



Private Sector Driven Business Models for Clean Energy Mini-Grids

Lessons learnt from
South and South-East-Asia



Alliance for
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Shining a Light for Progress

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About the Alliance for Rural Electrification (ARE)

ARE is an international business association with 130+ Members that promotes a sustainable decentralised renewable energy industry for the 21st century, activating markets for affordable energy services, and creating local jobs and inclusive economies in emerging countries in Sub-Saharan Africa, Asia-Pacific and Latin America & the Caribbean.

With a vision of achieving affordable energy for all, since its inception in 2006, ARE has taken leadership in many ways and got well-known for its efforts on mobilisation, linking and coordination of private sector activities with international cooperation and development support programmes. ARE is active globally and tries to solve the issue that more than 1 billion people lack access to energy.

To find out more about how ARE supports sector and industry development please visit: <http://www.ruralelec.org/are-service-lines>

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List of Abbreviations

A Ampere	DSM Demand Side Management	MMK Burmese kyat	RREL Rahimafrooz Renewable Energy Limited
ABC Anchor Business Communities	DU Distribution Utility	MPPT Maximum Power Point Tracking	RTN Nickel Mining Corporation
AC Alternating Current	EC Electric Cooperative	MSME Micro, Small & Medium Enterprise	SARR Subsidised Approved Retail Rate
ADB Asian Development Bank	ELA Electrical Load Analysis	MW Mega Watt	SDG Sustainable Development Goals
AEEP Africa-EU Energy Partnership	ERC Energy Regulatory Commission	MWp Mega Watt Peak	SHS Solar Home System
AEPC Alternative Energy Promotion Centre	ESMAP Energy Sector Management Assistance Program	MYE Mandalay Yoma Energy Co. Ltd.	SMU System Monitoring Unit
AFD Agence Française de Développement	ESS Energy Storage System	NDA Non-Disclosure Agreement	SNV Stichting Nederlandse Vrijwilligers
AGM Annual General Meeting	EUR Euro	NEP National Electrification Plan	SO₂ Sulphur dioxide
Ah Ampere hour	FOREX Foreign Exchange	NGO Non-Governmental Organisation	SPV Special Purpose Vehicle
ARE Alliance for Rural Electrification	GDP Gross Domestic Product	NOx Nitrogen dioxide and nitric oxide	SSESC Subas and Sujan Electric Service Center
ARPU Average Revenue Per User	GHG Greenhouse Gas	NPC National Power Corporation	STS Secure Transfer Specification
BDT Bangladeshi Taka	GIZ Deutsche Gesellschaft für Internationale Zusammenarbeit	NPR Nepalese Rupee	TCGR True Cost of Generation Rate
BLGU Barangay Local Government Unit	HH Household	O&M Operation and Management	TDL National Electricity Rate Indonesia
BTS Base Transceiver Station	h Hour	OPEX Operational Expenditure	TDS Total Dissolved Solids
C&I Commercial & Industrial	IDR Indonesian Rupiah	PALECO Palawan Electric Cooperative	THB Thai Baht
CAPEX Capital Expenditure	IEC International Electrotechnical Commission	PEU Productive Energy Users	TV Television
CEP Community Enhancement Platform	IFC International Finance Corporation	PHP Philippine Peso	UC Users Committee
CFL Compact Fluorescent Lamp	INR Indian Rupee	PLN Perusahaan Listrik Negara	UCME Universal Charge for Missionary Electrification
CMP Charging Mobile Phones	IoT Internet of Things	PPA Power Purchasing Agreement	UNDP United Nations Development Programme
CO₂ Carbon Dioxide	IRR Internal Rate of Return	PSPI PowerSource Philippines, Inc.	USD United States Dollars
COE Cost of Electricity	kg kilogram	PubCon Public Consultation	V Volt
CPI Clean Power Indonesia	km kilometre	PURE Productive Use of Renewable Energy	VDC Village Development Community
CSR Corporate Social Responsibility	kVA kilo-volt-ampere	PV Photovoltaic	VEC Village Electrification Committee
DAP Direct Aid Program	kWh kilowatt hour	QTP Qualified Third Party	VRLA Value-Regulated Lead-Acid
DC Direct Current	kWp kilowatt Peak	RE Renewable Energy	Wh Watt hour
DENR Department of Environment and Natural Resources	L litre	REEEP Renewable Energy and Energy Efficiency Partnership	WTU Water Treatment unit
DESCO Distributed Energy Service Company	LB Light Bulbs	REP Rural Electrification Project	YMP Yoma Micro Power
DG Diesel Generator	LCOE Levelised Cost of Electricity	RERL Rural Energy for Rural Livelihood	
DISCOM Electricity Distribution Company	LED Light-emitting Diode	RMI Rocky Mountain Institute	
DoD Depth of Discharge	Li-ion Lithium-Ion		
DOE Department of Energy	LPG Liquefied Petroleum Gas		
DRD Department of Rural Development	LT Low Transmission		
	LV Low Voltage		
	ME Micro Enterprises		
	MHP Micro Hydro Power		
	MiB Mini-grid-in-a-Box		
	MLE Monitoring Learning and Evaluation		

Introduction

Dear Reader,

With this publication, **ARE highlights lessons learnt from 11 private sector driven clean mini-grid projects across South and South-East Asia.**¹ The purpose is to assist developers with know-how for the development of future projects and to inform investors about what to expect when considering mini-grids in their investment portfolios in this specific region.

The 11 **case studies, that come from eight different countries (Bangladesh, Cambodia, India, Indonesia, Myanmar, Nepal, Philippines and Thailand), include both financial and technical data,** and also span across technologies from solar PV hybrids to biomass and hydro projects.

In total, **the projects provide electricity to 5,715 households and have lowered GHG emissions by an estimated 3,257 tonnes CO₂ per year. Moreover, via the productive use of renewable energy (PURE)², nearly 1,000 jobs have been created in local communities.**

The publication demonstrates the potential of the private sector to be a frontrunner in achieving SDG 7, bringing technological and financial innovations to build investable portfolios of clean energy mini-grids, which can power the rural economy in emerging countries.

At the same time, **the private sector still faces a number of risks in emerging markets, which makes it challenging to build mini-grids at scale.** Most importantly:

- Mini-grids serve last-mile customers, who live in remote and poor areas, making demand for electricity hard to estimate. The socio-economic standards of the rural customers often limit both their demand for electricity and the ability of consumers to pay; and

The projects provide electricity to 5,715 households and have lowered GHG emissions by an estimated 3,257 tonnes CO₂ per year

1 *"Mini-grids are electric power generation and distribution systems that provide electricity to just a few customers in a remote settlement or bring power to hundreds of thousands of customers in a town or city. They can be fully isolated from the main grid or connected to it but able to intentionally isolate themselves from the grid. Mini-grids supply power to households, businesses, public institutions, and anchor clients, such as telecom towers and large agricultural processing facilities."* (ESMAP, *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers, Executive Summary*, 2019: page 12)

2 ARE defines PURE as *"...agricultural, commercial and industrial activities, powered by renewable energy sources, which generate income"* (AEEP & ARE, *The Productive Use of Renewable Energy in Africa*, 2015: page 4)

-
- political and regulatory environments often limit access to capital or make the cost of capital extremely high.

By dealing with these challenges head-on, the private sector has already shown its willingness to take risks and overcome adversity. **ARE, therefore, firmly believes that with key partnerships and the right mix of financial support mechanisms (for both mini-grid companies and mini-grid end-users), the mini-grid sector in Asia-Pacific can fulfill its potential and reach scale for the purpose of contributing to the achievement of the Sustainable Development Goals (SDG) objectives.**

It is with these considerations in mind, that ARE has illuminated the results already achieved by a number of mini-grid companies in South and South-East Asia.

ARE sincerely thanks Energy for All Partnership of the Asian Development Bank (ADB) and the Renewable Energy and Energy Efficiency Partnership (REEEP) for their valuable input to the study, as well as all the case study contributors who have shared their projects and insights with the wider community.



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Key recommendations

to de-risk private mini-grid investment and deployment in South and South-East Asia

The Energy Sector Management Assistance Program (ESMAP) estimates that because of falling costs for new technologies and an increasing amount of favourable enabling policy environments in key countries, **clean energy mini-grids can connect 490 million people globally by 2030.**³

The market for energy access solutions in South and South-East Asia was recently estimated by Bloomberg New Energy Finance at more than 339 million people,⁴ out of which clean energy mini-grids are estimated to make up 44% of all new energy access connections.⁵

The **private sector will be the key driver of this clean energy transition, offering high quality, cost effective and innovative solutions to reach last mile consumers and to power local economies.** Yet to get to the point where mini-grids can truly achieve scale, costs of mini-grids will have to decrease further.

Given the intrinsic link between lowering of costs and de-risking of mini-grid project portfolios, ARE has analysed a range of clean mini-grid projects across South and South-East Asia with aim to identify key lessons learnt and hence to enable knowledge sharing across geographies.



While the case studies exhibit diversity in their approach to mini-grid development, **ARE has four recommendations, which if followed properly will drive the mini-grid industry further towards scale and long-term sustainability.**

1. Further explore innovative approaches to increase the uptake of productive appliances

⚡ PROBLEM

Two of the main risks in clean energy mini-grid projects are lack of payments from end-users and the demand risk, typically related to either low demand and uptake from households or wrongly forecasted demand and hence a mismatch between supply and demand. Moreover, local industries and businesses might be hesitant to connect to the mini-grid at first.

To address these risks, developers across South and South-East Asia link the

3 ESMAP, *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers, Executive Summary*, 2019: page 2

4 Bloomberg New Energy Finance, *Powering the Last Billion*, 2019: page 22

5 Microgrid Investment Accelerator, *Microgrid Market Analysis and Investment Opportunities in India, Indonesia, and Tanzania*: page 8

generation of electricity with productive uses of renewable energy. Productive uses include agricultural machinery, local shops, rice hullers, welding machines and other income generating activities. Some developers also opted for anchor-business-community business models to lower payment risks.

While productive uses of renewable energy have been widely recognised as a core element to the sustainability of mini-grid business models, **estimating demand remains a cumbersome process, which can be potentially be optimised.** Moreover, financing options to empower end-users to purchase productive and energy efficient appliances (e.g. via micro-loans) while considering how to best promote local entrepreneurship (e.g. via entrepreneurship training at the village level) need to be further explored.

★ RECOMMENDATION

Further **map out the potential of different productive uses in various regions of South- and South-East Asia, including productive and energy efficient appliances** (both AC and DC), as well as **income generation from coupling energy access with other sectors, such as agriculture, fishery, refrigeration and digital services.**

For project developers, **it is recommended to start the community engagement process from the earliest stage of the project to understand what productive uses can be connected. Conduct additional studies on which types of financing and capacity building are effective at the end-user level to increase the uptake of productive appliances** (e.g. micro-loans, entrepreneurial training to local community groups).

2. Leverage digital and disruptive technologies



↪ PROBLEM

Payment risks, demand, technology and operational risks still pose challenges for mini-grid developers. By leveraging digital solutions, such as remote monitoring, smart meters and mobile money, developers are recognising the potential of digitalisation to lower risks. For example, digital solutions can be leveraged to manage demand, to remotely monitor grids lowering operations and maintenance costs and to collect payments online via mobile applications, lowering payment risks. New digital technologies such as the Internet of Things (IoT), artificial intelligence (AI) and blockchain will need more exploration to understand the full potential to lower risks of mini-grid projects.

★ RECOMMENDATIONS

In Sub-Saharan Africa, off-grid developers (especially in the solar home system sector) have had great success in partnering with mobile money companies (such as M-Pesa in Kenya). **With partnerships between the mini-grid sector and the telecom sector in South-East Asia focusing on the wider spread use of mobile money, as well as mapping of demand via mobile phone coverage maps, further gains in terms of better quality and cost reductions can be made.**

Moreover, **additional research or funding for innovative projects will help explore the potential of the newest digital technologies and their role in optimising mini-grid site selection, system design processes, O&M and payment models.**

3. Develop public-private partnerships (PPP) across the South-East Asian region

↪ PROBLEM

The **political and financial risk of grid arrival remains among the key risks for mini-grid developers and investors.** Given the often extremely low (subsidised) tariffs offered by national utilities, grid extensions are often detrimental to mini-grid project economics. Especially in areas, where grid extension is a risk, **the mini-grid industry will require long-term cooperation between the public and private sectors.** Additionally, public-private partnerships help to enable access to different types of capital,

which could help finance more projects on the ground (e.g. money from climate financing).

★ RECOMMENDATIONS

As is the case in some projects showcased in this publication (see for example case on Mandalay Yoma's mini-grid in Dee Doke South, Myanmar and Clean Power Indonesia in Mentawai, Indonesia), **public-private partnerships can be leveraged to increase the financial sustainability and to lower the risk of projects, while securing utility or government buy-in in projects.**



© Clean Power Indonesia

The mini-grid sector in South and South-East Asia especially needs public-private cooperation across countries to coordinate efforts of governments and development finance institutions, which typically run parallel support programmes. Inspiration can, for example, be found in the Energy Access Workstream of the Africa-EU Energy Partnership (AEEP) led by ARE, which served as a cross-country public-private partnership focusing on training, policy dialogues and research.

4. Cultivate additional community-private partnerships (CPP)

↳ PROBLEM

Social acceptance risks (community dissatisfaction) constitute another type of risk of mini-grid projects, which can hinder project deployment. For example, local customers might be sceptical towards electricity supply from a mini-grid because of its higher tariffs than a subsidised national grid. Additionally, customers might have the prejudice that private companies will not protect end-users, but only operate mini-grids to maximise profits. **By working with communities at all stages of projects, including pre-project planning and post-commissioning engagement and job creation, the sustainability of projects and impact on local development can be maximised.**



© Mandalay Yoma Energy

★ RECOMMENDATIONS

Consider community and customer engagement in all stages of mini-grid projects. Communities can either fully own projects, partially invest in the project via equity or gradually overtake ownership of projects. If the mini-grid is privately owned and operated communities can be involved via consultations, discussions and on-the-ground surveys during the site selection phase. During implementation, operations and maintenance local managers and operators can be hired to ensure ownership and thereby sustainability of mini-grid projects. Additionally, **given the tremendous amount of community-owned projects in South- and South-East Asia, more work is needed to investigate how and where private operators could support communities in existing mini-grid projects.**

1

**The billion-dollar
investment
opportunity for
mini-grids**

in South and South-East Asia

The billion-dollar investment opportunity for mini-grids

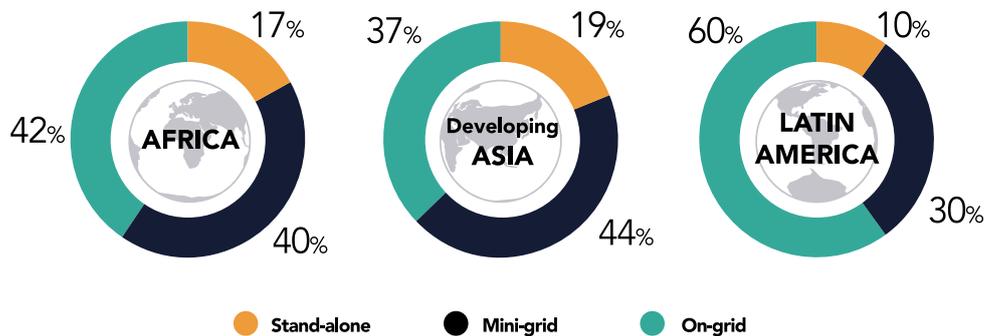
in South and South-East Asia

Connecting **490 million people to mini-grids by 2030 will require more than 210,000 mini-grids and almost USD 220 billion in investment.** In other words, **1,700 mini-grids will need to come into operation each month over a period of the next 10 years.**

Moreover, such investments will **enable an estimated potential annual profit for private mini-grid developers of USD 3.3 billion between 2019-2030** and a **net profit potential across all mini-grid component and service suppliers in 2030 alone of USD 4.7 billion.**⁶

