demand levels are reduced by ~ 40% for cases where only unelectrified households are connected to the microgrid. Residents chose similar appliances — lights, TV's, fans, and radios. The demand of the 'all connected' efficient scenario is comparable to the demand of service level 3. The baseline efficiency scenario where all households connect to the microgrid is about halfway between service levels 3 and 4.

We obtained willingness to pay (WTP) information on a categorical and numeric basis. Figure 10 and Figure 11 show the WTP results from the individual surveys and focus group discussions.

Figure 10: Devari Bharat – Willingness to pay by service level

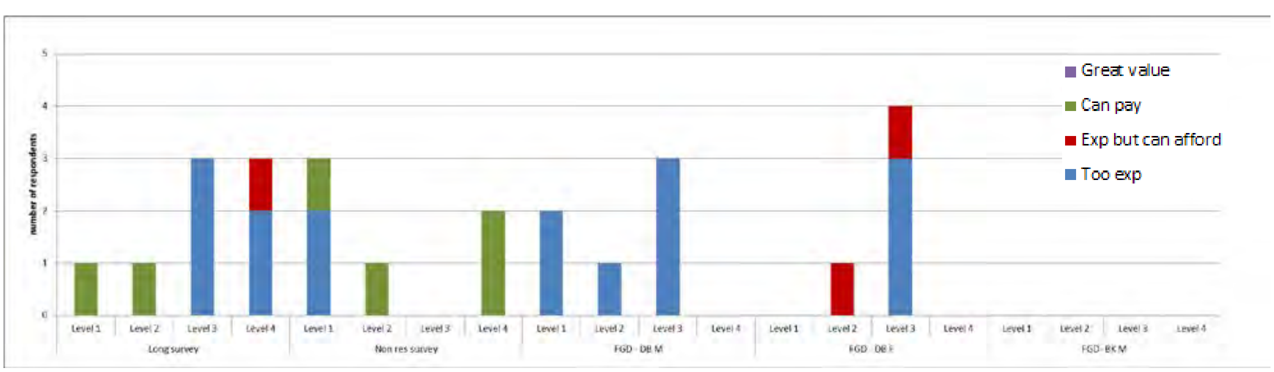
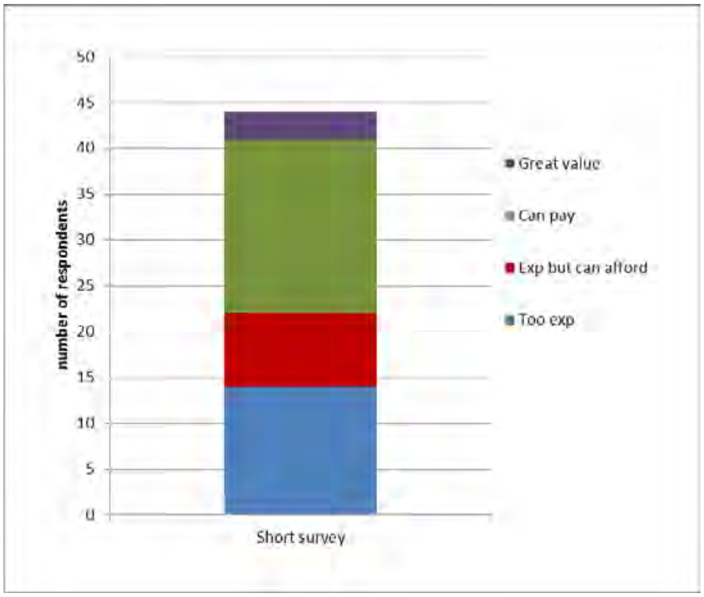


Figure 11: Devari Bharat – Willingness to pay for service level 1 (short residential survey)



Roughly 70% of the short survey respondents are willing to pay for service level 1, based on a cost of service of INR 27.5 per kWh. The WTP for higher levels of service is significantly lower based on the long survey, non-residential and focus group discussion results. FGD results showed that service level 3 was most popular among the two groups. However, the cost of each of the service levels is generally viewed as too expensive to afford.

We obtained WTP numeric data for Devari Bharat; these are shown on a kWh basis in Table 4 and Table 5 for participants without and with grid electricity (see Tables 9 and 10 in Appendix 4 for WTP on an absolute INR per month basis).

Table 4: Devari Bharat - Willingness to pay by level of service –surveyees without electricity (INR per kWh)

Source	Surveyed	Service Level 1	Service Level 2	Service Level 3	Partial 3	Service Level 4
Short survey	10 4 4	17.1 17.1 10.3 17.1 8.6 13.7 25.7 17.1 17.1 12.8		8.4 11.3 12.7 14.1	6.3 8.4 8.4 6.3	
Non res survey		17.1 10.3	31.9			
FGD-DB-M		8.6	12.7		8.4	
FGD-BK-M			19.1		6.3	

Each entry in the table represents a specific individual respondents' willingness to pay. We show the individual data points rather than statistical summaries to preserve the richness of the data and because there are a limited number of responses.

Table 5: Devari Bharat - Willingness to pay by level of service –surveyees with electricity (INR per kWh)

Source	Surveyed	Service Level 1	Service Level 2	Service Level 3	Partial 3	Service Level 4
Short survey		8.6 8.6		8.4	10.5	
Long survey					12.6 12.6	5.5 7.4
Non res survey	5					

Each entry in the table represents a specific individual respondents' willingness to pay. We show the individual data points rather than statistical summaries to preserve the richness of the data and because there are a limited number of responses.

Willingness to pay *decreases* with increasing service level for non-connected participants, while it *increases* with increasing service level for surveyees with electricity. Consumers without grid electricity generally indicated a willingness to pay ~ INR 200 per month for service levels 2 and beyond.

5 Feasibility approach

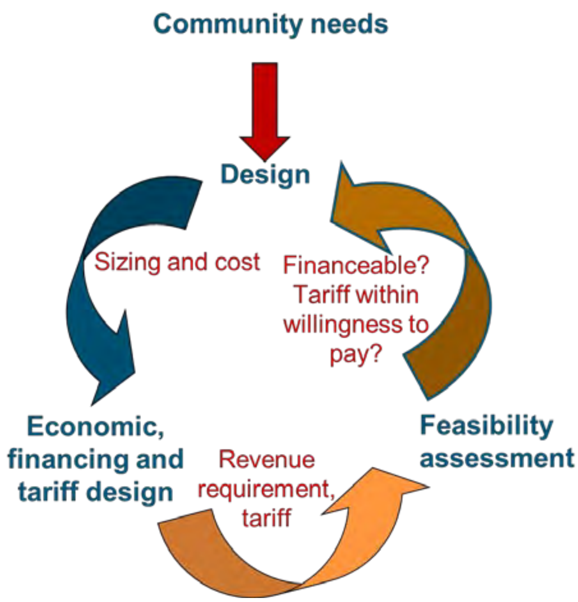
5.1 Summary

A key goal of this project was to develop a microgrid design and implementation strategy that meets the needs of the community. In contrast to utility scale generation projects, microgrids require greater attention towards the demand side of the equation. What electricity services are desired, when is electricity needed, and how much, are key considerations. We applied an integrated and iterative design approach that consisted of the following elements:

+ Needs-based design approach, beginning with the electricity services desired by the village
+ Optimized for affordability and scalability
+ Integrated design approach in which economic, technical and implementation aspects were considered collectively and iteratively

Figure 12 illustrates the project flow of an integrated design approach at a high level. Beginning with the needs of the community, the technical design is iterated to achieve a design that is affordable and attractive from a business perspective.

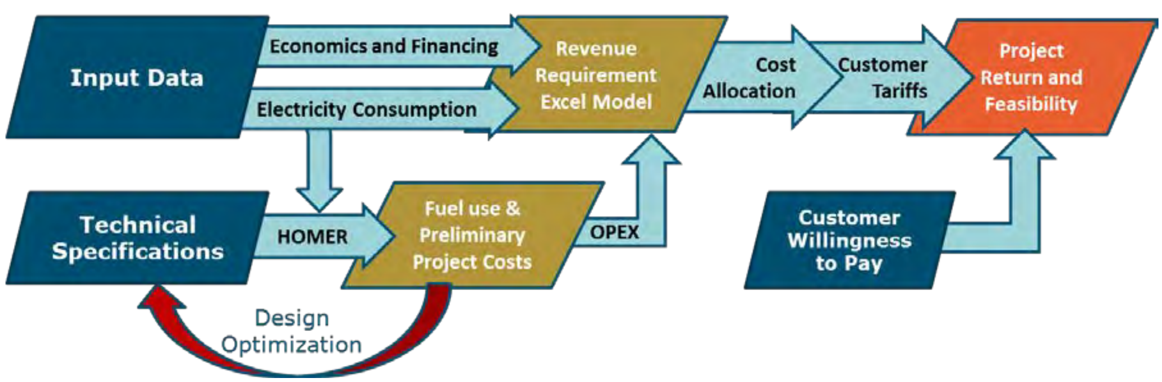
Figure 12: Integrated design approach



An integrated design that begins with the needs of the community, and simultaneously addresses economics and technical design, is essential to achieve an optimally designed solution. Unlike utility scale solar power design, microgrids have to continually achieve balance between supply and demand, without the 'storage' capacity of the grid.

Our team utilized a combination of tools to achieve a feasible microgrid design. Figure 13 illustrates the modeling architecture and flow of information among the technical tasks.

Figure 13: Model architecture and flow with technical tasks



The HOMER microgrid software tool was used to evaluate various microgrid configurations —sizing of the PV array, battery, diesel generator. HOMER converts future costs to a present cost using a discount rate, and reports this present cost of the various configurations. We selected the top configurations identified by HOMER, conducted more refined analysis for engineering details not considered in HOMER, and developed a detailed engineering cost estimate in which all components were priced, including the fixed cost components, such as meters, distribution network and site preparation. The total system cost over the lifetime of the system was then exercised through a detailed economic model that solves for the revenue requirement and tariff that would be charged to the customers, given a set of financing criteria — debt/equity share, cost, terms. Several financing scenarios and tariff designs were evaluated. At the final assessment, the tariff and monthly bills are compared to willingness to pay to assess feasibility. We repeated the whole cycle several times to improve the feasibility.

The approach we utilized is described across a few different tasks and appendices. Task 5 describes the solar data, which is a key input to the design of the solar plant of the microgrid. Tasks 6 through 8 focus on the technical design of the microgrid, while Task 9 integrates all aspects into the overall economic assessment. These are contained in Appendices 5, 6, 8 and 9.

5.2 Principles of design

We summarize the key principles of design that we applied in this project. They are specific to hybrid PV/diesel microgrids and assume that a goal is to minimize the long run cost of energy. (Additional details are provided in the Task 6 / Appendix 6 of the report.)

General principles of design

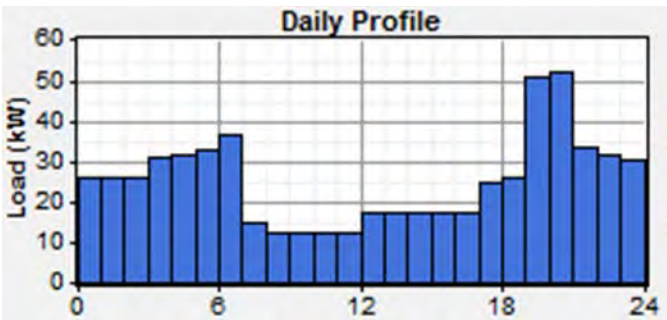
Aim for flexibility. This is very important because mini-grid loads, particularly in areas where there are populations without electricity, will grow over time. Thus, the design should build in the ability to expand the system over time. The following practices can help achieve this goal.

+ Oversizing components that can't be marginally upgraded. This includes distribution lines, transformers, and diesel generators.
+ Obtaining sufficient land for increased solar array size.
+ Using batteries isolated by multiple separate inverters on an AC bus allows for redundancy and ability to add new battery & inverter capacity. If all batteries are connected to a common DC bus, adding new batteries to old causes problems on the overall pack performance.

System optimization steps. Optimization means balancing the amount of solar, batteries, diesel generators (and diesel consumption) so that a properly operated system leads to overall lowest cost of electricity (COE). HOMER is an excellent tool for this as it tests thousands of different systems, simulating each system through 8760 hours and selects the one with lowest cost of energy over lifespan of project. Commercial tools also exist; SMA, for example, has its own optimization software, similar to HOMER. The key data requirements for HOMER include information on loads, specifications and prices of candidate equipment (PV, inverter, batteries, diesel generator), diesel prices, solar resource and economic information (namely, the discount rate).

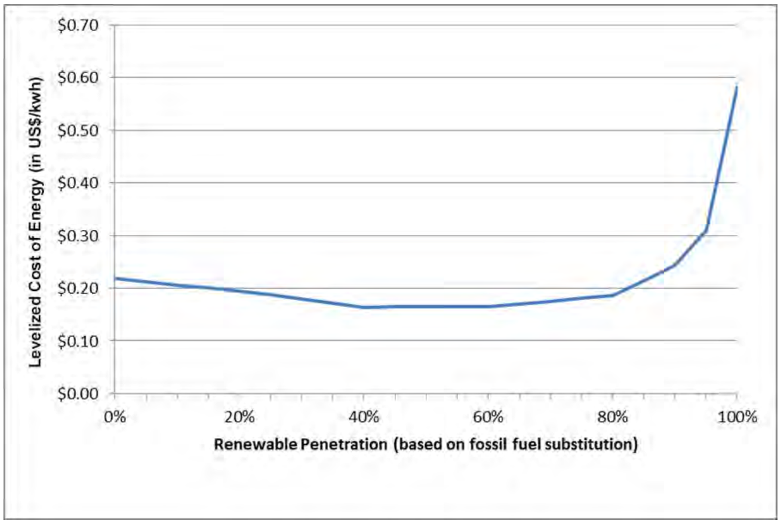
Estimating loads. If the community has an existing diesel generator, obtain operator records with kWh every hour. If the records are inadequate, use a simple datalogger such as a HOBO logger U-12 together with appropriately-sized current transformers to record consumption (typically one transducer on each phase). If there is no existing diesel generator, use surveys and or cross-reference with nearby villages that do have electricity (as was the case in this study). Search out loads that are deferrable or flexible, such as pumps. These can minimize need to burn diesel. Figure 14 shows a typical load profile shape.

Figure 14: Typical daily profile for a rural village



Hybrid solar PV/diesel design. A 100% renewable energy is likely to lead to significantly higher costs because of the need to over-build to accommodate periods of cloudiness. Figure 15 shows an illustrative lifecycle cost of energy as a function of the renewable energy penetration. The early part of the curve, beginning with 0% renewable energy, depends on the cost of diesel. As the renewable penetration increases, the lifecycle cost decreases. In this illustration, at around 85% renewable penetration, the lifecycle cost dramatically starts to experience, as shown in the "hockey stick" part of the curve. A small amount of diesel helps to keep the overall costs low.

Figure 15: Illustrative lifecycle cost of energy vs. renewable penetration (Source: www.homerenergy.com)



Generator design. Multiple sizes of diesel generators should be considered. Diesels are most efficient when operating at 80% of the rated capacity of output. The addition of batteries in the system allows diesel generators to operate at 80% of output and then turn off rather than following load. This alone leads to considerable lowering of the lifecycle cost in "battery + diesel" compared to diesel-only case. An IBE charger or additional converter capacity may be necessary to make use of all the power being generated by the diesel generator.

Batteries. The batteries are one of the most expensive components of the microgrid and are the most demanding component in terms of the operating and maintenance they require. The following factors should be considering in the battery design:

- Lead-acid vs. lithium: Lead-acid has far more track record in village mini-grids. Inverters (SMA, Outback, Princeton, etc. are built around lead-acid charge/discharge profiles. The costs of lead acid batteries, currently, are below lithium batteries.
- Flooded lead acid or valve-regulated lead acid: Flooded lead batteries are cheaper. However, they require more maintenance (topping up with distilled water), ship dry or (if wet) ship carefully. Valve-regulated lead acid batteries can be shipped charged and require less maintenance. However, they are more expensive.
- More electrical connections means more failures: For systems with peak load over 10 kW, consider 2-volt cells of 600 Ah or larger (fewer bigger individual cells). 2-volt cells up to 3,250 Ah or more are available (but weigh 230 kg).

Lastly, batteries are heavy, so consider the logistics.

Sensitivity analysis. While it is possible to perform sensitivity analysis of several factors in HOMER, the most important ones are load and diesel cost. This is because future load is unpredictable and diesel price can fluctuate.

Principles applied to Bar and Devari Bharat designs

We summarize specific aspects of the technical design approach for the Bar and Devari Bharat designs.

3 Phase AC system. We selected a 3 phase AC system design for both the Bar and Devari Bharat designs. In the case of Bar, the size of the system required a 3-Phase solution. In the case of Devari Bharat, though it was a smaller system than Bar, we found that a single phase design would have required more costly single phase PV inverters. 3 phase AC systems also allow for easier expansion in the future. Lastly, diesel generator suppliers' preference is 3 phase.

Additional design choices are listed below:

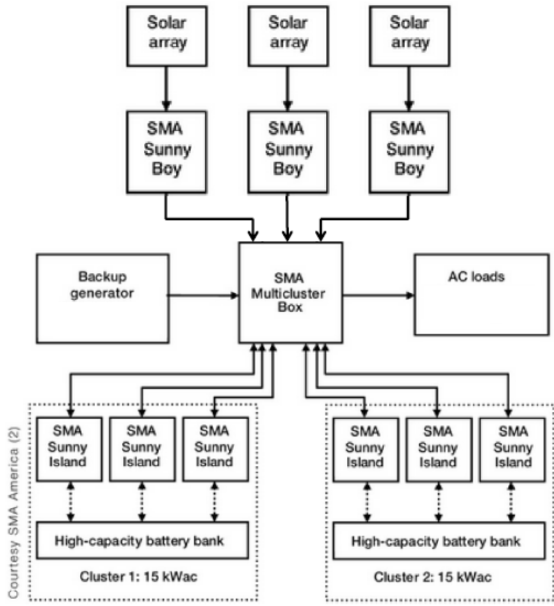
- Lead acid batteries
- Diesel generator sized to meet more than what is necessary to meet 100% of the load
- Battery inverter (converter) capacity oversized so that the diesel generator can operate at high efficiency (diesel generator charges the batteries in addition to serving load)

SMA building blocks. We selected SMA equipment as the proxy building blocks of the microgrid. SMA equipment was used to inform the cost and performance estimates of the microgrid. The table below lists the building blocks and is shown visually in Figure 16.

Table 6: System building blocks

Type	Name	Capacity (after derating)	Number in one "building block"
PV Inverter	Sunny Tripower Economic Excellence) (Model name)	15 kW	1
Converter (battery inverter/charger)	Sunny Island SI-8.0h	6 kW continuous	3 (total 18 kW for 3 phase)
Controller	Multicluster box for Sunny Island	55 kW, 110 kW or 300 kW	1 per system

Figure 16: SMA Building blocks



Source: Schwartz,, Joe. (2012) "AC Coupling in Utility-Interactive and Stand-Alone Applications" Solar Pro. Aug/Sep.

Adjustments post HOMER

We reviewed the design configurations recommended by HOMER and made adjustments to improve the microgrid design, following the design principles outlined above.

+ Upsized diesel generator to increase system reliability (this was more important in the context of serving the Forest Department resort anchor tenant load)
+ Selected the larger converter sizing among the optimal design configurations recommended by HOMER, to achieve an oversized converter

We reviewed the designs for the following technical constraints: (1) varied the battery sizes in order to achieve an appropriate strings per battery block/cluster (typically three); and (2) maximum of 12 kWac of PV inverter can be connected to one 6 kWac Sunny Island 8.0h inverter/charger. (For a three phase system it is 36 kW of PV inverter for an 18 kW Sunny Island inverter/charger system).

Distribution network and metering

The distribution network design and costing estimate took into account the peak power demand and a typical village topography. The distribution system was designed to the grid code and for possible future interconnection with the utility grid with the following characteristics. Additional details are provided in Task 7/ Appendix 7.

+ Distribution voltage level of 400 volts and supply frequency of 50 Hz
+ 4-wire 3 phase with neutral
+ All equipment enclosures grounded and lighting protection for equipment
+ Overhead distribution network with shielded power cables was selected (shielding to prevent power theft; overhead, rather than underground was selected because of cost)

Multiple metering options were analyzed. Due to their ability to ensure payment collection, and that they come at no cost premium, prepaid meters were selected.

5.3 Solar, demand and cost inputs

Solar data

Solar irradiation data is necessary to determine how a solar facility will perform once it has been constructed. In conjunction with the plant's design, this data is used to model the energy generation. Data can be satellite modeled data, measured on site or combination of the two. Because solar resource is a major factor determining economic viability of utility scale PV plant, large plants typically use a combination of measured and satellite data. The onsite measure solar radiation data is used calibrate the entire historical dataset which often spans over ten years. Onsite measurements should not be used alone to generate production forecasts for PV plants because the resource varies over time and a single year will not necessarily be a representative of the average solar resource over many years.

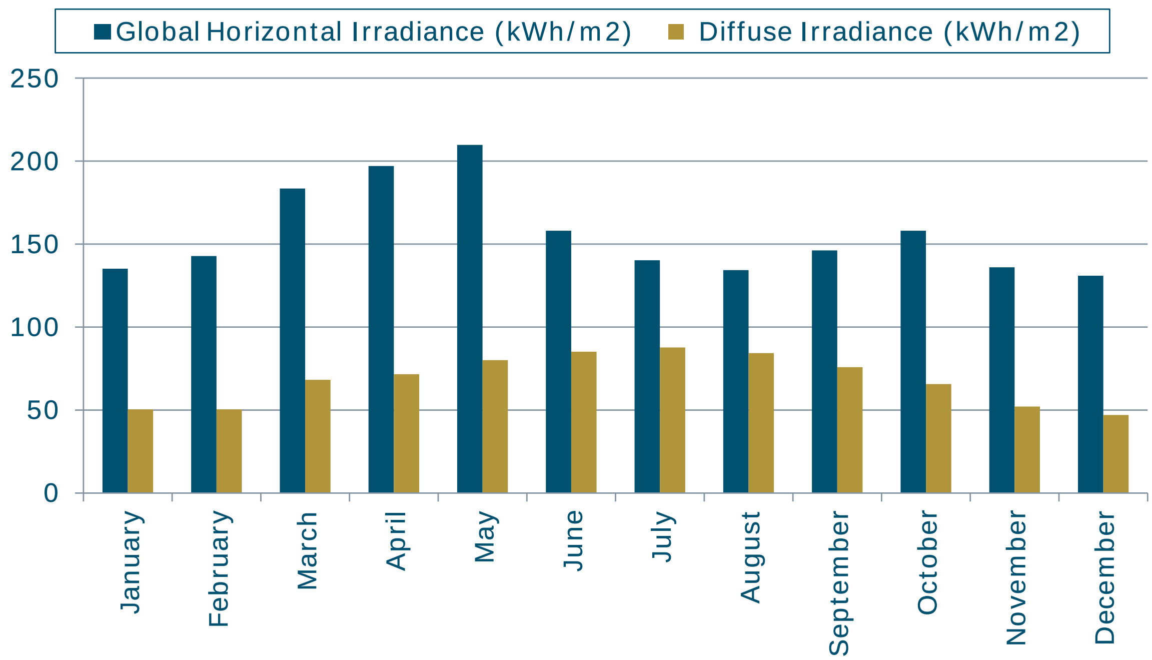
Long term solar resource datasets and typical meteorological year satellite data was purchased from 3Tier. We compared the 3Tier solar resource with limited data available from ground solar resource measuring stations installed by Centre of Wind Energy Technology (CWET). Details are presented in the Task 5/ Appendix 5 of this report. We show the solar resource for both sites in the figures below.

Table 7: 3Tier Solar resource summary

Parameter	Bar	Devari Bharat
Global Horizontal Irradiance (GHI)	1,870.1 kWh/m^2/year	1,709.8 kWh/m^2/year
Diffuse Irradiance	815.6 kWh/m^2/year	811.0 kWh/m^2/year
Ambient Temperature	22.3° C	22.4° C
Wind Velocity	2.1 m/s	1.6 m/s

Figure 17 shows the monthly solar resource for Bar. Devari Bharat has similar trends, although the winter time resource is roughly 30% less.

Figure 17: Bar monthly solar resource



A shading analysis was performed using the PVsyst software to understand the impact of shading due to trees and buildings. We were able to conclude that shading is not a concern for the site at Devari Bharat since the main site is far from buildings. For Bar, we were able to conclude that between the two potential sites, Site 1 was superior in terms of having minimal shading effect, while Site 2 would result in a 6% decrease in solar output due to shading from trees.