The market for energy access solutions in South and South-East Asia was recently estimated by Bloomberg New Energy Finance at more **than 339 million people,**⁷ **out of which clean energy mini-grids** are estimated to make up **44% of all new energy access connections.**⁸

Estimated source of additional generation required to achieve universal electricity access by 2030 (by region)



Source: Mini-grid Investment Accelerator, 2017

The bulk of the people without access to energy in South-East Asia live in four countries: Myanmar (16 million), Philippines (11 million), Indonesia (5 million) and Cambodia (2 million). In South-Asia, India still has the largest energy access deficit (99 million people). Other countries such as Bangladesh (20 million), Pakistan (57 million) and Nepal (2 million) also remain priority countries.⁹

6 ESMAP, *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers, Executive Summary*, 2019: page 2-7

7 Bloomberg New Energy Finance, *Powering the Last Billion*, 2019: page 22

8 Microgrid Investment Accelerator, *Microgrid Market Analysis & Investment Opportunities in India, Indonesia, and Tanzania*: page 8

9 World Bank, *Tracking SDG 7 - The Energy Access Progress Report*, 2019: page 123-131

It should also be considered that in some cases, even where a grid connection exists, that connection might be of poor quality leading to many hours of brownouts. According to a recent study by the Smart Power Initiative of the

The advantage of third generation mini-grids is that they can provide 24x7 reliable, locally managed power with local ubiquitously available resources

Rockefeller Foundation in Bihar, Uttar Pradesh, Odisha and Rajasthan (India), almost 40% of grid electricity users did not express satisfaction with grid-electricity services. Only 65% of enterprises in the study had grid-electricity connections, revealing a large market potential for mini-grids to compliment the national grid and offer electricity especially to productive end uses in India.¹⁰

More than 16,000 mini-grids have been installed to date in South and South-East Asia, whereof a vast majority rely upon expensive diesel, are not compatible or able to connect to the main grid and operate for a limited amount of hours per day. In the terminology of ESMAP, these mini-grids constitute the ‘first and second generation’ of mini-grids.¹¹ As an example, in Myanmar the vast majority of the 4,312 mini-grids installed are not commercially viable, nor grid-ready and only operate for a limited number of hours per day.¹²

However, a new ‘third generation’ of mini-grids is now in the process of being implemented. **The advantage of third generation mini-grids is that they can provide 24x7 reliable, locally managed power with local ubiquitously available resources such solar (combined with storage, diesel backup or both), as well as with biomass, hydro and wind.** Additionally, they are quickly deployable, cost-competitive and able to integrate with the main grid (in case of grid arrival). They often couple energy generation with digital control technologies such as remote monitoring, smart meters and in some cases digital pay-as-you go solutions.¹³

Last, but not least, via the use of productive renewable energy, clean energy mini-grids create local jobs and bring significant socio-economic development in rural areas, which also increases the end-users ability to pay for the electricity they consume. Examples of productive uses include income-generating loads such as agricultural machinery, water treatment units, grain mills, welding machines, power tools, internet cafés, sewing machines, water pumps, refrigeration units, small shops, other productive appliances, etc.¹⁴

10 Smart Power India, *Customer Behaviour and Demand for Rural Electrification in India*, 2019: page 1, 73

11 ESMAP, *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers, Executive Summary*, 2019: page 12

12 Smart Power Myanmar, *Decentralised Energy Market Assessment Myanmar*, 2019: page 10

13 ESMAP, *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers, Executive Summary*, 2019: page 5-7

14 AEEP & ARE, *The Productive Use of Renewable Energy in Africa*, 2015: page 5



© InnoEnergy Master School

2,200 'third generation mini-grids' are currently planned for installation in South and South-East Asia by 2030.¹⁵

With this publication, ARE highlights lessons learnt from 11 private sector driven clean mini-grid projects across the region. **ARE primarily aims to assist project developers when developing new projects and investors when considering new investment portfolios.**

The case studies include key considerations and data both on the financial

and technical side and go hand-in-hand with the ambition of ARE to facilitate knowledge sharing across regions. They come from eight different countries (Bangladesh, Cambodia, India, Indonesia, Myanmar, Nepal, Philippines and Thailand) and span across technologies from solar PV hybrids to biomass and hydro projects.

In the 11 case studies, more than 5,715 households were electrified and 988 jobs were created in remote communities, averaging 89 jobs per project. The projects range in size from **8 kWp to 893 kWp** in size and fall across different technologies such as solar PV hybrids to biomass gasifiers and micro-hydro mini-grids. In total, **the projects lower GHG emissions by approximately 3,257 tonnes of CO₂ per year.**

In the 11 case studies, more than 5,715 households were electrified and 988 jobs were created in remote communities



© Clean Power Indonesia

¹⁵ ESMAP, Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers, Executive Summary, 2019: page 2

Private Developer(s)	Location	Commissioning year	Size & technology	Households electrified	Jobs Created	Annual GHG emissions avoided (tonnes CO ₂)
Rahimafrooz Renewable Energy	Ghorjan Island, Bangladesh	2018	80 kWp solar PV hybrid	310	60	25
Okra and Pteah Baitong	Kbal Damrei, Cambodia	2018	8 kWp solar DC hybrid	64	5	1
Mlinda Foundation	Sahitoli, India	2016	22.4 kWp solar PV hybrid	124	18	29
Tara Urja	Derni, India	2018	31.2 kWp solar PV hybrid	141	43	44
Clean Power Indonesia	Mentawai, Indonesia	2018	700 kWp biomass gasifier	1,250	450	3,000
Mandalay Yoma	Dee Doke South, Myanmar	2018	55 kWp solar PV hybrid	126	23	5
Yoma Micro Power	Thit Seint Gyi Village, Myanmar	2017	31.2 kWp solar PV hybrid	270	20	23
Gham Power	Khotang, Nepal	2015	52 kWp solar PV hybrid	650	200	36
Subas and Sujan Electric Service Center	Simli Khola, Nepal	2016 (original project start 2009)	29 kWp hydro	495	140	9
PowerSource Philippines	Rio Tuba, Philippines	2016 (original project start 2005)	893 kWp biomass gasifier	1,885	16	n/a
Blue Solar and Symbior Solar	Koh Jik Island, Thailand	2018 (original project start 2004)	60 kWp solar PV hybrid	400	13	85

Table 1. Overview of mini-grid case studies and their impact in rural South and South-East Asia

2

De-risking mini-grid

deployment in South and
South-East Asia

2.1 Site identification and selection

2.2 Technical design and selection of hardware

2.3 Operations and maintenance

2.4 Revenue and financing sources

2.5 Billing and metering

2 De-risking mini-grid

deployment in South and South-East Asia

While clean energy mini-grids show tremendous potential from a socio-economic growth perspective, private developers often face the challenge of raising sufficient finance to build larger project portfolios, rather than individual projects. To achieve scale, the mini-grid sector in South and South-East Asia will need to attract significant private debt capital in combination with equity investments and continuous public and donor commitments.¹⁶

However, private investors often bring forward the argument that there is a lack of sustainable business models for mini-grids and a lack of 'good' projects to invest in, largely because of the high risks perceived in mini-grid projects.

Compared to large utility investments, higher risk profiles of mini-grids come with investor expectations for considerably shorter payback periods and higher returns and internal rates of investment (IRR). For the time being, the return of mini-grids is typically in the range of 10 to 15% IRR, significantly lower than the 20% and above a typical investor would expect for a comparable on-grid project. **To resolve this challenge of a mismatch between return on investment to actual and perceived risks, two main options are available for private developers:**

- **Improve the IRR to compensate for the higher risk** (by increasing tariffs charged to end-users); and
- **Reduce the risk of the project, so that the lower risk profile of the business model corresponds to the low IRR the projects generate.**

Improve the IRR

As mini-grid tariffs are regulated in many countries, **the option of increasing the IRR via a substantial increase in the tariffs charged to end-users is often challenging.** Additionally, **increasing the tariff charged often to very poor consumers poses a moral problem, typically combined with the added downside of increasing risks of non-payment and social acceptance from end-users.** Therefore, often the only chance to increase IRR is that mini-grid developers offer differentiated prices for household consumption and productive loads, such as shops and other businesses.¹⁷



© Yoma Micro Power

¹⁶ ARE, *Outcome Report & Recommendations: 5th Energy Access Investment Forum*, 2019: page 6

¹⁷ ARE, GIZ, HNU & id.eee, *Risk Management for Mini-Grids*, 2015: page 28-29

Reduce the risks of the project

The other option is to reduce risks in the project in order to lower the risk profile. To do so, developers will need to mitigate risks along the phases of mini-grid projects, including:

1. Site identification and selection
2. Technical design and selection of hardware
3. Operations and maintenance
4. Revenue and financing sources
5. Billing and metering

The five phases of the mini-grid value chain highlighted above build on an earlier IFC study, which benchmarked mini-grid developers (distributed energy services companies – DESCOS), especially in Tanzania. It presents a holistic view of the value chain in mini-grid projects, highlighting common challenges and the various solutions across common denominators that exist in the industry.¹⁸

Similarly, **a recent study from Rocky Mountain Institute (RMI) found that by optimising different parts of the mini-grid value chain, costs of mini-grids can be reduced dramatically by 2020.** Key areas to optimise are: reduction of hardware costs, optimisation of load management, customer acquisition and relationship management, optimisation of construction and operations, enabling of low-cost financing as well reducing regulatory barriers.¹⁹

It should be noted that RMI mentions regulatory barriers as a key area that could be optimised. Regulations remain a central topic in the mini-grid sector and also a key area where ARE provides support work. Particularly, it is important for private sector developers to have a solid plan in case of main grid arrival and to consider possibly long licensing procedures or risks of not obtaining a license. In this study, policies implemented by the public sector will not be the core focus of the analysis.²⁰

Instead, the study discusses how mini-grid developers consider key risks when developing their project, especially focusing on payment (off-taker) risks, technology risks (e.g. failure of components), operational risks (e.g. initially low, as well as unpredictable demand), political risks and social acceptance risks.

By optimising different parts of the mini-grid value chain, costs of mini-grids can be reduced dramatically by 2020

18 IFC, *Operational and Financial Performance Of Mini-Grid DESCOS*, 2019: page 12

19 RMI, *Six Ways To Reduce Minigrid Costs By 60% For Rural Electrification*, 2018: page 7-8

20 For more info, see for example: ARE, EUEI-PDF, RECP & REN21, *Mini-Grid Policy Toolkit*, 2014 | IRENA, *Policies and Regulations for Renewable Energy Mini-Grids*, 2018 | ESMAP, *Mini Grids and the Arrival of the Main Grid: Lessons from Cambodia, Sri Lanka, and Indonesia*, 2019

Project Phase	Potential risks to mitigate	Description
1. Site identification and selection	Payment (off-taker) risks	Customers do not pay
	Political and financial risks	Main grid arrives and mini-grid assets are stranded
	Social acceptance risk	Community resists the mini-grid if not properly consulted
	Demand risk	Demand does not meet supply or vice versa
	Environmental and force majeure risks	Natural circumstances negatively impact grid performance (e.g. storms, lightning, rainfall, droughts, etc.
	Theft or vandalism risk	Components or fuel is stolen or destroyed
	Land rights risk	No space to develop mini-grids or land cannot be acquired
2. Technical design and selection of hardware	Technology risk	Sub-optimal components are selected, or components are of poorer quality than expected
		Mini-grid wrongly sized (supply does not meet demand or vice versa)
	Resource price variability risk	Variable price of diesel or biomass feedstocks
	Construction competition risk	Non-completion of projects due to cost overruns, material shortages, structural difficulties or engineering challenges
	Environmental and force majeure risks	Natural circumstances negatively impact grid performance (e.g. storms, lightning, rainfall, droughts, etc.
3. Operations and maintenance	Operational risk	Components break down ahead of time, leading to lower efficiency
		Maintenance more expensive than anticipated if not properly planned for
		Lack of skilled technical or managerial personnel
	Theft or vandalism risk	Components or fuel is stolen or destroyed
	Payment (off-taker) risk	Customers do not pay
4. Revenue and financing sources	Payment (off-taker) risk	Customers do not pay
	Social acceptance risk	Risk of community, or local government not accepting or showing resistance to mini-grid solution
	Foreign exchange risk	Risk of fluctuations in currency values
	Political risks	Main grid arrives and mini-grid assets are stranded

5. Billing and metering	Payment (off-taker) risk	Customers do not pay
	Demand risk	Demand does not meet supply or vice versa
	Operational risks	Components break down ahead of time, leading to lower efficiency and higher costs

Table 2: Mini-grid value chain and risks

(Based on: ARE, GIZ, HNU & id.eee, Risk Management for Mini-Grids, 2015: page 26-30)

2.1 Site identification and selection

General considerations

Mini-grids typically have relatively high capital expenditure (CAPEX) and therefore equally high costs of relocating deployed assets. It is hence crucial for developers to choose their project sites carefully.

According to IFC, key parameters for site selection are: geographical suitability and renewable energy resource potential, existing economic activity in the village and availability of target customers (especially anchor loads), population density, community demand for mini-grids, security situation, as well as distance and risk of main grid arrival.²¹



On a similar note, GIZ Kenya has identified five categories that are central to site selection: exact location of the mini-grid, productivity of the village, estimated ability to pay, magnitude of potential power consumers and security.²²

Observations from ARE case studies in South and South-East Asia

Two main criteria for selecting mini-grid sites emerged as key from the 11 case studies analysed:

- **the local economic development potential (including the potential for productive uses); and**
- **proximity to the national grid (the remoteness of the site).**

Moreover, **other reasons for site selection included the proximity to company headquarters and hence the ease of transport (Okra in Cambodia and Gham Power in Nepal), as well as demand from the community (RERL in Nepal and Koh Jik project in Thailand).**

Across the board, developers highlighted the importance of engaging, partnering with and educating community members to ensure their buy-in from the start of the project.

²¹ IFC, Operational and Financial Performance of Mini-grid DESCOs, 2017: page 12-14

²² GIZ, Where shall we put it?, 2014: page 7

A. Local economic development potential

In selecting villages with significant development potential, **developers especially try to mitigate payment risks arising from low demand.** This is also closely linked with the demand risk.

In selecting villages with significant development potential, developers especially try to mitigate payment risks arising from low demand

For example, Mlinda Foundation estimated for its mini-grid Sahitoli in Jharkhand, India, that it had significant potential for productive uses of renewable energy, such as agriculture. Household and enterprise surveys were used to determine the village profile, number of households, appliances used, productive devices already present in the village, as well as the current consumption behaviour of the village community.

For Yoma Micro Power and Mandalay Yoma in Myanmar, the presence of a telecom tower was a key factor in site selection, as this allowed for an ABC business model design. Yoma Micro Power also determined that there were potential productive uses such as rice mills, oil mills and other small machines like water pumps

that were being run by individually owned diesel generators that were both expensive and polluting. By accurately mapping out productive uses, risks of low demand and non-payment were thus lowered.

Similarly, during the field visits in Dee Doke South, Mandalay Yoma focused on understanding what electrical appliances were in use by the different types of consumers, while understanding the planned purchases for appliances and goods, in order to anticipate energy demand.

Gham Power in Nepal also partially selected its two project sites in Harkapur and Chyasmitar in Khotang District because of the presence of a telecom tower and because of estimates on potential use of productive end use equipment.

Lastly, PowerSource identified Rio Tuba as project location for the reason of high economic development prospects with the provision of reliable and adequate electric power supply. Productive uses in the project include cold storage and mini-ice plant modules, internet access, and communications modules. The process for site identification included: site visits with local interviews, load analysis, public consultation to involve the community in the process, as well as area mapping. The close link with the community was also an early step to lower the social acceptance risk.

B. Distance from the national grid

A second key criterion for selection of the project site locations is the distance from the national grid, hence lowering the potential political and financial risk of stranded assets arising from grid arrival.