Demand inputs

We used the demand analysis described in Section 4.2. The hourly demand profile across the entire year is inputted into HOMER. The demand scenarios we used are described in the table below.

Table 8: Demand scenarios used in design process

Included in report or appendix	Bar village microgrid demand scenario	Devari Bharat village demand scenario
Main report	Base demand scenario: Villagers' new loads are served by the microgrid (existing loads, which are served by solar home systems would not be connected to the microgrid); base efficiency levels are assumed.	Only Villagers without existing grid connectivity (legal or illegal) are assumed to become customers of the microgrid. Base efficiency levels are assumed.
Main report	Hypothetical scenario 1: Similar to the previous scenario, except we show the effect of including the Forest Dept resort as a customer. This is a hypothetical scenario since the resort is no longer a possible customer.	
Task/Appendix 6-8 & 9	Hypothetical scenario 2: similar to hypothetical scenario 1 except the air conditioner units in the Forest Dept resort are replaced with evaporative coolers (as was mentioned in discussions with the Forest Dept)	
Task/Appendix 9	Hypothetical scenario 3: Similar to hypothetical scenario 1, except power is not provided between the hours of midnight and 5 am	

The figures below show the demand profiles for the scenarios that are included in the main report.

Figure 18: Bar village summer daily profile for base scenario (left frame) and hypothetical scenario 1 including forest dept resort (right frame)

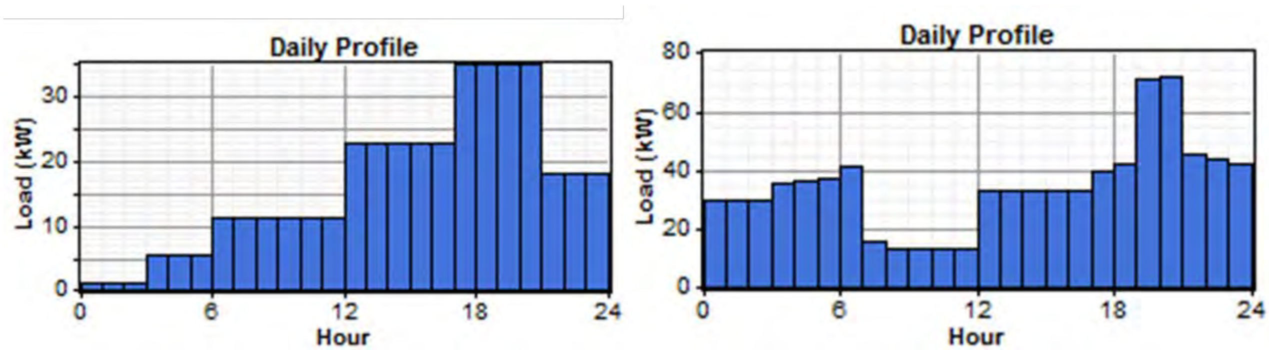


Figure 19: Bar village seasonal variation for the base scenario

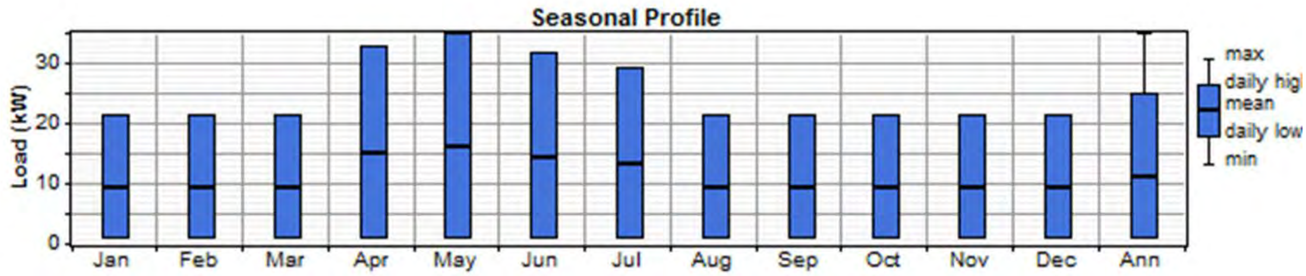
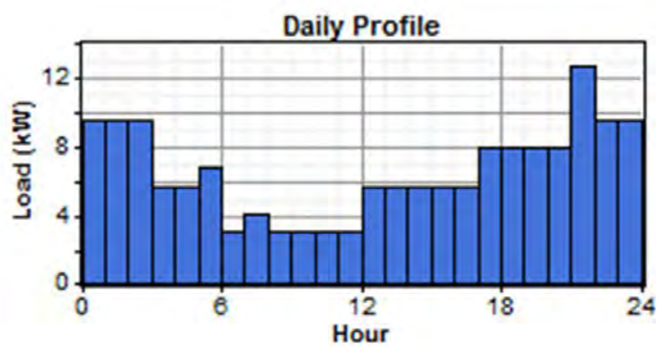


Figure 20: Devari Bharat village summer base demand scenario



We describe the key metrics and end uses for the three demand scenarios shown above.

Table 9: Demand scenarios used in design process

Demand scenario	Key metrics	Example end uses (see Appendix 4 for details)
Bar village, base demand scenario:	280 kWh/day avg daily load; 35 kW maximum load; 0.33 load factor	lights, fans, pumps, refrigerators power tools, mobile charging
Bar village, hypothetical scenario 1	610 kWh/day avg load; 90 kW maximum load; 0.29 load factor	Above + forest dept resort end uses: AC units, lights, fans, TVs, pump etc.
Devari Bharat, base demand scenario	72 kWh/day avg load; 13 kW maximum load; 0.23 load factor	lights, fans, mobile charging, TV's

The load shapes for both villages are complex and non-ideal. They are dominated by evening loads, rather than daytime loads that follow the solar shape, and by seasonal swings (e.g., fan use in the summer and the resort closures in the middle of the year). Each scenario is characterized by relatively low load factors. There are a number of design implications that arise from the demand shapes. First, the diurnal trends drive the need for a battery. Second, the season swings suggest that a diesel generation system, in addition to the solar, can help lower overall costs so that the solar is not dramatically upsized in order to meet the summer peak loads.

Cost inputs

The key cost inputs included in the HOMER simulation include equipment capex quotes and fuel costs. Table 10 lists the main cost assumptions.

Table 10: Primary equipment and fuel cost inputs to HOMER (base design costs)

Component	Unit type	Unit cost USD	Unit cost INR (a)	Sourcing
PV panels	Per Watt DC	$0.66	INR 41	Indian or Chinese
BOS, PV plant	Per Watt AC	$0.43	INR 27	N/A
Batteries	Per kWh	$156 (1500 Ah cell)	INR 9760	Indian
PV inverter	Per Watt AC	$0.27	INR 17	German
Battery inverter	Per Watt AC	$0.66	INR 42	German
Diesel cost	Per gallon	$1	INR 62	N/A

a Conversion rate: INR 62 to 1 USD

Given the goals of the USTDA, we specifically obtained cost quotes for equipment that could be sourced from the US. These quotes were used to conduct conducted sensitivities using these cost inputs.

Table 11: Primary equipment costs for design oriented on US sourcing

Component	Unit type	Unit cost USD	Unit cost INR (a)	Source of estimate
PV panels	Per Watt DC	$0.84	INR 52	Solar World
Batteries	Per kWh	$175	INR 10,850	Trojan
PV inverter	Per Watt AC	$0.65	INR 41	Outback
Battery inverter	Per Watt AC	$0.65	INR 41	Outback

a Conversion rate: INR 62 to 1 USD

Although the true discount rate depends on several complex financing factors, which we evaluated in the Excel based economic model, we modeled a range of discount rates ranging from 3-7% in HOMER to explore the sensitivity of the discount rate on the system design selection.

The table below provides contact information for the potential US suppliers listed in the prior table, along with contact information.

Table 12: Prospective US sources of supply

Business name	Equipment that could be supplied	Name of point of contact	Address, telephone, fax number, email	Notes
Wholesale Solar*	Solar World PV Panels	General Sales	Phone (530) 926-2900 Fax: (530) 926-1162 sales@wholesalesolar.com 412 N. Mt. Shasta Blvd. Mt. Shasta, CA 96067	Solar World PV Panels can be purchased for numerous distributors; large scale purchases (~1 MWdc) would require working directly with the manufacturer
Pvpower	Solar World PV Panels	General Sales	Phone (866) 274-0642 Fax: Not available CustomerService@PVPower.com 4256 N. Ravenswood Ave. Suite 201 Chicago, IL 60613	
Manak Engineering Services (Distributor in India)	Trojan Batteries	Subodha Raheja	Phone +91-9810411336 Fax +91-9871381011 B- 46, Flatted Factory Complex, Phase 3 Okhla, New Delhi 110 020 India	Trojan Batteries are widely distributed. They can be purchased from various distributers in the U.S. and around the world. Distributers in the U.S. include Battery Systems
Battery Systems (Distributor in U.S.)	Trojan Batteries	Erich Heidemeyer (San Francisco Location)	Phone – 415 – 648- 7650 Fax 415-648 0333 10 Loomis St. San Francisco, CA 94124	
Outback Power	PV Inverters and Battery Inverters	Gord Petroski, U.S	Phone: (360) 220-8123 Fax: 360 435 6019 GPetroski@alpha.com Sales office in India # 255, Block -25 LIC Jeevan sathi,10th Cross J.P.Nagar Phase I Bangalore - 560087 Karnataka (India) Phone: +91 8861640001 Fax: N/A E-Mail: sales.india@outbackpower.com	Equipment can be purchased directly from manufacturer or distributors
*Wholesale Solar carries all the U.S. manufactured equipment considered for this project (modules, inverters and batteries)				

5.4 Economics, financing, tariff design

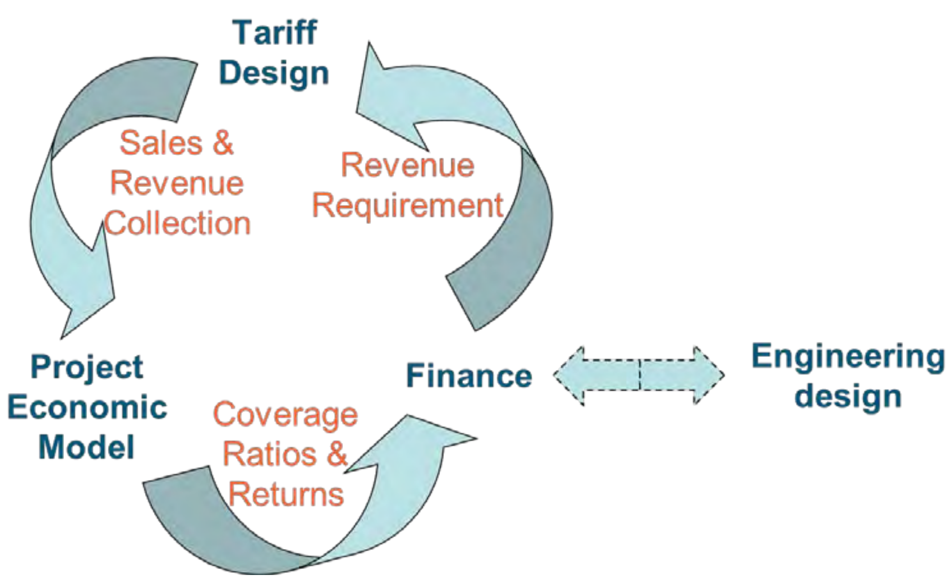
The overall objective is to identify an economically feasible business model for the two demonstration sites. This entails identifying a system with the following characteristics.

+ Meets the developer's goal for return on equity (ROE)
+ Is financeable

+ Results in affordable rates for the community

Ultimately, by implementing the microgrid and providing service to the community, Azure is exercising the functions of a vertically integrated utility. It is financing and building generation, balancing supply with demand, determining the tariffs that customers will face, collecting payments, and expanding the microgrid as necessary in the future to address load growth. It is entering the wholesale and retail side of the market. Figure 21 illustrates the interactive relationship between the core functions of tariff design, financing and economic analysis.