For PowerSource in the Philippines, Clean Power Indonesia and Rahimafrooz

Renewable Energy in Bangladesh remoteness of the islands, played an important role in the site selection:

- In Rio Tuba in the Philippines, the local electric cooperative Palawan Electric Cooperative (PALECO) deemed the area unviable for connection to the existing distribution network of PALECO. It hence opened the possibility for PowerSource to become the Philippines' first Qualified Third Party (QTP);
- In Mentawai, three villages (Madobag, Saliguma, and Matotonan) were chosen on the island of Siberut. Because of the remoteness of the island, Clean Power Indonesia entered into a 20-year Power Purchase Agreement (PPA) with the national utility, Perusahaan Listrik Negara (PLN);
- Rahimafrooz Renewable Energy equally identified Ghorjan Island as a suitable location because of the distance to the national grid and because of the potential for productive uses mostly in agriculture and fishing.

Likewise, for the analysed projects like Okra in Cambodia, Mandalay Yoma and Yoma Micro Power in Myanmar, as well as Gham Power in Nepal, **remoteness and the lack of grid extension plans have been key factors for site selection.**

Private Developer(s)	Project	Main criteria for site selection
Rahimafrooz Renewable Energy	Ghorjan Island, Bangladesh	Economic development potential, distance from national grid
Okra and Pteah Baitong	Kbal Damrei, Cambodia	Distance from national grid, proximity to company HQ (ease of transport)
Mlinda Foundation	Sahitoli, India	Economic development potential
Tara Urja	Derni, India	Economic development potential
Clean Power Indonesia	Mentawai, Indonesia	Distance from national grid (PPA agreement with PLN)
Mandalay Yoma	Dee Doke South, Myanmar	Economic development potential, distance from main grid
Yoma Micro Power	Thit Seint Gyi Village	Economic development potential (anchor client), distance from national grid
Gham Power	Khotang, Nepal	Economic development potential, distance from national grid, proximity to company HQ (ease of transport)
Subas and Sujan Electric Service Center	Simli Khola, Nepal	Distance from national grid, community demand
PowerSource Philippines	Rio Tuba, Philippines	Economic development potential, distance from main grid
Blue Solar and Symbior Solar	Koh Jik, Thailand	Replacement of outdated components, community demand

Table 3. Main selection criteria for clean energy mini-grids in South & South-East Asia

2.2 Technical design and selection of hardware

General considerations

In the technical design process of a mini-grid, several factors need to be assessed. **Key considerations include the choice of power generation (and potentially also storage) technology, sizing of the grid, choice of configuration and the distribution system.**²³

The choice of generation source generally depends on resource availability and cost of technology. Calculation of optimal generation mix is a multi-dimensional task where many factors affect the optimal combination of renewable energy technologies. The typical load profile, fuel price (related to diesel back-up), and solar and wind resource quantity at the selected location are the most important influencing factors on calculations.²⁴

The choice of energy storage/batteries also plays a key role in PV and wind hybrid mini-grids because of their intermittency.²⁵ **The choice of batteries depends on the following parameters: cycle life, temperature sensitivity, round trip efficiency, initial price (USD/kWh), specific energy (Wh/kg).**²⁶

Steps during the sizing process of the mini-grid can be split into the demand assessment and forecast on the one side and the technical and financial analysis on the other. **The end-product of the demand assessment is a load curve in kW over time. This is then provided as input to various simulation and sizing tools, which sometimes also require additional specific data and information. By making use of simulation tools, a tailored technical design can begin to take shape.**²⁷

Moreover, developers will need to decide between three basic configurations: alternating current (AC) coupled, direct current (DC) coupled or hybrid (both AC and DC), which each has its up and downsides. Lastly, developers need to consider the distribution system, which is often complex in mini-grids due to different power sources requiring extra controls and software.²⁸

According to RMI, **mini-grid developers will benefit from global trends of cost reduction** (especially on PV panels and batteries) and estimate that the costs of the hardware needed for mini-grids will decline 18% during 2019-2022. Moreover, **by doing bulk purchasing, using standardised designs and construction methods, as well as refining 'mini-grid-in-a-box' designs (modular mini-grids)**

Mini-grid developers will benefit from global trends of cost reduction

23 USAID, *What Are The Key Steps Of Mini-Grid Technical Design*, 2019 (online)

24 ADB, *Deployment of Hybrid Renewable Energy Systems in Minigrids*, 2017: page 1

25 ARE, *Using Batteries to Ensure Clean, Reliable and Affordable Universal Electricity Access*, 2013: page 1

26 USAID, *What Are The Key Advances In Mini-Grid Energy Storage?*, 2019 (online)

27 GLZ, *What size shall it be? A guide to mini-grid sizing and demand forecasting*, 2016: page 20-21

28 USAID, *What Are The Key Steps Of Mini-Grid Technical Design*, 2019 (online)

mini-grid developers can lower LCOE for projects further.²⁹

Observations from ARE case studies in South and South-East Asia

A. Generation technology

In eight out of the 11 case studies, solar PV hybrid mini-grids are deployed. The size of the mini-grids ranged from 8 kWp (Okra DC mini-grid in Kbal Damrei) to 80 kWp (Rahimafrooz AC mini-grid in Ghorjan Island). Two biomass gasifier projects (PowerSource 893 kWp mini-grid in Rio Tuba and Clean Power Indonesia 700 kWp mini-grid in Mentawai), as well as one micro-hydro project (29 kWp in Simli Khola operated by Subas and Sujana Electric Service Center) are also analysed.

The choice of technology depended largely on resource availability in the villages, as well as cost estimates.

For example, Mandalay Yoma chose a PV solution with batteries and diesel back-up because of good irradiation levels and no potential for micro-hydro or wind.

In Simli Khola, Nepal the project was implemented based on local demand, expertise and availability of sufficient flows in the mountainous areas of Nepal.

Clean Power Indonesia uses bamboo as biomass feedstock for their projects, because of the fuel characteristics of the crop along with the possibility to align its cultivation, production and usage with environmental and developmental agendas. Local availability of the bamboo, potential to grow in and restore degraded lands, rapid carbon sequestration, and the potential to support rural livelihoods are added benefits of using bamboo as a feedstock. Because of its ubiquitous availability, bamboo as a feedstock also mitigates one of the core risks in biomass projects namely the resource price variability risk.



© Tara Urja

B. Choice of energy storage technology

Out of the eight PV hybrid mini-grids in this study, six use lead-acid batteries, whereas two use lithium-ion batteries. Energy storage was not used in the biomass mini-grids, nor in the micro-hydro mini-grid.

For example, Mandalay Yoma opted for lithium-ion batteries, because of the length of the project, the convenience of the batteries with more life cycles (meeting the IEC specifications with 90% DoD and 80% usable capacity after 6,000 cycles), their compactness, and minimum maintenance requirements.

In contrast, Mlinda Foundation opted for lead-acid batteries (VRLA Gel) in the Sahitoli solar hybrid mini-grid. The main criteria for selection were the efficiency of the storage option, cost considerations and low maintenance requirements. Another consideration, for Mlinda was limited empirical data on mini-grids projects using lithium-ion batteries.

29 RMI, *Six Ways To Reduce Minigrad Costs By 60% For Rural Electrification*, 2018: page 20

Battery Type	DoD	Estimated Lifetime	Cost	Maintenance
Lead-acid (VRLA Gel)	50%	5 years	INR 14 (~USD 0.20)/Ah	Low
Lithium-ion	80%	10 years	INR 30 (~USD 0.42)/Ah	Low

Table 4: Mlinda Foundation's selection criteria for batteries in Sahitoli mini-grid

C. Grid size and configuration

The developers generally took the three following steps when designing and deciding the configuration of the grid: **load analysis, energy mapping and village mapping**. In the load analysis and energy mapping, productive uses and productive appliances were central to determine the size and choice of components for the mini-grids.

The seasonality of loads also has to be considered. Moreover, several developers demonstrated a modular and 'grid ready' design of their grids as a preparation for potential increases in demand and interconnection with the main grid.

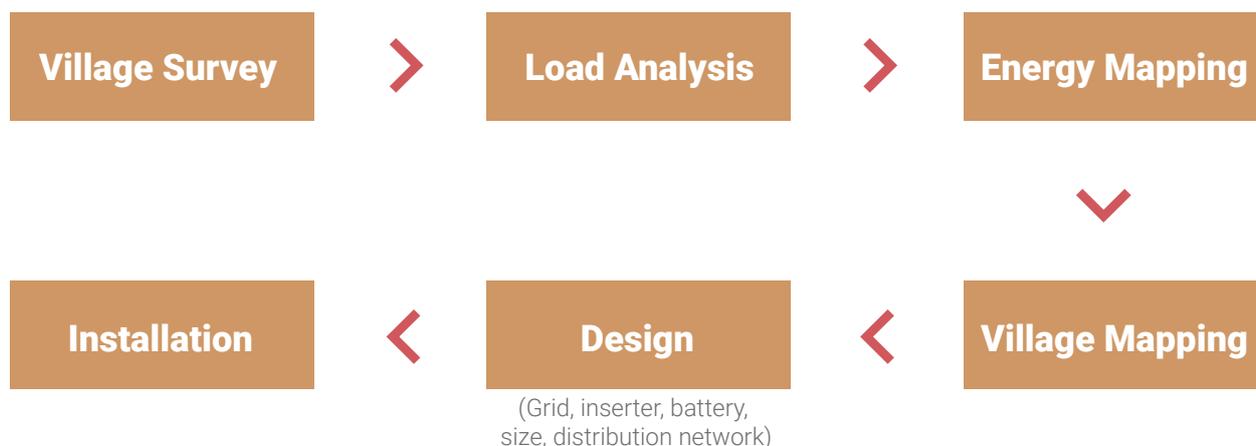


Table 5. Typical design process of a clean energy mini-grid (based on figures from Mlinda Foundation and Mandalay Yoma)

The load analysis estimates the total load present in the village from the devices present and the electric capacity of each device in households, agriculture and enterprises.

For example, Okra performed an appliance audit to investigate expected appliance purchases resulting from mini-grid installation in Kbal Damrei.

In Mentawai, a pre-project survey of 1,250 households was conducted by Clean Power Indonesia to assess the total electricity demand. After the survey and analysis, the total demand turned out to be 700 kW. To meet this demand, Clean Power Indonesia opted for an Ankur Scientific biomass gasifier, which produces

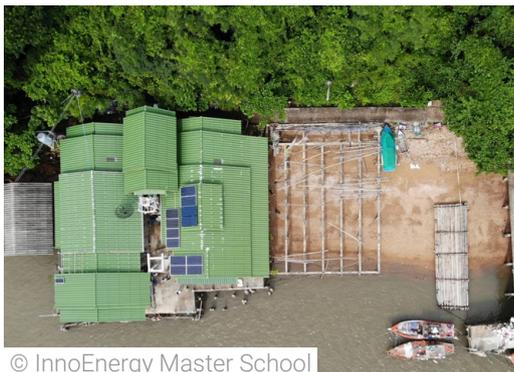
extremely clean and consistent gas quality. The total capacity of the gasifier system chosen for this project was 700 kW which consists of six units of 100 kW system and two units of 50 kW system.

In Ghorjan Island, Rahimafrooz sized its mini-grid on the basis of a baseline survey conducted among 400 households. One representative from each household on the island was interviewed to understand the socio-economic condition, kind of appliances used in the households, current consumption behaviour and scope of productive use of energy on the island. The survey also covered current expenditure for energy, type of appliance usage, challenges to improve the energy condition, as well as educational and industrial conditions of the region. Based on the survey findings, an 80 kWp solar PV hybrid mini-grid was set up to provide 230 V electricity for domestic, productive and commercial loads.



Energy mapping informs about the daily energy (kWh) requirement of the village loads present, power of each load, number of hours of running each load and

the number of loads present. The main variables analysed are the conversion rates of the loads present, the power of each load, number of hours of running each load and the number of loads present. The number of converted loads into hours of running and power requirements gives the total daily requirement of the village for energy.



In Gham Power's mini-grids in Khotang, one key observation was that both the load analysis and mapping should also consider the seasonality of the productive loads. Gham Power geo-tagged

each household and sent follow-up questionnaires sought to manually calculate the load requirements of each household to appropriately size systems. A seasonality chart was drawn to ensure that the mini-grids energy production could meet energy requirements throughout the year while ensuring a high enough utilisation rate to sustain the use across seasons.

Similarly, seasonality of demand has been a critical factor in sales of the water treatment unit, which is the anchor client of Tara Urja's solar PV mini-grid grid in Dorni. This is because demand for chilled water diminishes in monsoon and winter months although safe drinking water is needed year-round.

Village mapping was performed by developers to efficiently design the distribution network.

In Sahitoli, operated by Mlinda Foundation, the solution implemented was a 22.4 kWp solar powered mini-grid to provide 24x7 AC power single phase 230 volts and three phase 415 volts for domestic, productive and commercial loads. It is built in a modular manner for incremental growth in installments of 5 kWp. According to Mlinda calculations, 5 kWp is the optimal size of an array wherein

additional demand generated by villages will be met while keeping the expansion cost efficient.

In Darni, Tara Urja uses a single-phase modular mini-grid solution, Mini-grid-in-a-Box ('MiB'), Model U30 solution, which reduces the cost and time of installation through use of pre-assembled electrical boxes and innovative pipe foundation.

Yoma Micro Power determined to build a power plant with 31.2 kWp of solar, that provides 230 V single-phase AC or 415 V three-phase AC energy depending on customers' needs. Further expansion of the mini-grid with the rise in demand was also foreseen.

Private Developer(s)	Project	Size & Technology	Energy Storage	Distribution System
Rahimafrooz Renewable Energy	Ghorjan Island, Bangladesh	80 kWp solar PV hybrid	Flooded Lead-acid (538.56 kWh)	AC three phase LT 230 V
Okra and Pteah Baitong	Kbal Damrei, Cambodia	8 kWp solar (DC) hybrid	Lead-acid (60 kWh)	n/a
Mlanda Foundation	Sahitoli, India	22.4 kWp solar PV hybrid	Lead-acid VRLA (71.28 kWh)	AC single phase 230 V and three phase 415 V
Tara Urja	Darni, India	31.2 kWp solar PV hybrid	Lead-acid VLRA (96 kWh)	AC single phase 230 V
Clean Power Indonesia	Mentawai, Indonesia	700 kWp biomass gasifier	n/a	AC three phase 415 V
Mandalay Yoma	Dee Doke South, Myanmar	55 kWp solar PV hybrid	Lithium-ion (160 kWh)	AC single phase 230 V and three phase
Yoma Micro Power	Thit Seint Gyi Village, Myanmar	31.2 kWp solar PV hybrid	Lead-acid VLRA (192 kWh)	AC single phase 230 V and three phase 415 V
Gham Power	Khotang, Nepal	52 kWp solar PV hybrid	Lead-acid Exide (336 kWh)	AC single phase 230 V
Subas and Sujan Electric Service Center	Simli Khola, Nepal	29 kWp hydro	n/a	AC single phase 230V and three phase 400 V
PowerSource Philippines	Rio Tuba, Philippines	893 kWp biomass gasifier	n/a	AC single phase 230 V and three phase 460 V
Blue Solar and Symbior Solar	Koh Jik Island, Thailand	60 kWp solar PV hybrid	Lithium-ion (240-260 kWh)	AC three phase 380 V / 220 V

Table 6. Technical design and hardware in clean energy mini-grids in South & South-East Asia

2.3 Operations and maintenance

General considerations

Operation and maintenance (O&M) is a critical element for the long-term sustainability of mini-grids and should be planned in advance of the start of operations.

It can be managed in-house or contracted out to a local service company. Which-ever model is chosen, **it is essential that the O&M staff have the required skill, motivation, integrity and relationship with the community.**³⁰

RMI calculates that by building clusters of mini-grids and combining this approach with streamlined project development and O&M, the final cost of power can be reduced by 8%.³¹ Another study by AMMP indicates that basic monitoring solutions can lead to a roughly 15% cost saving in comparison to a baseline where no remote monitoring is in place. Additionally, more advanced solutions can reduce the O&M costs of remote off-grid assets by around 30% in comparison to the same baseline.³²



Observations from ARE case studies in South and South-East Asia

A. Digitalisation and remote monitoring

Developers in South and South-East Asia are leveraging digital solutions to optimise operations and management of projects and to keep control of plant operations. In many cases, remote monitoring plays a key role in reducing OPEX costs and improve efficiency of systems.

Mlinda estimates that the direct cost reduction benefit of implementing remote monitoring has been a reduction of OPEX by USD 2,400 per mini-grid grid per year. The management portal also shows the real time load, consumption pattern, generation and battery usage. This has proved to be an important information and monitoring tool, as it helps to assess demand and assists in load scheduling.

Gham Power also uses remote diagnostics and a Schneider control panel that feeds data using internet connection. However, the calculations of the cost-savings of using these smart diagnostic measures are yet to be undertaken.

Okra has piloted a plug & play smart controller along with a software as a service to remotely monitor and control solar energy mesh networks and manage payments from households. The Okra controller acts as a charge controller with an

³⁰ AfDB, Green Mini-Grid Help Desk – Operation and Maintenance, 2019 (online)

³¹ RMI, Six Ways To Reduce Minigrad Costs By 60% For Rural Electrification, 2018: page 30

³² AMMP, Reducing the cost of operations and maintenance for remote off-grid energy systems: The impact of remote monitoring, 2019: page 1

in-built meter and at the same time an IoT Remote Monitoring Device.

Mandalay Yoma also carried out monitoring by using an online portal. The platform monitors, consumption pattern, generation and battery usage as well as daily information on the consumption for each villager, as well as when to conduct PV panel washing.

B. Clustering

Clustering of grids is another interesting approach to lower O&M costs for mini-grid projects.

Yoma Micro Power employs a local caretaker for cleaning and basic maintenance functions, while each cluster of grids is also covered by an O&M engineer, who may be responsible for maintaining four-five solar power plants. The mini-grids are designed to be unmanned and remotely monitored, to reduce OPEX costs further.

Similarly, Mlinda Foundation employs an engineer that is shared between the two villages of Narotoli and Sahitoli and one full time operator stays in Sahitoli and works with the community, individual entrepreneurs, women's self-help groups and farmer groups, to help them make the transition from diesel and kerosene to clean energy. The salaries of the engineer, operator and land rent form the operating costs of the grids.

C. Local community involvement in operations and maintenance & training

In several case studies, training of local staff is an integral part of the project to ensure that O&M is conducted properly.

For example, RERL conducted training on hands-on skills for operations staff and management team in the Simli Khola project in Nepal. The private leasing company, Sujan Electric Service Centre, has been mandated to be in charge of operations and payment collections, has also created and set up a maintenance fund, which acts a reserve in case maintenance is needed for the micro-hydro mini-grids.



© Mandalay Yoma Energy

Mandalay Yoma trains operators from the local Village Electrification Committee to help operate the mini-grid in Dee Doke South.

PowerSource also employs local residents of the barangay (community) for operations and maintenance of Rio Tuba mini-grid. This includes three linemen to maintain the distribution network, three operators, a finance officer and a cashier responsible for issuance of monthly billing statements and collection respectively, as well as a Site Supervisor for overall supervision of the facility.

Private Developer(s)	Operations and Maintenance Measures
Rahimafrooz Renewable Energy	Remote monitoring, training of supervisor
Okra and Pteah Baitong	IoT monitoring device in Okra controller, local maintenance agent
Mlinda Foundation	Remote monitoring, clustering (engineer shared between several grids), training of local community
Tara Urja	Remote monitoring through real-time Data Management System, integrated mobile application for field agents and customer service application (Smart Connect), two local operators including technician and field agent for mini-grid.
Clean Power Indonesia	Ankur Scientific (technology provider) has responsibility of troubleshooting and maintenance of the mini-grids
Gham Power	Local operators hired from among the communities and trained, Remote monitoring
Subas and Sujan Electric Service Center	Maintenance fund established, local private company has taken over O&M of community-run mini-grid
Mandalay Yoma	Remote monitoring, training of operators from local Village Electrification Committee
Yoma Micro Power	Remote monitoring, clustering (cluster of 4-5 grids has one O&M engineer)
PowerSource Philippines	Training of local operators, finance officers, cashier, billing assistant, security person
Blue Solar and Symbior Solar	Community in charge of O&M, SMU to measure performance

Table 7. O&M measures for clean energy mini-grids in South and South-East Asia

Training of local staff is an integral part of the project to ensure that O&M is conducted properly



© Yoma Micro Power

2.4 Revenue and financing sources

General considerations

When private sector developers plan their business models, **the choice of source of revenue is the most important decision. Closely linked is the question of where ownership of the mini-grid project lies.** ADB outlines four ownership models, which can also be used to understand how private companies can generate revenues from mini-grid projects.³³

1. Private operator model: In this model, **the mini-grid is operated and owned by the private company.** Developers can typically employ two different revenue models in this type of mini-grid:

- A **micro-utility revenue model**, where consumers are charged a price per consumed kilowatt hours (kWh). Invoicing occurs either after the power has been consumed or on a pre-paid basis where consumers top-up and then use power up to the value of the pre-paid amount;
- A **service model**, where consumers buy a certain number of hours of light, phone charging, or other appliances usage per month.³⁴

2. Public utility model: In this model ownership lies with a national or local public utility (e.g. electric cooperatives in the Philippines). For such projects one possible revenue model for private companies is to sign a power-purchase agreement (PPA) with the national utility to generate electricity, operate and maintain the mini-grid over a defined period of time. Electricity is sold to the utility, who then distributes to local households and commercial loads.

3. Community-based model: The mini-grid is owned by a local community. The commu-

nity-based model is very common in South and South-East Asia, especially in Nepal for micro-hydro projects. Potential revenue models for private sector in such projects are rarer, but not unheard of. For example, communities can hire private developers to build the mini-grid, upgrade an existing mini-grid system or operate and maintain an existing mini-grid under a PPA agreement.

4. Hybrid model: ownership is mixed or shared among several actors. For example, ownership can first lie with a private developer and then be transferred after a period of time to a community. Alternatively, ownership can be shared between actors each having equity in the project in a Special Purpose Vehicle (SPV).

While the source of revenue and hence also the overall business model for private developers differ depending on the ownership, a common denominator for many of the successful mini-grid businesses so far is that they have relied on an anchor-business-community (ABC) model.³⁵

Mini-grids that use an ABC-approach typically prioritise identifying and negotiating an agreement with an anchor load (e.g. agro-processing), then identify and help develop small local businesses, and lastly target domestic consumers and households. **The ABC model is often adopted because it lowers payment risks** (associated with providing electricity to households in very poor areas) **and increases profitability as higher tariffs can be charged to the anchor load and business in comparison with households.**³⁶

While not all clean energy mini-grid projects use the ABC model, **evidence has shown that mini-grid profitability and success is intrinsically linked to the productive use of renewable energy.** This is because of the typically

33 ADB, *Deployment of Hybrid Renewable Energy Systems in Minigrids*, 2017: page 14

34 IFC, *Operational and Financial Performance Of Mini-Grid DESCOS*, 2019: page 19

35 GET.invest, *Commercial viability of PV mini-grids for rural electrification in sub-Saharan Africa*, 2019: page 7

36 EEP, *Opportunities and Challenges In The Mini-Grid Sector in Africa - Lessons Learned From the EEP Portfolio*, 2018: page 7

low energy usage of residential customers. **Without support for productive uses of energy, mini-grids are likely to struggle to reach sufficient demand (and hence also revenue generation) needed for financial viability. Productive users are also important to enhance the economic and social development impacts of mini-grids, which in turn lowers payment risks from customers.**³⁷ Many different productive uses can be considered for mini-grid projects, a comprehensive list of which can be found in ARE's publication on "Productive Use of Renewable Energy in Africa".³⁸ More broadly energy companies can also seek to explore partnerships across sectors combining energy with water and agriculture³⁹, telecoms, internet and digital services, etc.⁴⁰.

When the source of revenue is established, **financing sources for the mini-grid project also has to be considered. The choice of a financing source for mini-grid projects and companies depends on the type of mini-grid and the stage of project development** (early stage pilot vs. later portfolio of mini-grids).

The more early-stage and risky projects will typically be financed through grants, subsidies and equity, while the more advanced and less risky projects can be increasingly financed by debt.⁴¹

Observations from ARE case studies in South and South-East Asia

A. Ownership

Ownership in the projects analysed varied across the four ownership models.

Privately owned mini-grids include the projects developed by Mandalay Yoma, Mlinda Foundation, Tara Urja, PowerSource Philippines, Rahimafrooz Renewable Energy, Yoma Micro



© Gham Power

Power and Okra.

In Mentawai, Indonesia, the mini-grid is owned by the national utility PLN, which has signed a 20-year PPA with Clean Power Indonesia to operate and maintain the biomass powered mini-grid.

In Simli Khola, the community owned mini-grid has leased out operations, maintenance and billing to a private company, Subas and Sujan Electric Service Center.

In Koh Jik, Thailand, two private sector companies, Blue Solar and Symbior Solar have invested in upgrading the capacity of an existing mini-grid project under the condition of engaging in a PPA with the community. The two private investors are now responsible for maintenance operations, billing and collecting the electricity revenue, under the PPA, which will last 10-15 years.

A hybrid ownership model is in place in Gham Power's projects in Khotang. **The two mini-grids are owned by an SPV, which consists of representatives from all key stakeholders, including representatives from the local government.**

37 NREL & Energy 4 Impact, *Productive Use Of Energy In African Micro-Grids: Technical And Business Considerations*, 2018: page vii

38 AEEP & ARE, *Productive Use of Renewable Energy in Africa*, 2015: page 9-18

39 REEEP, *Powering Agrifood Value Chains*, 2017: page 8

40 Facebook & Bloomberg New Energy Finance, *Powering Last-Mile Connectivity*, 2018: page 2

41 AfDB, *Green Mini-Grid Help Desk – Financing*, 2019 (online)

Gham Power partly owns the mini-grid as a board member of the SPV and it is also the primary point of contact if maintenance issues arise. After 10 years of operation, the ownership of the mini-grid will be transferred to the local community.

B. Revenue Models

Most of the mini-grid developers operating privately owned mini-grids earn their revenue via the micro-utility model, where consumers pay a small connection fee and then charge a price per consumed kWh.

Mlinda Foundation collects revenue from residential and commercial customers, which pay for upfront connection fees and then pay for energy use. There are different day and night-time tariffs (approximately USD 0.32 per kWh during the day and 0.64 per kWh during the night). Reaching 95% of mini-grid capacity utilisation in 30 months determines the success of the business model. Mlinda also provides loans to farmers to finance energy efficient devices to accelerate uptake. Existing agri-businesses such as rice hullers and wheat mills are converted from diesel to electric. Non-existing agri-businesses such as oil expelling, mini cold storage are incubated and livelihood activities such as poultry coops, welding shops, grocery shops, sewing machines are electrified.



© InnoEnergy Master School

Rahimafrooz Renewable Energy sells energy on a pre-payment basis at USD 0.41 per kWh. The revenue source is electricity sales on a per kWh basis to commercial and residential users. The payment model is different as the clients are required to purchase energy credit for at least one month. Energy will be credited through smart card from the vending station located in the project office and/or vending kiosk at the local market.

PowerSource Philippines also uses the micro-utility revenue model. The original tariff charge to customer was 0.51 USD per kWh. After approval of PowerSource as a Qualified

Third Party (QTP) in the Philippines, the new tariff for end-users was set at USD 0.17 per kWh, which is the approved tariff by the Energy Regulatory Commission of the Philippines (ERC) in missionary areas of the Philippines. PowerSource receives a subsidy to cover the difference between the True Cost of Generation Rate (TCGR) and the tariff charged to end-users, which is known as the Subsidised-Approved Retail Rate (SARR). The subsidy used to cover this difference is known as Universal Charge on Missionary Electrification (UCME).

Several developers root their micro-utility revenue model in an ABC business model setup, electrifying anchor clients first, then business and then households to lower payment risks.

An example is Yoma Micro Power, which uses off-grid telecom towers as its anchor clients. Secondly, the company offers electricity to rural businesses and communities. Customers pay for the electricity they consume, as well as a one-time connection and installation fee. Tariffs are roughly USD 0.20 per kWh during the day and USD 0.60 per kWh during the night.

Tara Urja also applies the ABC model. In Derni, the anchor client is a water treatment unit (WTU) with a connected load of 5.5kW. Tara Urja acts as a co-investor in the WTU, contributing 40-50% of the ~USD 8,000 CAPEX needed to buy and set up the filtration and chilling equipment. The entrepreneur pays Tara Urja for electricity, as well as a marginal fee per litre of water processed to pay back the co-investment. In addition to the WTU, residential users pay a tariff of USD 0.3-0.4 per kWh.

Others like Gham Power in Nepal earn their revenue by selling service packages. End-users can choose between a variety of different service packages, which include light bulbs, refrigerators, charging mobile phones and televisions. More expensive service packs are sold to businesses.

Another innovative approach to revenue generation is applied by Okra and Pteah Baitong in Cambodia. All households that have been connected to Okra networks pay a connection fee of USD 35 in addition to a monthly fee based on their selected energy package (which ranges from basic appliances such as lighting fans and mobile phones in the cheapest package to TVs, egg incubators, freezers and speakers in the more expensive package).

For Clean Power Indonesia, the revenue source is the USD 0.15 kWh charged tariff, which is paid by PLN to Clean Power Indonesia as part of the PPA agreement. The final tariff charged by PLN to households in Mentawai is USD 0.031 per kWh. The low tariff can be explained by subsidies.

In the case of Subas and Sujana Electric Service Centre, the private company has been hired by the community to maintain and operate the micro-hydro project

All households that have been connected to Okra networks pay a connection fee of USD 35 in addition to a monthly fee based on their selected energy package

under PPA. The private company operates the plant, collects revenue and pays the staff while ensuring continuous service delivery to the beneficiary communities. After taking over mini-grid operations, the company has revised tariff rates, introduced a new computer billing system, introduced rewards for timely payment, and created and operationalised a maintenance fund. The plant factor



has improved by 20% – daily operation hours have increased to 22 hours up from 12 hours before the lease out arrangement. The revenue source for the company is the tariff charged to consumer, which is minimum USD 1.09 up to 5 kWh, but USD 0.10 per kWh if more than 5 kWh is used.

In Koh Jik island, the revenue model for the two private investors, Blue Solar and Symbior Solar, is a 10-year PPA with the community energy company with the option of extending to 15 years under the provision of a battery upgrade included in year 11. This means that during the PPA duration, all the generation is handled by two private developers. The community is still in charge of operation and maintenance (O&M), but costs of O&M are being covered by the investors.

C. Project Costs and Financing Sources

The CAPEX in the 11 projects varied, with the lowest investment being USD 16,320 for a mini-grid in Kbal Damrei, Cambodia. The Kbal Damrei mini-grid was 100% grant funded by Agence Française de Développement (AFD) and Stichting Nederlandse Vrijwilligers (SNV). Okra expects 15% IRR over 10 years (payback 4 years).

The highest investment was USD 12,500,000 in the Mentawai project in Indonesia, 96% grant funded by Millenium Challenge Corporation (MCC).

Contrastingly, the Thit Seint Gyi Village project is 100% financed by Yoma Micro Power in which the shareholders are Yoma Group, IFC (World Bank Group), Norfund and Alakesh Chetia. The payback time is estimated at seven years.

In between the two extremes, the Dee Doke project with a CAPEX of USD 200,000-250,000 was financed by a 60% grant from the Department of Rural Development of Myanmar (DRD), debt from Mandalay Yoma and equity investments from local villagers. Payback time for Mandalay Yoma is estimated at 5-7 years. For villagers that made equity investments is expected to be 1-2 years.