Figure 21: Interplay of tariffs, economics & finance

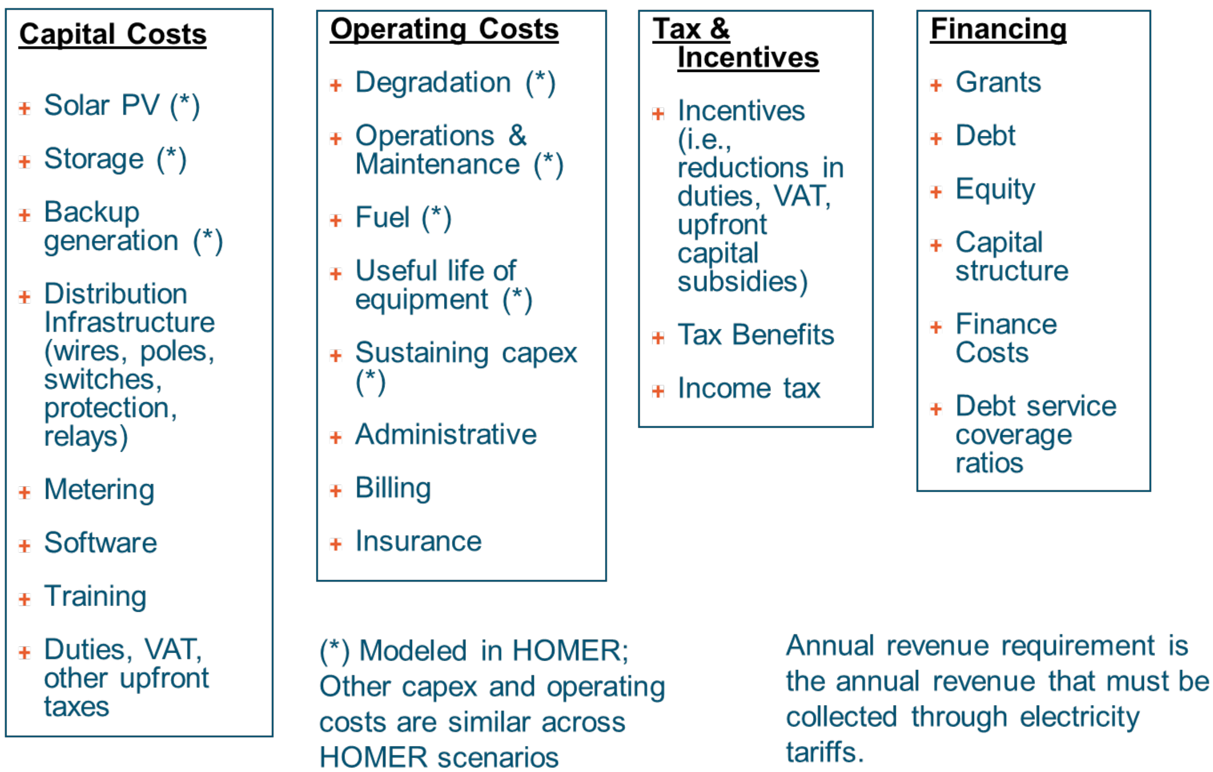


The engineering design determines the system capex, sustaining capex, and operating costs, including future fuel costs. These inputs, in combination with the financing assumptions and taxes are used to determine the revenue requirement. The revenue requirement is used to set the tariffs. The tariffs, along with electricity sales, determine the revenue collected. The revenue collected determines the debt coverage ratios and equity returns. For a given engineering design, several different financing structures and tariff designs may need to be evaluated. If the project still remains unfeasible based on the core criteria, then the engineering design must be reevaluated.

Revenue requirement

The annual revenue requirement determination is central to the economic model. The figure below lists the contributing elements to the annual revenue requirement determination.

Figure 22: Economic model development of annual revenue requirement



The economic model cost inputs represent comprehensive project development capex and opex costs equivalent to an investment grade estimate for the financing lifetime of the project (20 years). This includes elements such as site preparation, meters, development costs, distribution network, power house, interest during construction. Many of these components will not alter the relative cost effectiveness of microgrid with different levels of renewable penetration; therefore, it is not necessary to include the full list of cost inputs into HOMER. However, it is essential to include these elements to capture the full revenue requirement.

The treatment of taxes, particularly income tax, is a very important element of the revenue requirement and overall project feasibility. The following three income tax issues are very important:

- Income tax holiday from corporate income tax; there is an income tax holiday of 10 years
- Minimum alternative tax; minimum alternative tax liability applies within tax holiday window
- Accelerated depreciation and tax benefits

The accelerated depreciation schedule is 80%, however, companies will apply a 15% depreciation schedule and claim the tax benefits due to 15% depreciation at the holding company level. These tax benefits may be attributed towards the project if the holding company chooses so.

Tariff design, collection and metering

The tariff design is extremely important to the project feasibility as it is the tool that allows the developer to recover the project costs, promote reliability and provides price signals to customers. Meter selection and payment collection methods should be considered synergistically with tariff design, rather than as an after-thought. The unique challenges of a solar PV microgrid should be addressed:

+ Foremost, the tariff design, metering and payment collection methods should be compatible with the needs and acceptability of the village.
+ Regular revenue stream is required.
+ Metering, rates and collection should reflect the cost and availability of each supply type; solar PV is non-dispatchable; backup generation and storage are dispatchable but are costly
+ Limited resources may be available to implement and enforce collection
+ Tariff design should be adjustable to demand fluctuations

The basic principles of tariff design include (1) equitable design across customer types — costs are allocated according to the consumption patterns of each customer type; (2) tariffs should achieve the goal, which may include energy efficiency or demand reduction; (3) tariff design should be simple.

Table 13: Possible tariff types explored

Tariff type	Example	Pros	Cons
Fixed charge	INR 50/month	Simple, no meter	No price signal to encourage use that matches costs
Fixed unit price	INR 5/kWh	Simple and payment is based on usage	Does not address capacity problems; meter required
Time of use	INR 5/kWh off-peak; INR 10/kWh peak	Relatively simple; addresses capacity problems	More expensive meter required; more complicated
Inclining block tariff (‘consumption based tariff’)	INR 5/kWh: 0-10 kWh; INR 10 /kWh: 10-20 kWh; INR 20/kWh: > 20 kWh	Discourages excessive use; customers with low use pay less	No price signal no price signal to customers that reflect temporal variations in cost of electricity supply
Demand charges	INR 100/kW-mo during non-solar-peaking period	Discourages high demand when solar is unavailable	Complicated; meter required; relevant to commercial/industrial

Table 13 lists the possible tariff designs. Hybrid designs are also possible, for example, a fixed charge up to a certain level of consumption, followed by a fixed tariff beyond a certain level of energy use.

The collection systems should consider the labor requirements, infrastructure and metering required, and customer acceptance. Broadly, the collection categories are pre-payment and post-payment. Each has pros and cons.

- Prepayment strategies are simple, ensure cost recovery, and require minimal labor requirements. However, they require a prepay meter, may discourage electricity use and thus, may be counter to the goals of electrification.
- Post-payment strategies are simple. However, there is a risk of non-payment and carry the risk for new customers that they may encounter a very high bill at the end of the first monthly billing period if their consumption is high (e.g. used a lot of heating devices).

With the appropriate meter, almost all tariff designs can support either a prepayment collection method or post-payment collection method.

We developed the Excel model to support the following tariff design structures:

- Minimum monthly payment
- Connection fee
- Flat tariff
- Tiered tariff

Allocation of costs. All major types of costs are allocated across customer classes based on the consumption characteristics. The model allows up to three different customer classes (e.g., residential, commercial, industrial). The battery costs, for example, are allocated based on the fraction of the load during the night. PV capital costs are apportioned based on the annual energy. The screenshot shows the default values we applied.

Figure 23: Allocation of costs across customer types

Project Cost Inputs

	Allocation Method	% Bar Res Bas	% Forest Bas
OpEx			
PV Array			
Fixed O&M	Annual Energy	45%	55%
Backup generator			
Fuel	Load factor^-1	45%	55%
Fixed O&M	Annual Energy	45%	55%
Variable O&M	Load factor^-1	45%	55%
Battery storage			
Fixed O&M	Annual Energy	45%	55%
Variable O&M	Fraction of load during nic	35%	65%
Other opperating expense			
insurance	Annual Energy	45%	55%
performance monitoring	Annual Energy	45%	55%
metering, billing, collection	Number of customers	99%	1%
site security	Annual Energy	45%	55%
G&A, tax, administering lending docs & entities	Annual Energy	45%	55%
site, ROW lease (if land is not purchased but leased)	Annual Energy	45%	55%
CapEx			
Land Related Capital Costs	Annual Energy	45%	55%
Site Preperation Capital Costs	Annual Energy	45%	55%
PV Capital Costs	Annual Energy	45%	55%
Storage Capital Costs	Fraction of load during nic	35%	65%
Capital Costs backup generation	Load factor^-1	45%	55%
Distribution Capital Costs	Annual Energy	45%	55%
General/Other Capital Costs	Annual Energy	45%	55%
Finance Related Capital Costs	Annual Energy	45%	55%
CapEx Replacement	Annual Energy	45%	55%
Taxes	Annual Energy	45%	55%

Based on our site visits to the villages, it became apparent that the obvious customer class distinctions we apply here in the US will not be appropriate in the village context. Commercial operations are small shops that belong to the residence of the villager. However, the one exception was in the case of the Bar village scenario in which the Forest Dept resort was being considered as a potential customer.

Tariff design analyzed. Based on the available options and insights from the site visits, we adopted a hybrid tariff design in the analysis of tariffs. The hybrid design combines a minimum payment that covers a certain amount of usage with a consumption based tariff for usage above a specified level. This guarantees a minimum payment and encourages usage up to a certain level. This tariff design is analogous to slab/or tiered systems, however, the customer is paying for the entire first slab.

In the scenarios analyzed with the Forest Dept resort, we modeled both a traditional PPA and prepaid PPA using the connection fee feature of the model.

For the purposes of the feasibility assessment, we obtained quotes for both post and prepaid meters and included those in the modeling exercise.

Summary metrics

The excel model calculates a number of metrics to characterize project returns and feasibility.

- Customer tariffs and bills across 20 years: Are customer tariffs and monthly bills within willingness to pay?
- Achieved return on equity (ROE): Is the achieved ROE close to the target ROE? (typically 20%)
- Project lifecycle cost of energy (LCOE), where

  $$LCOE = \frac{\sum_{i=1}^{n} \frac{Annual\ revenue\ requirement}{(1+rate)^{i}}}{\sum_{i=1}^{n} \frac{Annual\ load}{(1+rate)^{i}}}$$

  $$Annual\ revenue\ requirement = total\ operating\ expenses\ plus\ finance\ costs\ plus\ taxes$$

  $$Rate = weighted\ average\ cost\ of\ capital$$

  $$n = project\ lifetime$$

  LCOE is not directly required to assess feasibility, but is a typical metric that is used when comparing the results across scenarios.
- Debt service coverage ratios: Are the debt service coverage ratios greater than 1? (Typically, 1.4 is the minimum target DSCR).

Each metric is assessed against village and project developer information.

6 Feasibility results

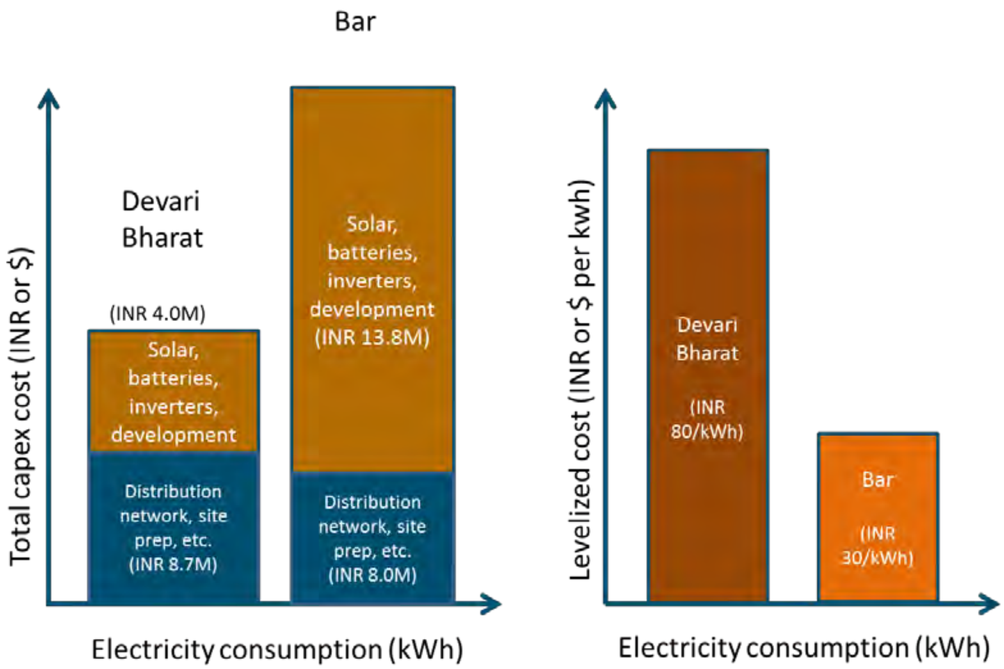
6.1 Summary

Overall, we found the economic viability to be quite varied between the two villages we analyzed. The tariffs estimated for Bar village, the larger one, are reasonably within reach of the willingness to pay of those villagers. This is based on today's technology costs, and assumes access to low-cost financing and availability of the National Solar Mission capex incentive. However, for Devari Bharat, the smaller village, the tariffs we calculate are well outside of the willingness to pay. For this village, the load is not sufficiently large to be able to provide basic services within the willingness to pay. In the case of both villages, the demand profile is not coincident with the solar shape. As a result, in order to meet the demand requirements, either considerable battery backup or diesel generation is required. Both batteries and diesel fuel are expensive. By using HOMER, we were able to identify the optimal combination of solar, battery and diesel generation to meet the demand requirements of the villages. This process resulted in a solar-diesel system of 75 kWac for Bar and 15 kWac for Devari Bharat.