Rahimafrooz Renewable Energy and Mlinda projects were also funded partly by grants, partly by equity and partly debt, as is Gham Power's projects in Khotang. Both Gham Power and Rahimafrooz estimates an IRR of 10% over 10 years. Mlinda Foundation estimates a payback time of 7 years with an IRR of 5%.

Private Developer(s)	Project	Size & technology	Project cost (USD) ⁴²	IRR	Financing sources	Revenue model	Price charged to end-users (USD)
Rahimafrooz Renewable Energy	Ghorjan Island, Bangladesh	80 kWp solar PV hybrid	551,000	10% over 10 years	40% grant, 40% loan, 20% debt	Micro-utility	0.41 per kWh
Okra and Pteah Baitong	Kbal Damrei, Cambodia	8 kWp solar DC hybrid	16,300	15% IRR over 10 years	100% grant	Service packages; price per battery charge	Minimum package: USD 8 Maximum package: USD 15
Mlinda Foundation	Sahitoli, India	22.4 kWp solar PV hybrid	125,000	5 IRR% (7 years payback)	55% grant, 20% equity, 25% debt	Micro-utility	Day: 0.32 kWh Night: 0.64 kWh
Tara Urja	Derni, India	31.2 kWp solar PV hybrid	70,000	IRR not calculated (6 years payback time)	100% grant	Micro-utility (ABC model)	Tariff ranging from USD 0.3-0.4 per kWh
Clean Power Indonesia	Mentawai, Indonesia	700 kWp biomass gasifier	12,500,000	IRR of 13-15%	96% grant	PPA (operator only with PLN)	0.031 per kWh to HHs charged by PLN (0.15 per kWh on electricity sold to PLN by CPI)
Mandalay Yoma	Dee Doke South, Myanmar	55 kWp solar PV hybrid	200,000 – 250,000	IRR not calculated (7 years payback time)	60% grant, 20% equity, 40% debt	Micro-utility (ABC model)	0.27 per kWh
Yoma Micro Power	Thit Seint Gyi Village, Myanmar	31.2 kWp solar PV hybrid	106,000	IRR not calculated (7 years payback time)	100% equity	Micro-utility (ABC model), service packages for households, price per kWh for productive uses, PPA with telecom towers	Day: 0.2 per kWh Night: 0.6 per kWh

42 Some CAPEX cost based on recalculation to USD with InforEuro (September 2019). Costs rounded to nearest thousand.

Gham Power	Khotang, Nepal	52 kWp solar PV hybrid	239,000	IRR 10% over 10 years	Mix of grant, equity and debt (% not disclosed)	Service Packages (ABC model)	Minimum package (USD 2.2 / month) – Maximum (USD 43 / month)
Subas and Sujan Electric Service Center	Simli Khola, Nepal	29 kWp hydro	112,000	n/a	75% Grant and 25% equity	PPA (O&M with local community)	Households: 0.10-1.09 per kWh Businesses: 0.10-2.72 per kWh
PowerSource Philippines	Rio Tuba, Philippines	893 kWp biomass gasifier	514,000	Not calculated	70% Debt and 30% equity	Micro-utility	0.17 per kWh (current TCGR = ~0.686/kWh)
Blue Solar and Symbior Solar	Koh Jik Island, Thailand	60 kWp solar PV hybrid	172,000	n/a	Fully funded by Blue Solar and Symbior Solar	PPA (with local community)	0.42 per kWh

Table 8. Revenue models, Project costs, IRR, financing sources and prices charged to end-users for clean energy mini-grids in South and South-East Asia

2.5 Billing and metering

General considerations

A key success factor in any mini-grid is to have a proper customer billing system and revenue collection mechanism to minimise payment risks. It is important to choose the right pricing and tariff structure, to use an appropriate payment technology and to find a suitable metering solution.

There are three common billing methods:

- **Cash payment** via agents and staff that collect cash payments directly from customers from door to door or in a central location the village;
- **Voucher payments** sold via designated kiosks or dealers; and
- **Mobile money payments**, where customers can top-up their energy balance remotely.⁴³

The key determinants of the metering solution include the payment model (whether electricity consumption is pre-paid or post-paid), the visibility on energy consumption data and the cost of the meter. Metering solutions typically fall into three types:⁴⁴

43 IFC, *Operational and Financial Performance Of Mini-Grid DESCOS*, 2019: page 19

44 AfDB, *Energy 4 Impact & INENSUS, Billing, Revenue Collection and Metering Models for Mini-Grids*, 2019: page 8-10

- **Post-paid meters** measure current monetary or energy balance;
- **Pre-paid meters** measure the amount of electricity consumed. They typically use tokens/codes for energy recharging; and
- **Smart meters** measure and communicate payment and consumption data without manual intervention. They allow for remote monitoring, operation and maintenance of mini-grid sites.

Observations from ARE case studies in South and South-East Asia

Billing methods varied across the three common methods highlighted above. The most common method remains cash payments with a majority of the mini-grids still employing personnel to collect payments locally, closely followed by mobile money.



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In both mini-grids from India (Mlinda Foundation and Tara Urja), payment was done by cash collection on site. Similarly, cash payments are used by PowerSource in the Rio Tuba and Subas and Sujana Electric Service Center in Simli Khola, Nepal.

Mobile Money payments have been enabled in the mini-grids operated by Gham Power in Nepal, by Yoma Micro Power in Myanmar and by Okra in Cambodia.

Gham Power partners with a local mobile money vendor, which has lent its support by agreeing to share its mobile application for payment collection. In this way, Gham Power can lower payment risks and enable top-ups for consumers to increase households' capacity to consume more electricity after the original quotas have expired. This has also increased financial access for some beneficiaries.

Yoma Micro Power uses Wave Money, a leading digital money platform in Myanmar. End-users are able to query their balance and top up using Wave Money at any time.

In Cambodia, due to the regulatory requirements, Pteah Baitong and Okra have rolled out an innovative energy-as-a-service business model that charges the end-user for energy via mobile payments based on the number of battery charges they consume (calculated based on Okra's remote monitoring data). The mobile payments have also reduced operational costs for distribution partners.



© Clean Power Indonesia

The voucher billing model is used in Rahimafrooz' mini-grid in Ghorjan Island. Energy is sold on a pre-payment basis. Any client willing to avail the service needs to be registered with an upfront payment of connection fees. This is a one-time payment that will cover the cost of the distribution line tapping for that particular load. Upon registering the customer will be supplied with a pre-paid smart card. All the clients are required

to purchase energy credit for minimum a month. Energy will be credited through smart card from the vending station located in the project office and/or vending kiosk at the local market.

In terms of the metering solutions used, smart pre-paid meters were the main solution across the board. Tara Urja's modular Mini-grid-in-a-Box includes a smart meter, which manages power consumption of each consumer. Gham Power, Mandalay Yoma, Yoma Micro Power, Rahimafrooz and Mlinda also use smart pre-paid meters.

In Koh Jik, the original meters were replaced by pre-paid smart meters. A grant of approximately 17,500 EUR was received from the Australian Embassy Direct Aid Program (DAP) to order, install and commission 100 smart meters with pre-payment functionalities in the scope of the project. The pre-payment capabilities ensure that electricity prices are paid beforehand and eliminates the risk of non-payments in addition to unlocking possibilities of tariff management and energy conservation measures.

Private Developer(s)	Project location	Billing solution	Metering solution
Rahimafrooz Renewable Energy	Ghorjan Island, Bangladesh	Voucher model (smart card from vending station)	Pre-paid smart meter
Okra and Pteah Baitong	Kbal Damrei, Cambodia	Mobile money	Okra Controller inbuilt meter
Mlinda Foundation	Sahitoli, India	Cash Collection	Pre-paid smart meters
Tara Urja	Derni, India	Cash collection	Pre-paid smart meters
Clean Power Indonesia	Mentawai, Indonesia	n/a	n/a
Mandalay Yoma	Dee Doke South, Myanmar	Cash collection	Pre-paid smart meters
Yoma Micro Power	Thit Seint Gyi Village, Myanmar	Mobile money	Pre-paid smart meters
Gham Power	Khotang, Nepal	Mobile money	Pre-paid smart meters
Subas and Sujan Electric Service Centre	Simli Khola, Nepal	Cash collection	Post-paid meters
PowerSource Philippines	Rio Tuba, Philippines	Cash collection	Post-paid meters
Blue Solar and Symbior Solar	Koh Jik Island, Thailand	Online payment + Cash collection	Pre-paid smart meters

Table 9. Billing and metering used in clean energy mini-grids in South and South-East Asia

3

Case Studies

3.1 Rahimafrooz Renewable

Energy:

80 kW solar-powered mini-grid in Ghorjan Island (Bangladesh)

3.2 Okra and Pteah Baitong:

8 kWp DC mini-grid in Kbal Damrei (Cambodia)

3.3 Mlinda Foundation:

22.4 kWp solar-powered mini-grid in Sahitoli (India)

3.4 Tara Urja:

31.2 kWp solar-powered mini-grid in Darni (India)

3.5 Clean Power Indonesia:

700 kWp biomass gasifier in Mentawai (Indonesia)

3.6 Mandalay Yoma Energy:

55 kWp solar-powered mini-grid in Dee Doke South (Myanmar)

3.7 Yoma Micro Power:

31.2 kWp solar-powered mini-grid in Sagaing Region (Myanmar)

3.8 Gham Power:

52 kW solar-powered mini-grids in Khotang (Nepal)

3.9 RERL and Subas & Sujan Electric Service Center:

29 kWp micro-hydro mini-grid in Simli Khola (Nepal)

3.10 PowerSource Philippines Inc. (PSPI):

893 kWp biomass gasifier in Rio Tuba (Philippines)

3.11 Inno Energy School, Blue Solar and Symbior Solar:

60 kWp solar-powered mini-grid in Koh Jik Island (Thailand)



3.9 Simli Khola (Nepal)

3.8 Khotang (Nepal)

3.1 Ghorjan Island (Bangladesh)

3.7 Sagaing Region (Myanmar)

3.6 Dee Doke South (Myanmar)

3.11 Koh Jik Island (Thailand)

3.2 Kbal Damrei (Cambodia)

3.10 Rio Tuba (Philippines)

3.4 Darni (India)

3.3 Sahitoli (India)

3.5 Mentawai (Indonesia)

3.1 Rahimafrooz Renewable Energy: 80 kWp solar-powered mini-grid in Ghorjan Island (Bangladesh)

About Rahimafrooz Renewable Energy Limited

Rahimafrooz Renewable Energy Limited (RREL) is a leading South Asia based solar home system (SHS) integrator and installer with over 600,000 customers based in Bangladesh and growing every month with the very first installation in 1989. It also develops mini-grids and manufactures solar PV modules and has unique storage technology for SHS. The company employs over 4,000 people with an extensive rural service and selling network for access to energy using on-line and smart phone-based systems.

Context



Commercial use of renewable energy in a sustainable manner is still a great challenge for Bangladesh. Despite all the government's policies, goals and progress, a significant population residing in the remote rural areas will be without electricity in distant future. The geographical diversity makes it difficult to provide grid electricity to the rural isolated villages. There are currently 1,034 villages where grid connectivity is not possible.

Site identification and selection

RREL implemented a solar-powered hybrid mini-grid to provide electricity to the Ghorjan Island, Chowhali in the district of Sirajganj, Bangladesh. Ghorjan Island is located in the western part of Bangladesh with an area of 6 square kilometres and 3,349 inhabitants. It is a remote island separated from mainland by the river Jamuna by a channel of 10 km and there is no possibility of grid electrification service in this area in the near future. **Because of the socio-economic condition of the island and its remoteness, this location was selected.**

Technical design and selection of hardware

A baseline survey was conducted among 400 households; one representative from each household on the island to understand the socio-economic condition, the kind of appliances used in the households, current consumption behaviour and potential for productive use of energy on the island. The survey also covered current expenditure for energy, type of appliance usage, challenges to improve energy condition, educational condition and industrial condition of the region.

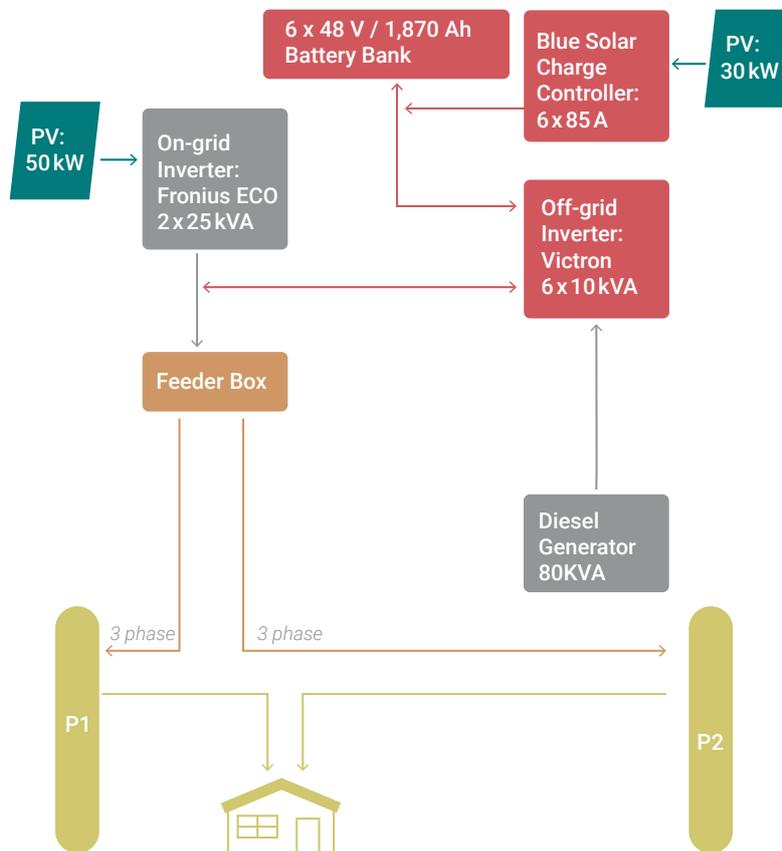
This reflected the scope of overall improvement in the island. Based on the survey findings, an 80 kWp solar-powered hybrid mini-grid was installed to provide 230 V grid standard electricity for domestic, productive and commercial loads.





The project initially concentrated on load of commercial importance and potential such as shops and agro-processing activities. Apart from this, the project provided electricity to basic health facility and households as well as education facilities. Based on load analysis, energy mapping and energy requirement, the grid and network distribution size were decided.

The project is a crystalline solar PV diesel hybrid with AC-DC coupling for maximum system efficiency. The AC coupled side will directly supply loads during the day from solar PV modules through the on-grid inverter. Night-time loads will be served from the energy storage system (ESS) (538.56 kWh), where energy will be stored from DC coupled solar modules as well as excess energy from the AC coupled side.



Flooded lead-acid low maintenance Tubular Plate batteries have been considered for the ESS because of its excellent deep discharging capacity, economic viability for such applications, and the expected life under high and extreme temperatures. A diesel-powered generator has been considered for peak shaving or energy deficit from Solar PV modules in bad weather.

The expected electricity demand of the target population (310 households and 40 shops) is 99,983 kWh per year. Initially, an 80% plant utilisation factor was

considered. The remaining 20% of plant capacity will be used in the 2nd year. Electricity demand is expected to increase by 5% per year assumed from the 3rd year. Increased demand will initially be supplied by the generator. Plant capacities will be increased to meet further demand.

To minimise cable and other transmission losses, the mini-grid is located at the central point of the targeted population. The local market is also very near to the project location.