The base case lifecycle cost for Bar Village was INR 30/kWh and INR 80/kWh for Devari Bharat Village. The cost on a Watt basis was INR 285/Wac for Bar and INR 830/Wac for Devari Bharat. A number of sensitivities were performed. To put the lifecycle costs in perspective, the capex cost for the Devari Bharat system is INR 1.3 Cr (INR 13 Million) or $210,000; for Bar INR 2.1 Cr (INR 22 Million) or $365,000 for Bar[11]. The solar, battery, inverters and development costs, which are the key capacity-dependent costs constituted ~65% costs for the Bar design and ~30% for the Devari Bharat system. Those costs which are unavoidable regardless of the capacity of the microgrid, such as the distribution system, meters, site preparation, drive up the unit cost of the electricity as shown in Figure 24.

[11] The panel cost of solar was assumed at $0.66/W or INR 41/W; BOS of the PV plant at $0.43/W or INR 27/W; batteries at $156/kWh or INR 9760/kWh, PV inverter at $0.3/Watt or INR 17/Watt; battery inverter at $0.66/W or INR 42/W; and development costs of 10% total capex.

Figure 24: Relationship between fixed, capacity-dependent costs, lifecycle cost and consumption



A broad finding is that the economic feasibility is highly dependent on both the total volume of electricity (total load) and when electricity is delivered. As the load becomes larger, the fixed costs of the microgrid (distribution network, metering, civil works) constitutes a smaller proportion of the total microgrid cost and can be distributed across a greater number of sales, lowering the unit price of delivered electricity. As electricity demand is more coincident with solar availability, the size of the battery can be reduced, reducing the overall cost of the microgrid.

Both quantity and time of use factors were challenging in our case studies as many villagers desire electricity in the evening, early morning and at night; lighting, fans, mobile charging, TV watching, are typically not services required during the day when solar availability is highest. This was found to be a challenging factor in two villages we studied since most villagers are outside doing agricultural work during the day and require services mainly at night. As electricity demand is more coincident with the availability of solar, the cost of the microgrid decreases, since the battery size can be reduced.

The presence of an anchor tenant load can improve the feasibility of the microgrid because it increases the electricity sales. At one point, the Forest Department resort was interested in being a customer for the microgrid for Bar Village. Including their load had significant benefits for improving the feasibility of the project. The lifecycle cost for the microgrid that includes the Forest Dept resort load is INR 6/kWh

(~20%) lower than the microgrid excluding the resort load and the village customer tariff is lower by INR 7/kWh (~25%). The presence of anchor tenant loads can also improve the prospects for obtaining financing, since they help lower the risk of deft default.

Financing and cost assumptions are important drivers to the overall feasibility. A 20-year debt term is helpful for achieving lower rates in the early rates with good debt service coverage. Low interest rates, as might be available from crowd source funding, can have a significant effect on project viability. The "impact/IREDA financing" scenario resulted in LCOE savings of 28% (INR 10/kWh) compared to a market financed scenario[12]. Better financing terms may improve pricing further. Project subsidies (NSM capex incentive) and holding company tax benefits produce large cost savings; removing the NSM incentive increased the lifecycle cost by 27% (INR 9/kWh increase) and removing the holding company tax benefit increased the lifecycle cost by 20% (INR 7/kWh increase). Diesel fuel cost is a key driver of operating costs. Our base case assumed 5% fuel escalation; increasing this to 8% annually had a relatively small influence on lifecycle cost of 4% (INR 1/kWh). Lastly, when Azure obtained component quotes, they were able to obtain pricing roughly 25% lower than our quotes. If purchases are made in bulk, for example by leveraging utility scale PV plant purchases, even lower pricing might be possible.

The design results are described in detail in **Appendices 6-8 / Tasks 6-8** and the economic results in **Appendix 9/ Task 9**.[13]

6.2 Design and capex

We describe the main aspects of the technical designs developed. The system designs are based on the performance specifications of the following components.

- PV Inverters: Sunny Tripower 15000 TL (15 kW, 3-Phase)
- PV Modules: Multicrystalline 72 Cell (280 to 300 W modules)
- Diesel generator: Cummins, various ratings (400 V, 50 Hz)
- Battery inverter/charger: Sunny Island 8.0H (6 kW continuous rating)
- Battery: AEGAN flooded lead acid (80% minimum depth of discharge); 2 V cells at various sizes

[12] Impact/IREDA financing scenario assumes 80/20 debt/equity structure; 5% and 10 year interest rate; 20% ROE.
Market financed scenario assumes 50/50 debt/equity structure; 15% and 10 year interest rate; 20% ROE.

[13] The appendices describe the following additional demand scenarios and designs: designing a microgrid for Bar Village that does not provide power at night (in an effort to lower the battery costs), designing a 100% solar and 100% diesel system; and considering a demand scenario for Bar in which the Forest Dept resort eliminates its existing air conditioners with evaporative coolers.

- Controller: SMA Multicluster box for Sunny Island; 55 kW, 110 kW or 300 kW

Table 14 summarizes the optimal designs for each scenario. The designs for both villages resulted in a hybrid solar PV-diesel microgrid with battery backup, as indicated by the presence of battery and diesel generator capacity. The percent of renewable energy ranges from ~ 60 to 90%. The use of more diesel generation in the case of Devari Bharat is due to the presence of more seasonal variation and peak load that is not coincident with solar production.

Table 14: Summary of optimal microgrid designs

Scenario	Maximum load (kW)	PV Capacity (kWac)	Battery capacity (kWh)	Converter size (kW)	Diesel gen capacity (kW)	Percent renewable energy	Generator run time
Bar village base demand scenario	35	75	240	36	50	73%	747
Bar village, hypothetical scenario 1 (a)	89	195	1,008	126	100	87%	418
Devari Bharat base demand scenario	13	15	72	18	15	57%	1629

(a) Microgrid serves village and Forest Dept resort

We show more detail on the exact configuration of the designs on a component by component basis. One complexity in designing optimal microgrids is the “chunkiness” of the components. The configuration must be physically and commercially viable. This was ensured by entering the appropriate blocks into the HOMER model. It is also worth noting that the simplistic assumption that total cost is proportional to system capacity is not always true as smaller components are often more expensive on a unit basis. This aspect becomes a significant issue when designing smaller scale microgrids.

Table 15: Configuration of PV modules, inverters, batteries

	Bar village base design Quantity	Bar village hypothetical scenario (a) Quantity	Devari Bharat base design Quantity
SMA Sunny Tripower PV Inverter (STP15000EE)	5	13	1
Multicrystalline PV Modules (300 W)	300	780	60
SMA MultiCluster Box 12 / 36 / 6	1	1	1
SMA Sunny Island Inverter 8.0H	6	21	3
Cummins Diesel Generator 50 kW / 100 kW/ 50 kW	1	1	1
Battery – Vented flooded lead-acid deep cycle; 2V cells 2500 Ah / 1500 Ah / 1500 Ah	48	336	24
Cost of these components ($) (b)	$210K	$610K	$60K

(a) Microgrid serves village and Forest Dept resort
(b) Total shown is exclusive of customs duties and taxes (these were added in the economic model and are incorporated into the calculation of the LCOE and tariffs in the subsequent section)

We considered the civil works for each site, taking into account the site preparation, access road development, building and fence construction as follows.

- Site Preparation: fill, gravel drains, internal road not necessary
- Access Road: 200 m water bound macadam (gravel) road strengthened to stay functional after construction
- Building
    - Primarily for battery storage
    - Fire suppression
    - Size of room varies with storage size
- Fence: barbed wire

The table below shows the civil works cost for the two villages.

Table 16: Civil works estimate

	Bar base case	Bar hypothetical scenario 1	Devari Bharat base case
Site preparation	$17,000	$17,000	$45,000
Access road	$7,000	$7,000	$7,000
Building	$6,000	$22,000	$6,000
Fence	$12,000	$12,000	$12,000
Total	$42,000	$58,000	$70,000

A comprehensive year to year capex and opex estimate was developed that included distribution network costs, civil costs, metering costs, development costs and sustaining capex requirements (namely battery replacements). We show the total capex, before the incentive, for each of the primary designs as well as the breakdown of the costs.

Table 17: Comprehensive capex and opex cost estimate

Scenario	Capex total		Capex cost per Watt (AC)		NPV total opex (b)	
	INR	USD	INR	USD	INR	USD
Bar village base demand scenario	Crore 2.1	$360K	INR 286/W	$4.6/W	Crore 2.0	$316K
Bar village, hypothetical scenario 1 (a)	Crore 5.3	$880K	INR 274/W	$4.4/W	Crore 2.7	$428K
Devari Bharat base demand scenario	Crore 1.2	$210K	INR 828/W	$13.4/W	Crore 1.0	$167K

(a) Microgrid serves village and forest dept resort.
(b) Net present value of opex includes fuel, equipment replacement, O&M and other operating expenses such as site security; the NPV is calculated using the discount rate (WACC) estimated in the economic model.

The PV capacity of the base Bar village design is 5 times that of the base Devari Bharat design. Yet the capex is less than twice the capex of Bar. The opex shows a similar trend to the capex. This is largely driven by the relative proportion of costs that are capacity related (such as PV, battery, inverter) and costs that are either independent or less dependent on capacity, such as distribution capital and site preparation. Figure 25 through Figure 27 show the breakdown of the capex.

Figure 25: System capex breakdown of Bar village base design

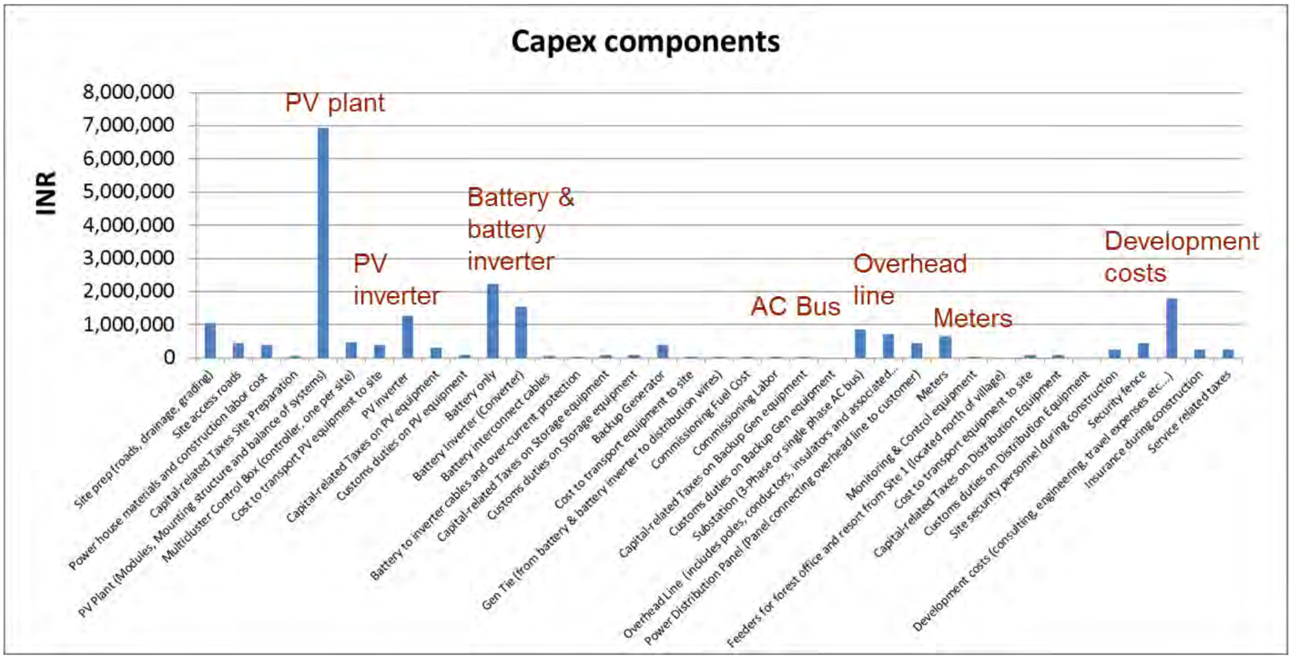


Figure 26: System capex breakdown of Devari Bharat village base design

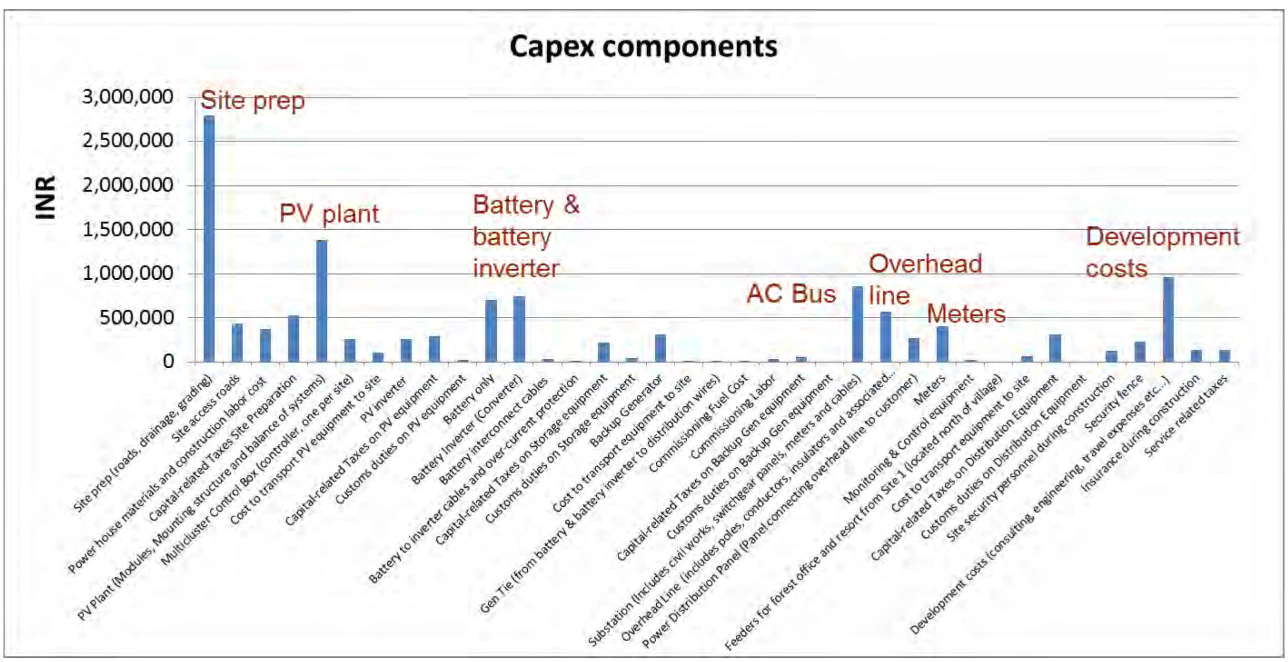
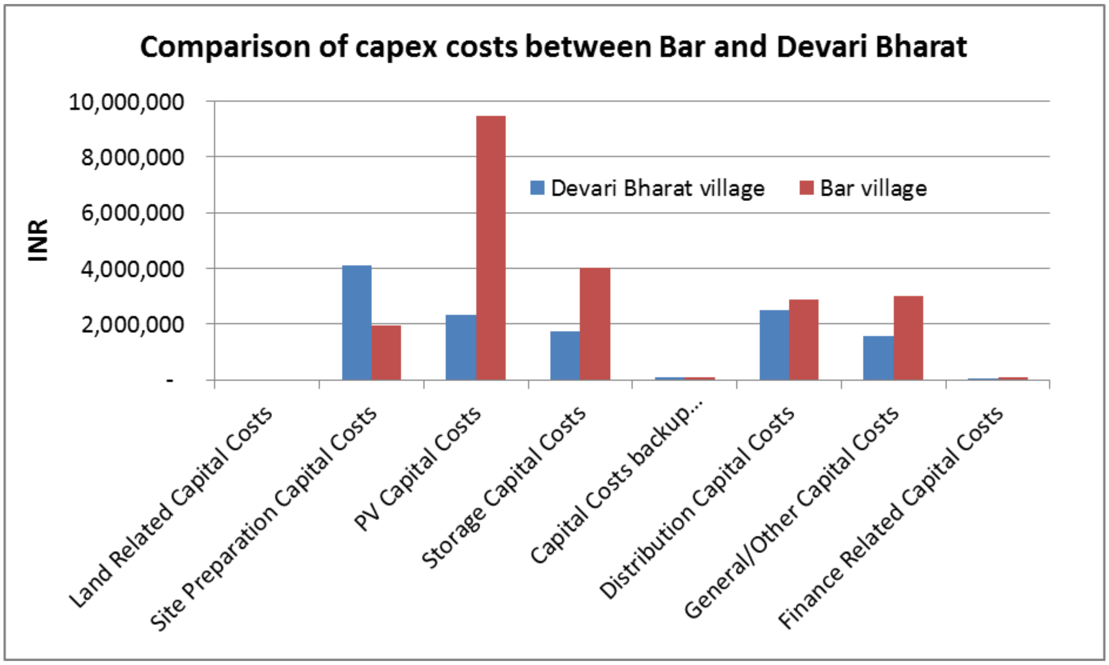


Figure 27: Comparison of capex costs between Bar and Devari Bharat base designs



In the case of Devari Bharat, fixed costs, particularly the site preparation constitute a large portion of the cost (the site preparation is the highest cost). The key microgrid components — PV plant, battery and inverters make up only ~30% of the total capex. In the case of Bar village, these same components constitute ~ 65% of the total capex. These relative proportions are evident in Figure 27.

The site preparation costs, in particular, for Devari Bharat are surprising. This cost estimate is based on a detailed civil assessment of the plot, which will require some level of grading , an access road and fence. The site preparation components and assumptions are listed below:

- Site Preparation
  - Grading (cut and fill of same area) estimated at $3 per cubic meter; if soil is brought in from 20 km range (as assumed for Devari Bharat) $6 per cubic meter (excluding cost of buying/leasing quarry to dig soil)
  - Gravel drains assumed to reduce cost; $3 per cubic meter
  - Internal road is not necessary
- Access Road: 200 m water bound macadam (gravel) road strengthen to stay functional after construction; $35,000 per km
- Building with fire suppression

- Unit cost varies by number of batteries (lower unit cost for larger room)
- ~$100/ sq ft (for 60 sq ft room, Devari Bharat) to $30/sq ft (for 1,200 sq ft room)

+ Fence: Barbed wire; $12 per meter (fence cost was provided by Azure)

Overall, we encountered very few technical challenges in the feasibility assessment. However, we faced one noteworthy obstacle in the design process. It was challenging to find a suitable meter. Our criteria includes an AC-based prepaid meter; one that is cost-effective (we were targeting $30-50 a meter); one could support a consumption-based tariff with a minimum monthly payment; and one that does not require internet access for recharging. We eventually found two suppliers that would qualify, one US-based and one Indian-based, however, a majority of the prepaid meters available and used in microgrids are DC based and the AC-based meters are very expensive. This issue is discussed at length under the implementation section (Section 7).

6.3 Economic feasibility

The lifecycle cost, tariffs and bills are impacted by the load, system capex, operating costs including diesel fuel escalation, financing (including return on equity), tax benefits, and tariff structure. The economic feasibility is based on whether the tariffs and bills are within the willingness to pay. We briefly review the willingness to pay for each village. Overall, both villages showed promise in terms of willingness to pay (WTP) and stronger willingness to pay (WTP) for essential services (lighting, fans, mobile charging) with the following distinctions:

+ Bar: WTP for essential services ranges from ~ INR 100-200 ($1.6-$3.3) per month; for higher service, generally between INR 300-500 per month (~$5-$8). These values translate to unit prices of INR 8-42/kWh ($0.13-$0.70/kWh) with a median INR 19/kWh ($0.32/kWh).
+ Devari Bharat: WTP for essential services ranges from ~ INR 50-150 (~$1-$2.5) per month; for higher service, generally between INR 100-300 per month (~$1.6-$5). These values translate to a unit price of INR 4/kWh to INR 10/kWh ($0.07/kWh to $0.16/kWh).

Base case results

We show the lifecycle cost along with the tariffs and monthly bills. The base case financing assumptions (“Impact/IREDA financing scenario”) assumes 80/20 debt/equity structure; 5% and 10 year interest rate; 20% ROE. This financing scenario is based on access to crowd-source funding (which would be lower interest rate) and/or access to government low-cost financing through the Indian Renewable

Development Agency, which offers a 5% loan through the National Solar Mission. The base case results also assume access to the National Solar Mission 30% capex incentive.

The base case tariff design is based on a hybrid fixed-consumption based tariff in which a minimum payment of INR 160 per month is made that allows up to 8 kWh of consumption per month (equivalent to INR 20/kWh). Consumption above 8 kWh is assessed the "Tier 2" tariff shown. The monthly bills are the sum of the minimum payment plus the consumption based component. The tier 2 tariffs are adjusted every 5 years. Table 18 lists the LCOE, year 1 and average tariffs for the two villages.

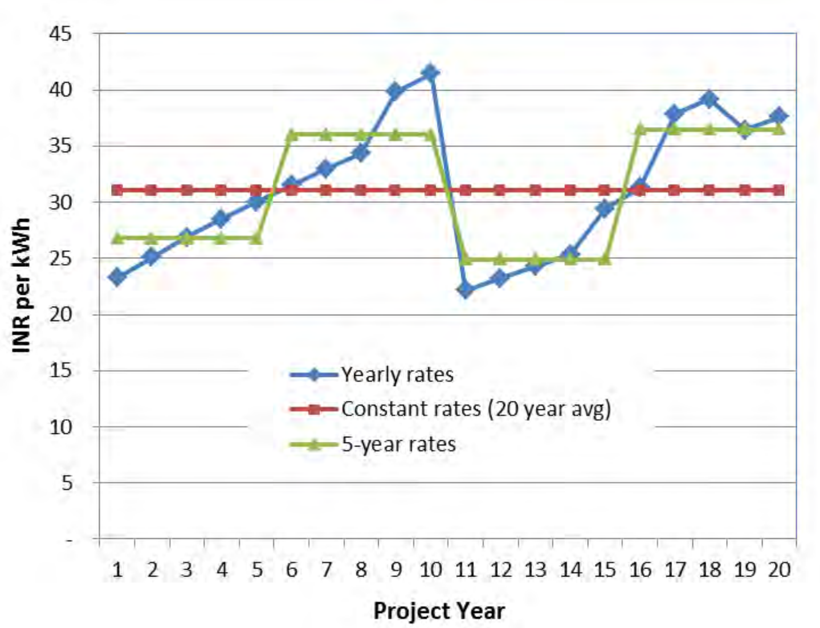
Table 18: Base case LCOE and tariffs

	LCOE INR/kWh	Year 1 tier 2 tariff INR/kWh (a)	Avg tier 2 tariff INR/kWh
Bar village base case	30	27	31
Devari Bharat village base case	80	112	112

(a) Bar village base case tariff is based on 5 year tariff changes; Devari Bharat is based on constant tariffs.