Design Basis	AC-DC coupling
On-grid production capacity	50 kWp
Off-grid production capacity	30 kWp
Distribution line length	6 km
Number of poles	139
Distribution Line Scheme	3 phase LT
Line Voltage	440 V
Phase Voltage	230 V
On-grid Inverter	2 Pcs 25 kW Inverter
Off-grid Inverter	6 Pcs 10 kVA inverter
Charge Controller	6 Pcs 85 A
Battery	144 Pcs 1875 Ah/2 V
Diesel Generator	One 80 kVA

Technical design and hardware components

Operations and maintenance

Operations and maintenance have been undertaken through a remote monitoring system. In addition, a local supervisor was trained to ensure flawless operations and maintenance.

Revenue and financing sources

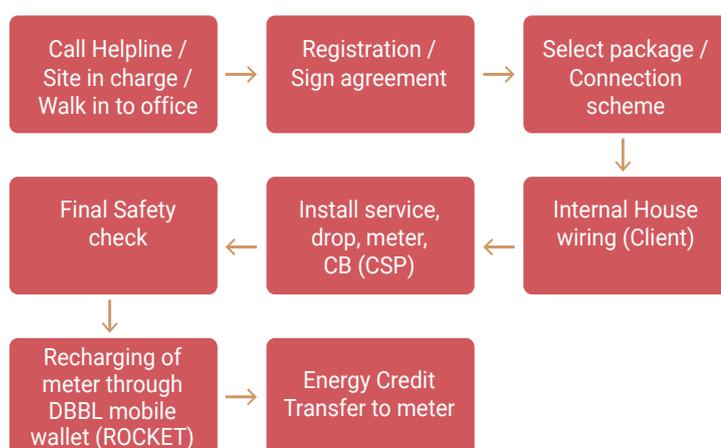
The mini-grid is owned and operated by RREL.

Energy is sold on a pre-payment basis and the revenue model is sales of electricity on with a differentiated day and night-time tariff averaging to ~USD 0.41/kWh.

The project was completed in 12 months and the total capital cost (CAPEX) of the project was USD 551,250. The project IRR is 10.08% over 10 years. The

initial infrastructure CAPEX is relatively high compared to this 80 kWp plant size. There are future plans to expand the capacity of the mini-grid and the Project IRR will increase accordingly. The operational model is shown below.

The project was financed through a mix of a grant, a loan and equity. The proportion of each is 40% grant, 40% loan, and 20% equity.



Billing and metering

Energy is sold on pre-payment basis. Any client willing to avail the service needs to be registered with an upfront payment of connection fees. This is one-time payment that will cover the cost of the distribution line tapping for that particular load. Upon registering the customer will be supplied with a pre-paid smart card.

All the clients are required to purchase energy credit for minimum a month. Energy will be credited through smart card from the vending station located in the project office and/or vending kiosk at the local market.

Metering is done through smart pre-paid meters which are monitored online through cloud communication.

Project outcomes

This mini-grid has been operational since February 2018. A survey was conducted in August 2018 to assess the impact of the mini-grid on the people of Ghorjan Island. As a result of the project, socio-economic changes have taken place. For example, the number of people per household earning a living increased by 25%. Engagement in productive work has also increased by 33.33%, especially among women who are now engaged in weaving, sewing. The monthly average income per household has increased by 13.98% over a six-month interval. People are being attracted to small business from physical labour, farming, and fishing. Business activities at night have also increased.

Appliances usage for entertainment and commercial appliance usage has increased significantly; e.g. TV, computers, energy efficient refrigerators etc. Light and TV enables students to have more study hours and recreational facilities.

The number of shops has increased in all three markets. Average daily sales have also increased from BDT 18,000 (~USD 212,98) to BDT 21,000 (~USD 248,48) (16.6%) over six months. Female participation in education centres has also increased. School operating hours increased from five to six hours, providing increased practising time for the students.

RREL reduces the demand for non-renewable energy through both replacing traditional sources of energy, such as grid electricity and diesel, while introducing renewable energy for new energy demand. This reduces carbon emissions from existing energy practices and prevents emissions arising from new sources.



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3.2 Okra and Pteah Baitong: 8 kWp DC mini-grid in Kbal Damrei (Cambodia)

About Okra

Okra is an Australian technology company backed by Schneider Electric Energy Access, providing an IoT hardware and software solution to enable off-the-shelf solar panels and batteries to be connected together in modular, smart, pay-as-you-go mini-grids. Okra's mission is to achieve reliable, affordable and productive use of electricity for the 1 billion people living off-grid by 2025.



About Pteah Baitong

Pteah Baitong, created by the French NGO "Entrepreneurs du Monde" in 2015, is providing quality energy products and related services to poor households in remote areas in Cambodia through a responsible distribution network to improve the capacities and living conditions of end-users and distributors. Now Pteah Baitong is the only operator of DC mini-grids in Cambodia.

Context

In the period 2018-2019, Okra and Pteah Baitong worked together to deliver the first DC mini-grids in Cambodia to communities in Kbal Damrei, Kampong Spue Province. During this pilot project, 64 households were electrified by multiple nanosized networks that energised over 300 people. The site was chosen due to its distance from the grid and proximity to the operational HQ of Pteah Baitong. The project served as a proof of concept for Okra's technology and Pteah Baitong's deployment of the energy-as-a-service business model.

Site identification and selection

Off-grid communities are often sparsely populated and difficult to access. Kbal Damrei is no exception, hence the grid was likely to never extend to this village. Traditional AC mini-grids rely on a critical population density in order for the economics to work as the cost of cabling increases too much if houses are too far from each other. Okra's technology served as a good fit to serve this community due to its ability to cater to clusters of households and form grids as small as three houses.



Technical design and selection of hardware

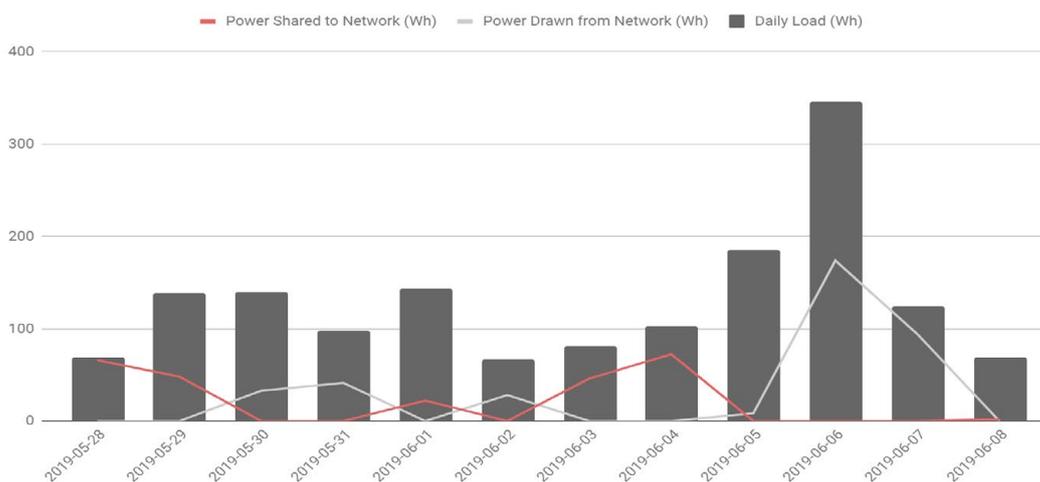
The total generational capacity of the installed networks is 8 kWp. Additionally, Okra's system is a modular and flexible system, meaning capacity and new households can be added to the network at any time, therefore eliminating a lot of the risk associated with sizing networks.



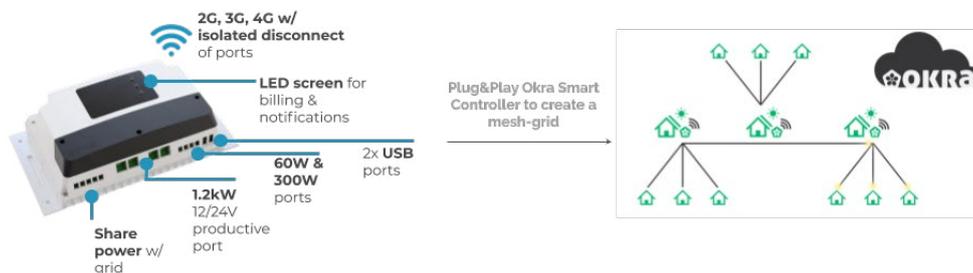
The load analysis consisted of an appliance audit at each household and surveying on expected appliance purchases after installation. This data was collected using an offline survey tool that fed directly into Okra's network planning tool which sizes the solar and storage for each household as well as the optimal path/connections for power-sharing.

The system architecture is fully distributed. This means each household is fitted with the following system configuration:

- Solar panel (varying in size depending on households' load profile, typical size between 150 W-300 W/household. Households using freezers would typically have 2 x 300 W panels)
- Lead-acid battery (varying in capacity, typically between 65 Ah-100 Ah. For households using freezers, 200 Ah of storage was typically installed). Lead-acid batteries were preferred because of economic reasons and their local availability. Integration of Li-ion batteries in future is a possibility
- Okra Controller (acts as a charge controller, PAY-G + IoT Remote Monitoring Device)
- DC outlets to support DC appliances



Households are connected when optimal to do so. Connection decisions are made by algorithms in the network planning software that looks at load profiles of the households, the distance between the households, cable costs and existing connections. Based on this data, the software will suggest when it is optimal to connect houses together or whether it is optimal to leave a household standalone.



The total size of the system installed is 8 kWp of solar with 60 kWh of storage.

By removing the need for AC infrastructure and minimising power loss by connecting distributed systems together, Okra plug & play networks are less than one third the cost of AC mini-grids, while providing reliable power for productive use.

Okra's technology was capable of scaling to meet growing energy demands and able to cater for volatile load profile seen in off-grid communities. Real data from this project shows that loads vary significantly. Okra's technology allows houses to draw power from the network on the days when their load increases, while during the days when their load is lower, power can be shared with other households in the network. This significantly reduces the likelihood of blackouts for individual households and also ensures batteries are not heavily discharged extending individual battery life.

The result is that power-sharing increases reliability and power availability to over 99%. 64% of households drew power from the sharing cable in this period.

The result is that power-sharing increases reliability and power availability to over 99%

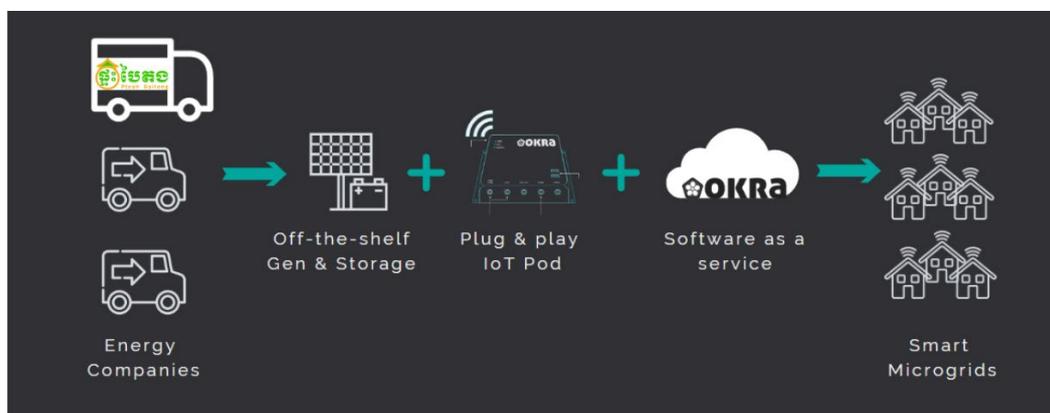
Operations and maintenance

The Okra technology consists of a plug & play smart controller along with a software-as-a-service to remotely monitor and control solar energy mesh networks.

Remote monitoring and mobile payments mean reduced operational costs for distribution partners. Stackable scalability means capacity can be added over time. When selecting the technology, Pteah Baitong, which has already been selling SHS since 2015, was looking for a technology that was low cost and plug & play like SHS but could cope with the load volatility of off-grid communities. On top of that, a local maintenance agent is hired to take care of the mini-grid. The maintenance agent is trained to do small tasks such as panel cleaning, fuse changing, checking the wiring and resetting the controller. The maintenance agent is retained with a monthly payment plus extra payments per task she conducts.

Revenue and financing sources

The business model innovates on two fronts. Firstly, the partnership between Okra and Pteah Baitong where the roles of the distributor/grid operator and the tech provider are disaggregated. The partnership takes on the form in the diagram below:



Pteah Baitong as the energy company and local distribution expert, purchase all the grid infrastructure including panels, batteries and Okra's hardware, the Okra Pod. Okra then licenses software to Pteah Baitong, which autonomously runs the networks and provides all the tools required for Pteah Baitong to simply react to maintenance requests.

Due to the regulatory requirements, Pteah Baitong has rolled out an innovative energy-as-a-service business model that charge the end-user for energy via mobile payments based on the number of battery charges they consume (calculated based on Okra's remote monitoring data). The consumers get a set amount of battery charges in their energy packages. When the set amount is used up, they must charge the battery at a slightly higher price which is not included in their package. This practice encourages consumers to stay aligned with the energy packages and thereby making the revenue prediction and system sizing easier.

Overall for future projects, Okra anticipates an Average Revenue Per User (ARPU) of more than USD 9 per household together with an average monthly cost of OPEX per household of USD 2.5. Combined with the above factors Okra expects an IRR of > 15% over 10 years with a payback period of approximately four years.

With the project being a pilot and therefore high risk, Okra and Pteah Baitong subsidised the cost of the pilot with funding from SNV's (Netherlands Development Organisation) Innovations Against Poverty programme and Agence Française de Développement's (AFD) Good Solar Initiative. The break down of costs is shown in the chart below:

Component	Cost
Distribution (incl. Cables)	USD 2,655
Okra Plug and Play Controllers	USD 4,425
Batteries 60 kWh	USD 4,434
Solar Panels 8 kWp	USD 4,818
Total	~USD 16,320

Billing and metering

All households that have been connected to Okra networks pay a connection fee of USD 35 in addition to a monthly fee based on their selected energy package. The average monthly revenue equals USD 7.1 per household with an average consumption of 200 Wh daily. The energy packages also vary depending on number of hours of usage and choice of appliances. Indicative package prices:

- USD 5 = 24h access to phone charging and lighting
- USD 8 = 24h access to phone charging, lights, fan, TV
- USD 12 = 24h access to phone charging, lights, fan, TV, speaker etc.
- USD 15 = for productive uses like powering freezers



There are three different entry-level packages households can choose from. The higher packages e.g. USD 15 package enable households and productive users to run multiple appliances simultaneously and larger appliances such as TV, egg incubators, freezers and speakers.

The Okra controller is a smart meter. The controller collects data on energy pulled from the load port and sends this to the cloud periodically (every 10 seconds).

Project outcomes

The pilot project has impacted the lives of over 300 people and has since expanded to new locations impacting a further 200 lives. Okra's technology more broadly has since been deployed in pilot projects in both Indonesia and the Philippines. At this stage, it is difficult to assess the immediate impact on the overall GDP per capita in the village, however, there are promising signs of the positive impact on income based on some individual households who are powering productive appliances.

In addition to individual cases, it is possible to look at the energy savings the community is making from using the Okra technology deployed by Pteah Baitong vs the existing solutions that were available to the community. These are detailed below:

Energy Consumption	Okra Monthly Cost	Annual Cost Okra	Diesel Fuel Cost per Month	Annual Battery Replacement	Annual Cost Battery Charging	Annual Savings Okra vs Battery Charging
6 kWh/month	USD 5	USD 60	USD 4.8	USD 90	USD 147.6	USD 87.6
9.6 kWh/month	USD 8	USD 96	USD 7.5	USD 140	USD 230	USD 134

There is also a range of environmental benefits typically seen in projects that transition communities from dirty stopgap solutions such as diesel and kerosene to renewable energy sources such as solar. It is estimated that 15 tonnes of CO₂ emissions have been avoided (this figure is based on the emission factors that are roughly 2 l of diesel per kWh, which is the figure normally associated with poor loading of diesel generators).

There were a lot of lessons learned from the first piloting of this technology that has been fed back to Pteah Baitong from the community, and also from Pteah Baitong as a first-time grid operator using the Okra network:

Lesson	Category	Action taken
The Okra controller is currently limited at 250 W max output, which limits the size of the loads that can be powered by the network and therefore limits how productive the power can be.	Technology	Okra has since redesigned its hardware to deliver 5x the power output in order to be more reliably power productive appliances such as freezers, fridges, ice makers and washing machines
Bill visibility is critical to the community in order for them to consume power responsibly and not have a shock at the end of the month when they receive their bill.	Technology/ Community	Pteah Baitong has taken efforts to work with Okra on setting up an automated SMS service that continually communicates with the community to let them know how much power they have been consuming. From Okra's side, they have redesigned the product to have a screen on new releases in order to be able to display billing to the end-user.
Productive use is king for returns on the project. There is a need for productive users in order to achieve USD 9+ ARPU which will give future project investors their desired return.	Finance	Increasing ARPU means making appliances available to end-users and providing tools and education for them to make more money. Pteah Baitong is partnering with relevant organisations to achieve this.
Productive appliance availability stands to have a huge impact on average household income in these communities	Community	For future projects, productive appliances are being financed to the communities with their repayments being tied to energy payments.

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MLINDA **3.3 Mlinda Foundation: 22.4 kWp solar-powered mini-grid in Sahitoli (India)**

About Mlinda Foundation

Mlinda is an operational NGO that works in ecologically sensitive and highly underdeveloped areas to reduce environmental degradation, by implementing projects that reduce GHG emissions, promote environmentally positive goods and reduce consumption of environmentally negative goods. Mlinda has its Head Office in Paris and its India office in Kolkata.

Context

In 2016, Mlinda, evolved its Rural Electrification Project (REP) from pico-grids to solar-powered mini-grids with a view of providing access to good quality and reliable electricity to households, as well as to meet the aspirational needs for energy along with the basic lighting needs of the community in rural areas.

Site identification and selection

Gumla district of Jharkhand State was chosen as the focus region, as it was amongst the most underdeveloped places in India in terms of access to electricity. Even though the national grid had penetrated majority of the villages in this district, only 32% of the households used it as the primary source of lighting when Mlinda first started working in 2016.



In June 2016, after a rigorous village selection process, which includes household and enterprise surveys to determine the village profile, number of households, appliances used, productive devices present in the village, as well as the current consumption behaviour of the village community, Mlinda selected Sahitoli village as a part of its Phase I of the REP.

Sahitoli is a hilly tribal village in Gumla district, which was an off-grid village until April 2018. The community depended on expensive and polluting fuels for their needs. The light emitted was of poor quality and the farm machinery run on diesel was inefficient in their functioning. As a result of this existing environment, business development in the village was inconceivable.

Technical design and selection of hardware

To meet demand in Sahitoli, a 22.4 kWp solar powered mini-grid was set up to provide 24x7 AC power single phase 230 volts and three phase 415 volts for domestic, productive and commercial loads.

Lead-acid batteries were selected as the energy storage method in the project. The main criteria for the selection of the storage solution were the efficiency of the storage option, cost and maintenance. Two main options (lithium-ion and lead-acid) were considered by Mlinda. Due to limited historical evidence (e.g. fewer mini-grids projects using lithium-ion), Mlinda opted for the safer option of lead-acid gel batteries which required lower upfront cost.

Considerations when choosing the battery in Sahitoli mini-grid

Battery Type	DoD	Estimated Lifetime	Cost	Maintenance
Lead-acid (VRLA Gel)	50%	5 years	INR 14 (~USD 0.20)/Ah	Low
Lithium-ion	80%	10 years	INR 30 (~USD 0.42)/Ah	Low

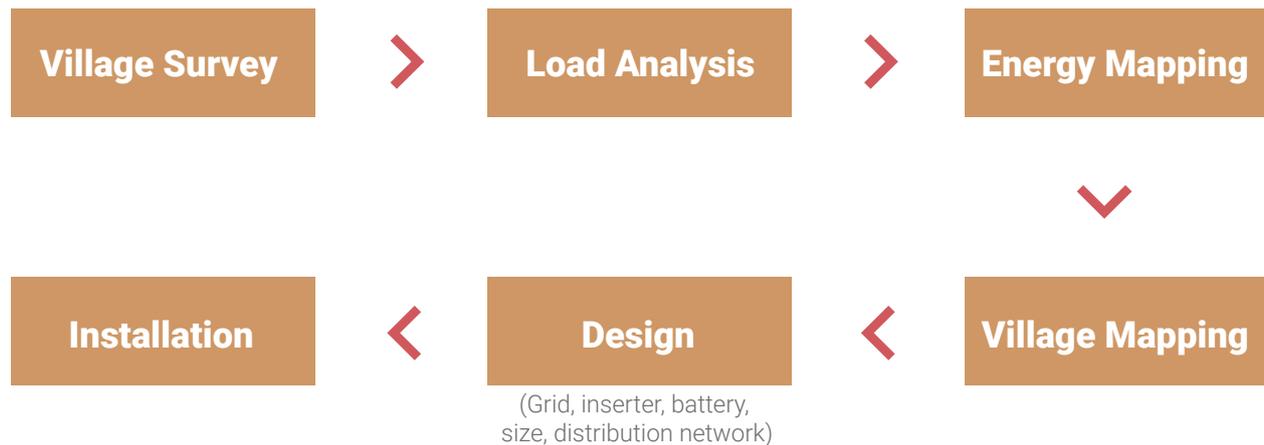
The **capacity of the battery** is calculated after studying the night-time utilisation patterns. A 20% buffer is considered to account for an increase in loads. Consumer behaviour regarding night-time utilisation (obtained from the village survey) is an important factor in determining the battery size. The depth of discharge (DoD) of the battery is set at 50%. A diesel genset of 15 kVA has also been added as a back-up.

Technical Specifications of the Sahitoli mini-grid:

Solar Plant	Battery Details							Charge Controller	Inverter
	kWp	#	Capacity/ battery	Type	System voltage	DoD	Battery Bank		
23.40	36	165 Ah, 12 V	Victron/ Gel	48 V	50%	71.28 kWh	35.64 kWh	150 V / 85 A x 6 nos.	48 V / 5 kVA / 70 A

The grid and network distribution size were decided through **load analysis, energy mapping, village mapping and load scheduling processes**. Mlinda has developed a customised template (see below) to design the grids.

- The **load analysis** involved estimating the total load present in the village from the devices present and the electric capacity of each device in households, agriculture and enterprises.
- **Energy mapping** informed us about the daily energy (kWh) requirement of the village. The main variables analysed were the conversion rates of the loads present, power of each load, number of hours of running each load and the number of loads present. The number of converted loads into hours of running and power requirements gives the total daily requirement of the village for energy.
- **Village mapping** helped in efficiently designing the distribution network. Single phase and three phase loads are charted on the village map to design the distribution network in the most efficient manner. Keeping in mind that the demand for energy grows gradually, the grid is built in a modular manner for incremental growth in instalments of 5 kWp. According to our calculations, 5 kWp is the optimal size of an array wherein additional demand generated by villages will be met while keeping the expansion cost efficient.



Design Process:



Operations and maintenance

The inverter systems are incorporated with a remote monitoring system which facilitates in overseeing the grid performance and taking corrective measures in terms of repair and maintenance. Monitoring is carried out locally or remotely using the open source “Victron Management Portal”. The portal is used to track health of the grid. It shows the real time load, consumption pattern, generation and battery usage. This has proved to be an important information and monitoring tool, as it provides the power requirement of the village (helps to assess demand) and assists in load scheduling.

A high level of lightning protection system has been incorporated in the grid, which includes sophisticated earthing matrix, electrodes, air terminals, lightning arrestors and surge protection devices on both AC and DC sides.

In terms of monetary benefits, the remote monitoring system has led to reduction in OPEX by USD 200 per month. Monitoring systems are already incorporated as part of the inverter software. Additional cost of activation with the help of a data card costs USD 150 per grid per annum. The benefits are in terms of reduction of OPEX by USD 2,400 per grid per annum.



An engineer is shared between the two villages of Narotoli and Sahitoli and one full time operator stays in Sahitoli and works with the community, individual en-

trepreneurs, women's self-help groups, farmer groups, to help them make the transition from diesel and kerosene to clean energy. The salaries of the engineer, operator and land rent form the operating costs of the grids.

Revenue and financing sources

The mini-grid is owned by Mlinda. However, Mlinda's model for mini-grid installation and support to the community is anchored in close ties with the communities. The mini-grid provides single phase and three phase electricity for domestic productive and commercial use. The consumers pay for upfront connection fees and then pay for energy usage through pre-paid meters. There are different day (~USD 0.32/kWh) and night (~USD 0.64/kWh) tariffs. These form the sources of revenue.

Reaching 95% of mini-grid capacity utilisation in 30 months determines the success of the business model. Mlinda grows demand responsibly, ensuring that it is based on low energy. Mlinda also provides loans to farmers to finance energy efficient devices to accelerate uptake. Existing agri-businesses such as rice hullers and wheat mills are converted from diesel to electric. Non existing agri-businesses such as oil expelling and mini cold storage are incubated and livelihood activities such as poultry coops, welding shops,

products for sale. In addition, to diversify the economic activities and the load mix, Mlinda is researching additional non-farm sectors such as health, education and manufacturing sectors.

The mini-grids are financially viable at the village level: the revenues collected are sufficient to cover the operations expenditures incurred at the village level. Mlinda has begun scaling operations to ensure the programme is viable at the regional and national level. Mlinda plans to commission 50 mini-grids by June 2020 with an installed base of over 1.1 MW with four grids installed every quarter between 2018 and 2020.

The project was financed through a mix of grant, debt and equity. The mix of the different sources of finance is grants (55%), debt (25%), and equity (20%).

The costs of design engineering, procurement and construction constitute the CAPEX: USD 5.5 per watt peak for a total of USD 125,000). Field officer and operator salaries constitute the OPEX: USD 280 per month per grid connection fees. Electricity revenues constitute the main sources of revenues for the mini-grids. As mentioned above, there is a different tariff for day and night. It will take seven years for payback. The IRR is 5% in this specific project.

Billing and metering

The connected households are provided with smart pre-paid meters of 5 kVA, which adds transparency to the system. The consumers can monitor and control the way they use electricity, thereby reducing their electricity costs. For Mlinda, the smart pre-paid make for an easy revenue collection process. Single-phase meters cost approximately USD 65 and a three phase meter costs approximately USD 100.

Project outcomes

In Sahitoli 124 houses have connected to the Mlinda mini-grid. Productive loads are increasing month by month. Currently, 19 small pumps, three rice hullers, two wheat mills and two shops in the village use electricity from the mini-grid. An impact assessment study conducted by an external Monitoring Learning and Evaluation en-

Currently 19 small pumps, three rice hullers, two wheat mills and two shops in the village use electricity from the mini-grid

grocery shops, sewing machines are electrified. The micro enterprises use locally grown raw material. Energy transforms raw goods into final

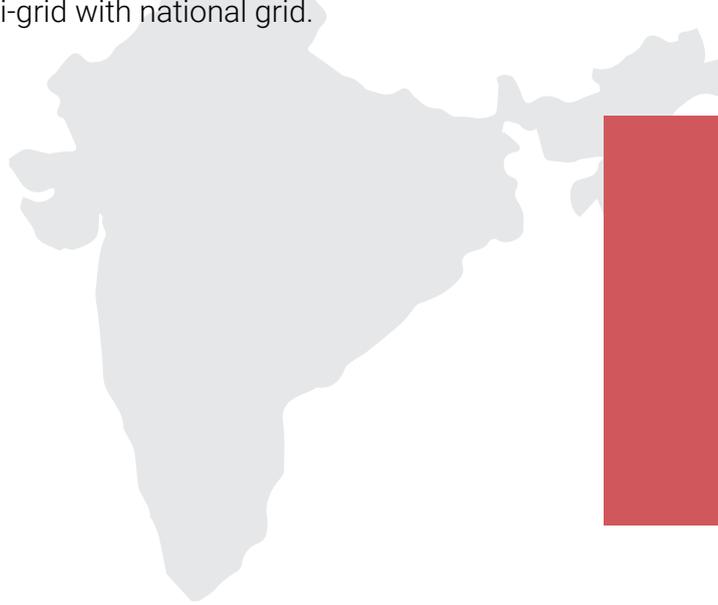
tity in the village found that GDP per capita in the village had increased by 10.6% as against 4.6% increase in similar villages. Household incomes had risen by 21%. GHG emissions had gone down by 48% and energy efficiency of GDP had gone up by 115%.

Agriculture has been the main economic activity in Sahitoli. However, only 23% of the population diversified into the second cropping season, instead leaving their homes and working as daily wage workers whenever they could in order to sustain themselves. This was mainly due to inefficient irrigation practices and weak market linkages. Mlinda decided to work on both these aspects: the mini-grid is extended to the Chandal dam where most of the farmland is located, so that the farmers can use electric pumps to irrigate their lands and through incubating oil expeller units which pass mustard oil, a demand for mustard crop, has been created at the farmers' doorsteps.



Two existing diesel-based rice hullers in Sahitoli were converted to electric and one new entrepreneur has bought an electric rice huller as an additional source of income since the conception of the mini-grid. Sahitoli was part of the Phase 1 and Phase 2 of the project which involved setting up mini-grids in eight villages.

Currently, the REP is in its Phase III, in which a total of 42 villages will be electrified. The total installed capacity in Gumla district under the REP by December 2020 will be 1 MW, connecting a minimum of 4,200 families to the mini-grid electricity; reducing 900 tonnes of GHG emissions per annum and contributing to 10-15% growth in incomes. 18 jobs were created in Sahitoli. These were mainly plant operator, technician, community link worker, rice huller and wheat mill entrepreneurs, pump user groups. By 2023, 125 villages will be powered. The aim is to electrify 250 villages by 2025 and enable other organisations to replicate the model. The developers are in talks with the State DISCOM regarding the interconnection of mini-grid with national grid.



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TARA URJA 3.4 Tara Urja: 31.2 kWp solar-powered mini-grid in Derni (India)

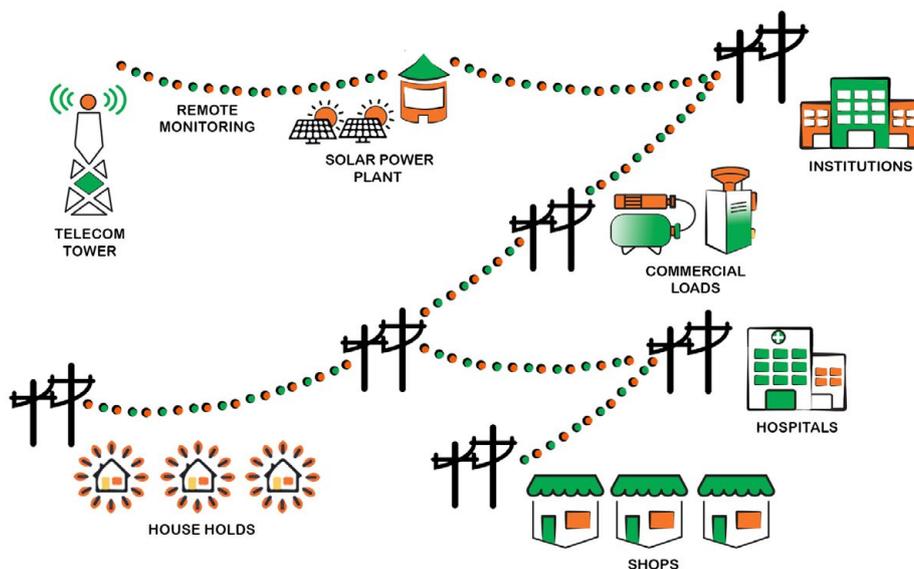
About Tara Urja

Tara Urja, an Indian non-profit organisation, is seeking to promote the economic development and well-being of rural communities by providing them access to clean, affordable, and reliable electricity from solar mini-grids. An entity of the Development Alternatives group, Tara Urja was conceived in 2014 in partnership with the Rockefeller Foundation to help meet rural India's need for reliable electricity. Smart Power India, a subsidiary of The Rockefeller Foundation is supporting Tara Urja along with 11 other mini-grid companies, to electrify rural communities and bring socio-economic development. With support from the Rockefeller Foundation and Smart Power India, Tara Urja has successfully built 22 solar mini-grid plants serving 1,750 connections across the states of Uttar Pradesh and Bihar, impacting over 5,000 lives.