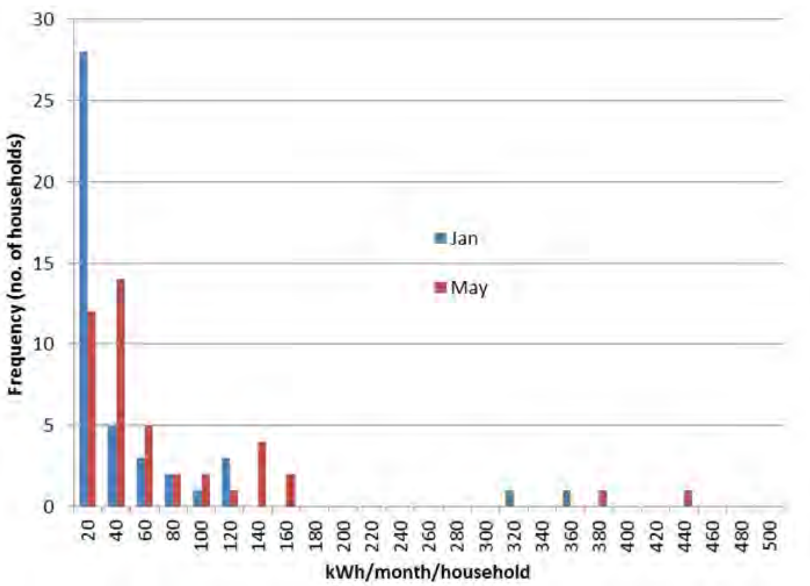
The year 1 tariff is reasonably within reach of the willingness to pay on a unit basis. Allowing the tariffs to fluctuate on a 5 year basis, rather than to remain constant, enables the year 1 tariff to be lower, as shown in Figure 28. The key advantage of having a lower tariff at the beginning of the lifecycle, which can help create acceptance. The drop after 10 years is due to the capex 10-year debt term expiry.

Figure 28: Tier 2 tariff by year for Bar Village base scenario



Our demand analysis resulted in a distribution of estimated monthly consumption based on the surveys we completed in the field (Figure 29). The monthly bills will vary for each customer based on their individual level of consumption.

Figure 29: Bar Village: distribution of monthly energy demand by household (new loads only)



The table below shows the estimated bills for May and December for the 50th and 90th percentiles. For Bar Village, 50% of the customers are estimated to have bills that reasonably within their willingness to pay. The 90th percentile bills are relatively high and may not be affordable by some customers who anticipated a desire for higher energy consumption.

Table 19: Base case monthly bills

	May bill 50th percentile, INR	May bill 90th percentile, INR	Dec bill 50th percentile, INR	Dec bill 90th percentile, INR
Bar village base case	975	3480	430	2510
Devari Bharat village base case	2210	5680	160	440

In the case of Devari Bharat, at least half of customers have estimated energy consumption that is below the Tier 2 level of 8 kWh, and thus, have bills that are at the minimum payment of INR 160 per month. The 90th percentile for Devari Bharat is potentially affordable at INR 440, although outside of the indicated willingness to pay. The summer bills for Devari Bharat are significantly outside of the affordability range for a majority of customers as indicated by the 50th percentile bill.

Finance scenarios

The analysis below shows financing scenarios that were conducted for both Bar village and Devari Bharat. The purpose of the financing scenarios is to understand how the economic feasibility will vary within reasonable bounds. We treat the "Impact/IREDA" financing scenario as the base financing scenario as it appeared to be the most promising financing scenario for these demonstration projects. (This is considered the most promising because the "Forest dept financing" scenario, while attractive, is largely a hypothetical financing scenario, since the Forest Dept resort is no longer a potential customer.)

In the case of Bar, at the time this analysis was conducted, the Forest Dept resort was a potential anchor tenant load. Thus, the analysis had focused on how to render that particular demand scenario (including the anchor tenant customer) more feasible. We analyzed two additional finance scenarios. The first emulated a scenario in which the anchor tenant, Forest Dept, would finance the project through a low cost and lengthy debt term. The second emulates a market financed scenario, such as from a domestic bank with high interest rates.

Table 20: Comparison of LCOEs by financing scenarios for Bar village demand scenario with resort

Finance scenario	Debt/equity	Debt interest and term	ROE	WACC	LCOE (INR/kWh)
Impact/IREDA financing	80/20	5% and 10 year	20%	7%	24
Forest dept financing	80/20	5% and 20 year	20%	7%	24
Market financed	50/50	15% and 10 year	20%	15%	34

Table 20 shows the assumptions for each financing scenario and the resulting WACC and LCOE. The Forest Dept resort financing scenario results in no change to the LCOE. The market financed scenario results in an LCOE significantly costlier (INR 10/kWh or ~ 40%).

The table below shows the tariffs for each financing scenario for Bar Village. In each scenario, the changes every 5 years.

Table 21: Comparison of tariffs by financing scenarios for Bar village demand scenario with resort; tariff changes every 5 years

	Average village tier 2 tariff INR/kWh	Year 1 village tier 2 tariff INR/kWh	Average Forest Dept resort tariff INR/kWh	Year 1 Forest Dept resort tariff INR/kWh
Impact/IREDA financing	23	20	25	23
Forest dept resort financing	27	12	29	15
Market financed	37	29	38	32

The year 1 village tier 2 tariff for the Forest Dept financing scenario is dramatically lower than the Impact/IREDA financing scenario, largely because of the lengthier debt term. At INR 12/kWh, the tariff is comparable to some utility tariffs. The year 1 Forest dept resort tariff is higher, which is expected given that the allocation of costs depends on nighttime use, and the Forest Dept has significant nighttime energy consumption. The tariffs are comparable to willingness to pay for lower levels of service.

The importance of the debt term on tariff is illustrated in Figure 30. Over the lifetime, the lengthier debt term results in a higher tariff, which is expected because of the effect of interest. However, it is advantageous to have lower tariffs at the beginning of the project as time will be required for customers to adjust to the microgrid and will encourage them to grow their load over time.

Figure 30: Comparison of Tier 2 tariff for 10 year (left frame) and 20 year (right frame) debt terms for Bar Village scenario with anchor tenant load

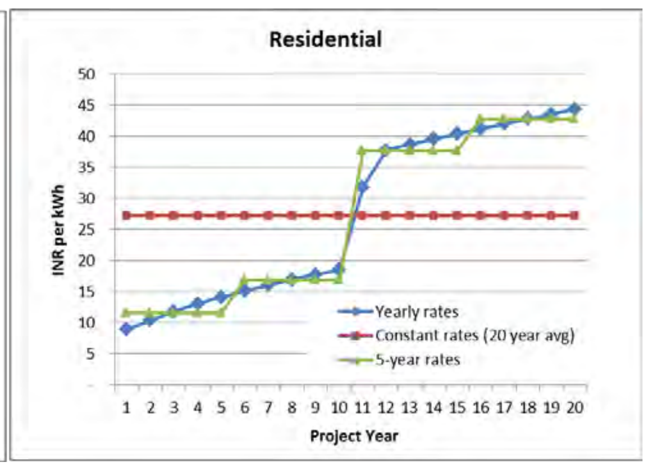


Table 22 shows the monthly bills for each financing scenario for the village customers. The year 1 monthly bills are safely within the willingness to pay for at least half of the customers as indicated by the 50th percentile. Overall, the bills are ~ 40% lower.

Table 22: Comparison of monthly bills by financing scenario for Bar village demand scenario with resort

	May bill 50th percentile, INR	May bill 90th percentile, INR	Dec bill 50th percentile, INR	Dec bill 90th percentile, INR
Impact/IREDA financing	755	2585	360	1880
Forest dept resort financing	515	1605	280	1185
Market financed	1055	3810	460	2750

Overall, the Forest dept resort financing is by far the most attractive scenario, lowering the bills and tariffs seen by the village customers significantly, compared to the base financing scenario (Impact/IREDA financing). The Tier 2 tariff with the base financing scenario is INR 20/kWh vs. INR 12/kWh under the Forest dept resort financing scenario, a 40% reduction.

We evaluated two additional finance scenarios for Devari Bharat. The first scenario assumes a 90% capex incentive, which is based on the Phase 2 proposed incentive. It is worth noting that this finance scenario is a purely hypothetical one; at the time of the analysis, it seemed possible that any microgrid may have access to a 90% capex incentive; however, recently it was confirmed that only remote microgrids would have access to the 90% capex incentive.[14]) The second scenario represents a market financed scenario. Table 24 and Table 25 compare the LCOEs, tariffs and bills for each scenario.

Table 23: Comparison of LCOEs by financing scenarios for Devari Bharat

Finance scenario	Debt/equity	Debt interest and term	ROE	WACC	LCOE (INR/kWh)
Impact/IREDA financing	80/20	5% and 10 year	20%	7%	81
Ph2 draft NSM subsidy (90%)	80/20	5% and 20 year	20%	7%	66
Market financed	50/50	15% and 10 year	20%	12%	100

The lifecycle costs range from INR 66-100/kWh. The Phase 2 draft NSM subsidy reduces the LCOE, tariffs and bills significantly, however, the tariffs and bills are still far outside of the willingness to pay, particularly for the summer months. It is worth noting the 90% capex subsidy is based on a benchmark price of INR 300/W. Our system cost exceeded this value (INR 828/W); this is why the “Ph2 draft NSM subsidy” finance scenario did not result in a more dramatic reduction on the LCOE and tariff.

[14] Per conversation with Dr. Tiwari, Ministry of New and Renewable Energy in July of 2014.

Table 24: Comparison of tier 2 tariff and monthly bills by financing scenarios for Devari Bharat

Finance scenario	Average tier 2 tariff, INR/kWh	May bill 50th percentile, INR	May bill 90th percentile, INR	Dec bill 50th percentile, INR	Dec bill 90th percentile, INR
Impact/IREDA financing	112	2210	5680	160	440
Ph2 draft NSM subsidy (90%)	89	1790	4550	160	385
Market financed	158	3060	7960	160	560

Overall, the finance scenarios illustrate the value of lengthier debt terms, lower interest rates and benefit of an anchor tenant customer.

Additional sensitivities

We conducted additional sensitivity analysis, using the Bar Village hypothetical demand scenario that includes the Forest Dept resort as an anchor tenant customer:

- Azure pricing: base case assumes Azure pricing; sensitivity scenario uses E3 Team pricing
- Diesel price escalation: base cases assume 5%; sensitivity scenario assumes 8%
- NSM sensitivity: base case includes incentive; sensitivity scenario excludes incentive
- Holdco tax benefit: base case includes holdco tax benefit; sensitivity scenario excludes benefit

Table 25 compares the LCOE for the base case against the sensitivity scenario.

Table 25: Additional sensitivities based on the Bar village demand scenario with resort

	LCOE base INR/kWh	LCOE new INR/kWh	Percent savings
Azure pricing (Azure pricing vs. E3 Team pricing)	24	32	25%
Diesel price escalation (5% vs. 8%)	24	25	4%
NSM incentive (with incentive vs. without incentive)	24	33	27%
Holdco tax benefit (with benefit vs. without benefit)	24	30	20%

The "Azure pricing" and NSM incentive sensitivities resulted in the most significant reductions on the LCOE. Further price savings in PV panels and batteries could drive the LCOE lower. The holdco tax benefit, also, has a significant price benefit. The diesel price escalation had minimal effect, likely because of relatively high fraction of solar PV.

7 Implementation

Our overall project execution was influenced strongly by implementation considerations. Thus, implementation was not an after thought but permeated throughout the study. It began with an understanding of best practices and was strongly informed by our village site visits and regulatory review. The approach and analysis described in Sections 5 and 6 took implementation factors into account, whether these were associated with technical suitability or economic feasibility. However, because implementation factors are so critical to project success, we include this dedicated section.

The following are the most important implementation considerations that we encountered:

- Community engagement to ensure buy-in and long term support
- Billing, metering and collection that meets community and developers' interests
- Financing strategy and terms that promotes economic feasibility and are attainable
- Sourcing of equipment and US export opportunities

Community engagement

In our feasibility assessment, we found community engagement to be essential towards developing support for the project, assessing the electricity needs and desires of the community, and in exploring various aspects of project feasibility and best strategies for implementation. We worked closely with the Panchayat in both villages to arrange the community-level stakeholder workshops and to solicit participation in these workshops. Our demand survey and willingness to pay approach went beyond identifying dollar amounts. We used this venue to understand how billing, metering and collection systems could be designed in ways that are understandable and accessible to villagers. We explored the possibilities of anchor tenant loads and agricultural pumping loads. Innovative financing strategies, such as leveraging high-credit-worthy customers was explored.

In our interactions with CREDA, who has ample experience in deploying solar microgrids in villages around Chhattisgarh, we learned that O&M of their microgrids is carried forth by villagers that are trained in this regard. These technicians have come to be highly regarded in the communities. Eventually, the microgrid CREDA has deployed in Bar Village failed because villagers began to expect increased service. Community engagement can be a tool to set expectations and design billing strategies that are commensurate with the service that will be provided. In the case of the CREDA system, villagers paid a very nominal fixed fee to support O&M, rather than a consumption based tariff.

Billing, metering and collection system

Our recommended billing, metering and collection system was deeply informed by the following goals:

+ Develop a tariff that is compatible with community preferences and simultaneously lowers risk to the developer of non-payment and failed cost recovery
+ Develop a metering system that has lower risk of non-payment, is cost-effective and can be managed remotely
+ Develop an overall billing, metering and collection system that promotes scalable use of electricity and can adjust to growing electricity needs

Metering options. Metering options roughly fall into prepaid and post-paid categories. We describe the characteristics of each option in the table below.

Table 26: Metering options

Basic postpaid meters	Prepaid energy meters	No meter plan
• Basic electronic meter • Manual meter reading • Deployment of trained manpower • Longer billing cycle • Prone to commercial loss (theft, corruption)	• In some cases, higher initial cost • Increased cost is nominal with strategic selection • There is availability of meters • In some cases, higher replacement and repair cost • Upfront payment as per uses • Minimal commercial loss • Social familiarity with the concept (similar to mobile phone) • Some prepaid meters come with load control functions	• Fixed charge based on connected load • Regulatory approval required • No initial cost of meters • Overdraw of energy possible • Difficult to control theft • Can't control load, energy consumption on individual basis • Contrary to the villages' preferences to be metered

We researched metering manufacturers to understand the availability and cost implications of such a system (Table 27). Despite that there are many microgrids in the field around the world, we found it challenging to find an AC-based prepaid meter that is cost-effective and can support the tariff designs we preferred. Initially, this was surprising, but given that many microgrids have been financed through grants and are DC-based, and that many do not charge tariffs or include meters, it is less surprising.

Table 27: Potential meter suppliers

Company	Mode	AC/DC	Frequency	Cost ($/Unit)	Country
SparkMeter	Both	AC	60/50 Hz	$35-70 (a)	U.S.
ElMeasure	Both	AC	50 Hz	$87	Indian
Husk Power	Prepaid	AC	50 Hz	$9	Indian
NatureTech	Both	AC	50 Hz	$33	Indian
Generic/Typical Utility Meter	Postpaid	AC	50 Hz	$34	Indian
WBREDA	Prepaid	AC	50 Hz	$28 to $37	India
Lumeter	Both	DC (b)	n/a	$20-$30	U.S.
Inensus (c)	Both	AC	50 Hz	$216-$283 postpaid $685-$1247 prepaid	German

a Upper range for cloud service; $35-45 for orders over 1000
b AC meters will soon be available though not on the market yet
c Considered only for the Forest Dept resort when it was a potential anchor tenant

Meter selection. Based on the availability of prepaid meters at no cost premium; the reduced risk of non-payment and lower labor requirements; and that villagers are familiar with the concept (through prepaid plans for mobile phones), we based our feasibility estimate on prepaid meters.

Financing strategy

We explored a multiple financing strategies through a combination of interviews and internet-based research. We considered traditional and non-conventional financing means in our analysis. The non-conventional financing types explored, with examples, are listed in the table below.

Table 28: Non conventional financing strategies

Customer based financing	Property based financing	Indian and international subsidy/grants	Crowd source funding	Impact investing
PPA with high credit quality customer • We explored these but could not identify financiers • Possibilities had included Forest Dept (though no longer a possible anchor tenant load) and Gram Pradhan of Devari Bharat	Generally, not available in the village context	• IREDA (provides 5% interest loans through NSM) • International Finance Corporation • Asian Development Bank • World Bank • Global Environment Facility	Engages regular people to invest small amounts • KIVA and SunFunder have funded rural energy projects in India	Generally fund portfolios not demonstration projects. Several have energy activities in India: • Acumen Fund • Ennovent • Oiko Credit • Unitus • Schneider Electric

We found the most promising financing scenario to be one that provides a longer debt term with low interest rates; a lengthier debt term enables the developer to charge lower tariffs in Year 1. Of the options described, crowd-source funding, impact investing, and IREDA financing meet these criteria. Impact financing and large banks such as IFC may be more appropriate, however, for financing portfolios of microgrids, rather than individual sites, due to the overhead cost.

Sourcing and US export opportunities

We obtained quotes from a variety of manufacturers based in the US, India and overseas. In terms of US export potential, PV panels, batteries, prepaid meters, and inverters could be sourced from the US with reasonably cost competitive pricing. In fact, of the two prepaid meters deemed viable at the time of this study (SparkMeter, NatureTech Infra), one is a US company. At this point, an additional third US company (Lumeter) may also provide AC-based prepaid meters targeting the microgrid market.

For the Bar Village design, we estimated the potential US components (solar panels, batteries, PV inverter, battery inverter, meters) to total roughly ~ $270K. If 50 microgrids similar to Bar Village are developed, a US export potential of ~$13 Million could be achieved.

One complication worth noting is the regulatory barriers to sourcing US components. The National Solar Mission requires that the solar panels be sourced from India.

8 Scalability

This section seeks to address how the business models developed based on our village assessment can be scaled to support broad deployment of solar microgrids. The overall market potential for rural microgrids is large, given the lack of electricity access in India and the lack of reliable power for villages that are grid-connected. Of the villages we assessed, the Bar Village project was generally feasible, and far more feasible than Devari Bharat village project. In the case of Bar, the tariffs are within reach of the willingness to pay; the village previously had electricity and is primed for load growth; and the grid will never be extended due to proximity to the forest.

Implications from case studies

Bar Village is an attractive site but unique in terms of its large loads and village experience with electricity. It is relatively low risk, particularly because the village is primed for load growth and the electricity grid will never reach the village, virtually eliminating the risk of future stranded assets. Scalability following the Bar Village model is possible but challenging. Most importantly, it requires identifying sites with sufficiently large loads, and ideally with an anchor tenant load. It is possible that additional villages like Bar, in proximity to protected forest areas with resorts exist. It might be possible to identify those sites by working with the State Forest departments. Lastly, villages with no access to grid electricity are preferred as they will be absent of any "spoiling" effect. Although villagers may prefer more expensive microgrid power, it is a risk that they will switch back to the cheaper subsidized (but unreliable) utility power at any point; or villagers may connect to both systems, using national grid electricity when available. This may result in lower revenue opportunities for the microgrid and also presents some safety challenges with the threat of inadvertent interconnection of microgrid and main grid voltages.

Recognizing that scalability based on the Bar model might be challenging, we evaluated a "package system" microgrid system that is meant to provide basic essential services.

- Each household receives a 20 Watt connection for 6 hours; this is sufficient for lights, mobile charging and a fan.
- Number of households from Bar village was assumed.
- Microgrid was designed as an AC-grid interconnectable system.

We found that this system was not within the willingness to pay for essential services (100-200 INR per month). We would need to see a total system cost decrease of 75% for the system to be cost-effective.

The PV plant and battery constituted 40% of the costs; thus, future reductions in these technologies, though possible, will only partly help. Many other 'fixed' costs, such as overhead line, substation, contributed towards the costs. (Details of this assessment are in Appendix 10/Task 10).

Key factors affecting scalability

Although the villages we studied contain unique attributes, there are broad insights regarding scalability that we can draw. In summation, the key factors that affect scalability include the following. These insights are specific to the type of microgrid we designed (solar PV, AC-based, grid interconnectable).

- Adequate load is essential — anchor tenant load or village size that is on the larger side (as in Bar village). This will help lower the tariffs charged.
- Sites with no current access to grid electricity is preferred as these villages will be free of any utility "spoiling" effect in terms of expectations of subsidized tariffs. There are many villages with intermittent access but the spoiling effect will be present and there is risk of non-payment. To compete with utility service in the near term, tariffs will have to be closer to INR 6-10/kWh.
- Some level of incentives at current technology prices; unless loads are very large, declines in capacity related costs — PV and battery —may have little effect, as the fixed costs of the system are still significant.
- Attractive financing terms — longer term and low interest rates. There may be opportunities for donor agencies to pay for the distribution network (this is a dominant model in African countries).

The top two factors are associated with the task of identifying suitable sites. Partnering strategies may be a useful strategy towards this task, such as working with the nodal agencies of MNRE to do preliminary screening, working with nonprofits who may have on-the-ground village experience. (The villages in our study were identified by working with MNRE nodal agencies.)

Regulatory risks

The risks from a developer perspective are significant and there is regulatory uncertainty. The Electricity Act of 2003 calls for regulation of the microgrid sector. Although the model regulations for microgrid has been adopted by the Forum of Regulators, no states have taken action. The model regulations provide guidelines on how tariffs can be set and also require the distribution utility to utilize the microgrid's distribution network, should the grid be extended to the area. Under the current regulatory framework, if the grid eventually reaches the village, then the microgrid runs the risk of becoming a stranded asset.

Over the long term, a core question is whether India provide electricity access to the roughly 300 million that lack electricity. If no, then the system we propose is a viable alternative and perhaps the most appropriate long term solution, but potentially a costly one. If the answer is yes, the system is still useful over the long term as all components can be utilized after grid connection. However, for many villages, robust and reliable microgrids may still be too costly to motivate private sector development and additional regulatory risks exist.

Given the regulatory uncertainty, alternative solutions that provide short-term electricity access with minimal risk may be more attractive from a developer perspective. This may include system such as solar home systems or “skinny” and DC based microgrids that are focused on essential services. These are likely to be the more cost-effective solutions since the distribution infrastructure costs of the system will be far lower (or negligible) and can be designed as portable solutions.

9 Conclusions

We assessed the feasibility of solar microgrids using a case study approach centered on two specific villages in India, Bar Village in the eastern State of Chhattisgarh and Devari Bharat Village in the northern State of Uttar Pradesh. The scope of our project included developing solar PV AC-based microgrids that could be interconnected to the grid at a future date. We did not assess alternative rural energy solutions, namely individual household systems (solar home systems, backup generators), skinny and DC based microgrids, and grid extension.

The villages we assessed represent a wide range of socio-economics, electricity demand requirements. Thus, although we took a case study approach, our findings may be generalizable to the broader market.

We find that the deployment of solar based microgrids under a private developer business model is feasible under certain conditions. These conditions require the following criteria:

+ There must be a willingness to pay and interest in electrification. We found that the willingness to pay was promising in both villages, but much stronger in the village that had no electricity access and higher incomes as compared to the poorer village with partial access. In both cases, a strong preference for a metered consumption-based tariff was present. The willingness to pay in both cases is generally above typical utility tariffs, however, there was a spoiling effect present in the village with partial access where some villagers were aware of the subsidized rates that urbanites and their wealthier neighbors pay for electricity.
+ Foremost, cost-effectiveness requires a significant load. The presence of an anchor tenant load can help reduce the tariffs charged to villagers significantly. We found that the village with the larger village-level load and an anchor tenant customer had significantly lower tariffs than the village with the smaller load. As energy use is coincident with solar production and with minimal nighttime production, the size of the battery is reduced, which is a key cost component. As load decreases, the fixed costs of the system (distribution network, meters, etc.,) become a higher portion of the system cost and drive up the tariff. This effect is true regardless of the tariff design (INR per kWh, INR per month).
+ Achieving a cost-effective solution requires an integrated process. The technical configuration, financing, and tariff design have to be linked processes to achieve an optimal result. We applied a two-tier process in which an engineering optimization tool was used first and then various

configurations evaluated in an Excel based economic model that supports the design of financing and tariffs. The process was repeated.

- There are market and regulatory risks to the developer. In the event the grid is extended, the microgrid may become a stranded asset. Though regulations have been proposed for the utilities to use the microgrid distribution system if the grid is extended and compensate the developer at book value, these regulations have not been adopted by the SERCs. Regulators and utilities should recognize that all components of the microgrid are valuable over the long term. The distribution network is necessary, whether it comes through a grid extension process or microgrid construction. The solar panels become distributed solar PV in the event the grid is extended. The battery and generator may be helpful for load balancing and improving reliability.

If the goal is to provide short-term electricity access with minimal risk, alternative solutions such as skinny microgrids or DC microgrids and solar home systems are likely to be the more cost-effective solutions and pose lower risks to the developer. But policy makers must recognize these are designed as stop-gap solutions, rather than long term solutions.

Appendices: Task reports