Context

While India has recently witnessed astonishing progress in grid connectivity, the quality of service continues to impede both domestic and commercial users from realising electricity's full developmental potential. Tara Urja was founded with an aim to demonstrate sustainable models of electricity delivery in some of India's most energy-deprived areas specifically targeting the productive uses other than entertaining individual consumers. Together, these provide important local services, drive economic activities, and, critically, generate jobs.



The concomitant increase in electricity demand also enhances the utilisation and viability of Tara Urja's mini-grids. Thus, under this model, all stakeholders benefit: the mini-grid operator, the local workforce, and the community.



A typical Tara Urja mini-grid catchment extends 1-2 km from the plant, allowing it to service 100-140 households, 50-60 shops, and a mix of productive users. A sustainable mini-grid business model depends upon a mix of varied community loads and a few mini-anchors to ensure optimal utilisation of the plant. To date, Tara Urja has established 35 new micro-enterprises across its mini-grid sites including an apparel manufacturing centre, bulk milk chiller, cold storage, digital dispensary, irrigation pump, oil expeller, water treatment unit, smart classes, and others.

Tara Urja aims to reduce customer's energy expenditure by encouraging the take-up of energy-efficient appliances including fans, LED TVs, and refrigerators. To date, more than 30% of customers have moved up the energy ladder and expanded their economic opportunities.

Site identification and selection

Selection of a potential mini-grid site is a multi-tier process which, for Tara Urja, critically relies upon existing market loads to act as mini-anchors. The site selection process entails a detailed assessment of existing as well as predicted loads across varied customer segments, with inputs captured through primary surveys and analysed via a series of site selection tools.

The village of Derni lies in the Saran district of Bihar, two hours' drive from the state capital Patna. The village's 8,000 inhabitants experience erratic grid elec-

A sustainable mini-grid business model depends upon a mix of varied community loads and a few mini-anchors to ensure optimal utilisation of the plant

tricity, with significant voltage fluctuations. Agriculture is the main source of livelihood for most of the households, but incomes are marginal, and over 50% live below the poverty line. In Derni, indeed throughout India, lack of access to safe drinking water comes at a high cost to health and economic development. Moreover, the responsibility of collecting water falls disproportionately on women, who could otherwise be supplementing household income, or improving their education and quality of life. Therefore, Derni was selected as a site to test a water treatment unit (WTU) as a mini-anchor in the mini-grid project.

The optimal paths to livelihood creation are context-specific: a strategy that works in one village may struggle to succeed in another. But the guarantee of high-quality, round-the-clock electricity is a powerful starting proposition, which can be leveraged for productive purposes depending on the available inputs and market linkages, the level of competition, and the aptitudes and motivations of local entrepreneurs. In other words, mini-grids can be a driver of local economic opportunities, livelihoods and well-being.

Technical design and selection of hardware

Tara Urja's single-phase 31.2 kWp solar mini-grid was commissioned in October 2018 in Derni village, Bihar. The plant includes two 48 V/1,000 Ah battery banks (total 96 kWh) of valve-regulated lead-acid cells to provide 24x7 power even as the batteries degrade over time. From the beginning, Tara Urja was confident of its ability to develop mini-anchors to utilise the plant, especially during daytime hours when solar energy is plentiful. The plant's current generation of 60 kWh/day continues to increase as new customers join and the ~100 existing customers' consumption grows.

The mini-grid system at Derni includes a Mini-grid-in-a-Box (MiB), Model U30 solution, fabricated with best-in-class components. This eliminates the need for constructing a control room to house all the power electricals and battery banks. This modular mini-grid solution reduces the cost and time of installation through use of pre-assembled electrical boxes and innovative pipe foundation. In addition, the MiB includes smart-metering functionality to manage power consumption for each consumer, with remote monitoring and advanced analytics to keep full control of plant operations.

Operations and maintenance

The plant and the mini-grid distribution network are remotely monitored with data feeding into a centralised real-time data management system, which is accessible to field agents and the central office. The field agents also have access to a mobile application to manage individual connections and track payments. A team of two trained personnel, including a plant technician

and customer service agent, monitors the daily on-ground operations.

Tara Urja provides its customers with a mobile application capturing all requisite information including customer profile, transactions, service issues and resolutions related to specific customer account. Tara Urja serves its customers with 24x7 power to meet the electricity demand of various rural consumer segments including households, shops and commercial establishments.

Revenue and financing sources

Under the ABC business model, the WTU serves as a mini-anchor to the mini-grid plant at Derni, with connected load of 5.5 kW. This unit has potential to serve around 120 households per day with an output of 2,500 litres. Tara Urja acts as a co-investor in the business, contributing 40-50% of the ~USD 8,000 CAPEX needed to buy and set up the filtration and chilling equipment. The entrepreneur engaged by Tara Urja runs the business as they see fit, fixing prices, marketing, arranging transportation, and hiring labour. The project financing was 100% grant-based by the Rockefeller Foundation.

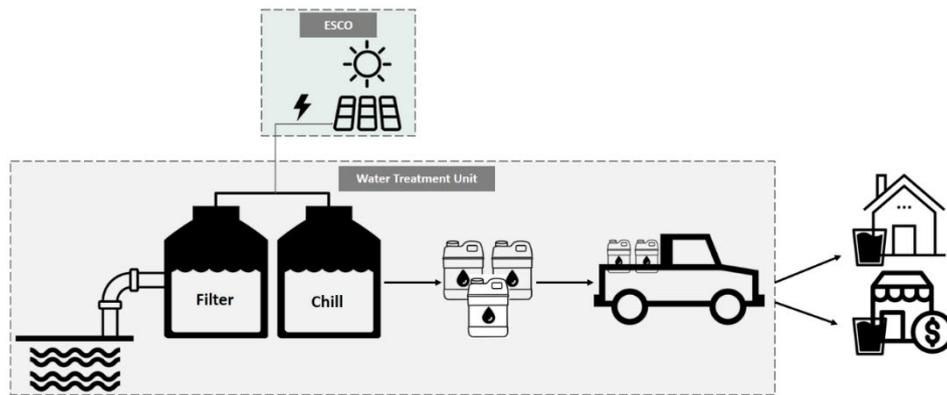
Tara Urja, in association with Smart Power India, has installed 15 Water Treatment Units across its mini-grid sites

WTU as an anchor client in the Derni mini-grid project

Tara Urja, in association with Smart Power India, has installed 15 Water Treatment Units across its mini-grid sites. These use reverse osmosis technology to purify groundwater, before chilling and distributing it to customers in insulated campers.

One WTU is installed at the Derni site where informal field assessments of demand for water

yielded promising results. This, combined with several rounds of experience with WTU business operations and access to the latest water treatment technology, gave Tara Urja the confidence to start Derni's WTU construction even before the plant was operational. Once the mini-grid came online, the WTU was the first customer.



Tara Urja's experience of operating WTUs at multiple sites proved extremely helpful in determining the water demand at Derni site. Tara Urja conducted primary surveys to assess the demand for clean drinking water. The survey results indicated daily demand of more than 160 water jars (20 litres each) met by two water treatment plants operational at a distance of more than 10 km from the site. Ground-water quality testing found Total Dissolved Solids (TDS) to be higher than 300 mg/l, unacceptable for drinking purposes. All this assisted Tara Urja in setting up the WTU and ensured steady demand of minimum 70 water jars from the first day of operation. The operating model of WTU is shown below.

Seasonality of demand has been a critical factor in WTU sales, because, while safe water is needed year-round, demand for chilled water wanes in monsoon and winter months. High operational expenses (~USD 9,000 annually) are a major barrier to the business model, with delivery vehicle rental being the largest contributor (~20-25%); as a result, several WTU operators have acquired their own vehicles.

Billing and metering

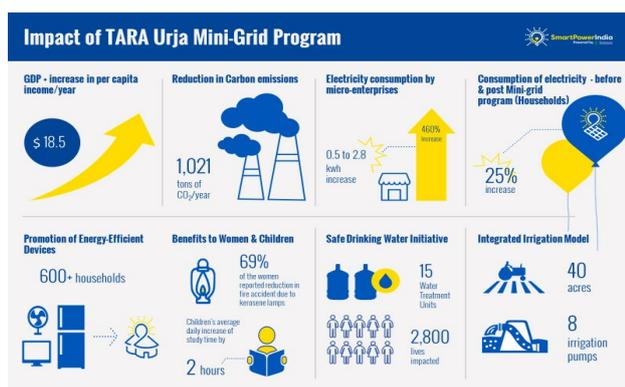
The electricity price is borne by the local entrepreneurs which in the case of Derni, is the WTU entrepreneur. The cost of electricity goes to Tara Urja as the mini-grid provider and is collected through cash collection on site. Along with that, the local entrepreneur also pays a small amount of fee per litre of water processed at the WTU as a refund of the co-investment done by Tara Urja.

The survey results indicated daily demand of more than 160 water jars (20 litres each) met by two water treatment plants

Project outcomes

Each WTU serves a catchment of 500 households while employing three workers to run the plant, make deliveries, and engage with customers. A WTU delivering 100 campers per day generates ~USD 500 additional monthly income for the entrepreneur and creates ~15kWh of daily energy demand (25% of the plant's total supply). Given the ubiquitous need for clean and cold water, the WTU model has significant scaling potential, so it is no surprise that this has been Tara Urja's most replicated micro-enterprise.

With reliable electricity, shopkeepers keep their shops open longer and earn more. Entrepreneurs set up new micro-enterprises to benefit the local economy. Banks, schools and health clinics are able to provide better services. Through these entities, communities have access to better choices and opportunities at their doorstep, including safe drinking water, safe cooking fuel and faster connectivity. Electricity helped to avoid use of harmful kerosene lamps and with improved earnings additional comfort and entertainment resources like fan and TV improve their lives. The mini-grid project helped generating 43 local jobs. On top of that, the mini-grids are grid compatible and therefore, will be easily interconnected by the national grid when it arrives.



Using solar mini-grids in Tara Urja's site has helped to accelerate rural economic growth has had a significant socio-economic impact including improving average per capita income by USD 19; installing 15 electric water treatment plants to provide 2,800 residents with clean drinking water; and reducing 44 tonnes of CO₂ emissions per year. The mini-grid provided electricity to 141 households in total.

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3.5 Clean Power Indonesia: 700 kWp biomass gasifier in Mentawai (Indonesia)

About Clean Power Indonesia

Clean Power Indonesia (CPI) promotes the development of renewable energy and sustainable economy based on the active participation of communities in managing renewable energy sources.

Context

The energy demand in Indonesia has increased significantly with its population growth, urbanisation, and economic development. The growing concern of meeting energy demand, while reducing dependency on fossil fuels, has resulted in an increasing demand for renewable energy. As a country with a rich biomass base, bioenergy is now an important component of Indonesia's energy agenda. However, a crucial problem in bioenergy production is the selection of species that can provide a sustainable supply of feedstock without having an impact on the food security and environment. Clean Power Indonesia found that the characteristics of bamboo, a perennial grass fit as a potential species for a sustainable bioenergy feedstock in Indonesia.

More than 50 million people in rural communities in more than 50,000 villages and 4,000 islands live without access to reliable power. The majority live in the Eastern part of Indonesia and island regencies/provinces like Mentawai in West Sumatra (see map below).

Site identification and selection

Three villages were chosen with respect to their remoteness and difficulties in access to electricity namely Madobag, Saliguma, and Matotonan on the island of Siberut.

CPI sees bamboo as a suitable bioenergy crop in Indonesia, because of its fuel characteristics, as well as the possibility to align its cultivation, production and usage with environmental and developmental agendas. Local availability and familiarity with bamboo, the potential to grow it in and restore degraded lands, rapid carbon sequestration, and the potential to support rural livelihoods are some of the other benefits of the crop.

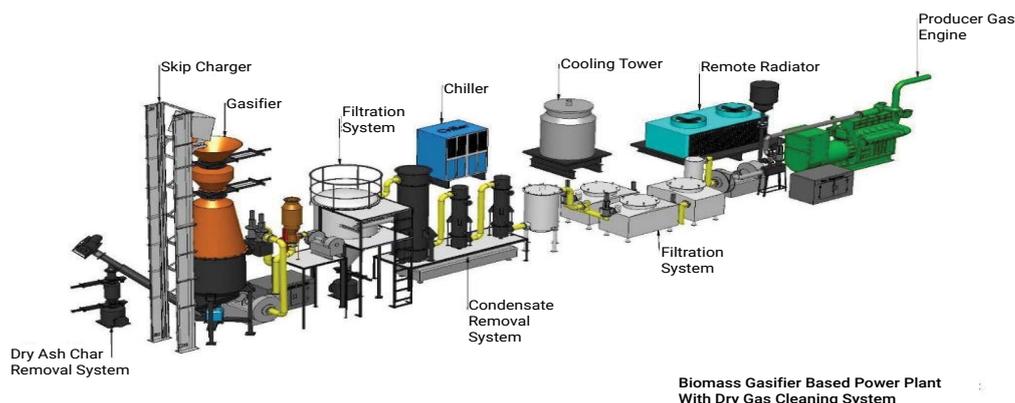


Technical design and selection of hardware



In total, about 6,000 people live in the selected above-mentioned location for mini-grid installation. 1,250 households were identified when the pre-project survey was conducted to assess the total electricity demand. After the survey and analysis, the total demand turned out to be 700 kW.

After looking at all the survey results, technical options and the technology due diligence, it was decided to go for “Down Draft Gasification” technology from Ankur Scientific Energy Technologies Pvt. Ltd. Gasification is conversion of solid hydrocarbonaceous fuels (wood/wood-waste, bamboo, various agricultural residues, wastes etc.) into a combustible gas mixture called producer gas. The gasifier is essentially a chemical reactor where various physical and chemical processes take place and break the solid fuel down into producer gases. An indicative schematic diagram is shown below:



Ankur Scientific biomass gasifiers are well-known for their extremely clean and consistent gas quality. The process of generating an ultra-clean gas with tar and particulate levels of just a few mg. per cubic metre of gas begins in the gasifier itself and along with their state-of-the-art dry gas cooling and cleaning systems. While using woody biomass like bamboo as feedstock in the gasifier, the by-product received from the bottom of the gasifier is charcoal and biochar. The total capacity of the gasifier system chosen for this project was 700 kW which consists of 6 units of 100 kW system and two units of 50 kW system.

The local population needs this electricity not only for residential lighting but also for commercial and productive uses. The village of Saliguma, which is located in the bay area, will construct new cold storage and seaweed processing facility. The village of Madobag will scale up their sago processing facility and expand into other agroforestry products. The village of Matotonan that is located near national park of Siberut will use the newly built electricity. The three villages will become reference for the other 75,000 villages all over the country on how to build self-sustaining renewable energy mini-grids to power their industries.



Operations and maintenance

A long-term service agreement has been signed with the technology provider, Ankur Scientific, which gives them the responsibility of troubleshooting and maintenance of the mini-grids with their warranty on equipment. The monitoring and tracking



of the mini-grids are done by the state-owned utility, PLN. The maintenance work is undertaken by the locals.

Revenue and financing sources

The project was funded by the grant from the Millennium Challenge Corporation from the USA (96%), the rest from in kind contribution by Clean Power Indonesia with its local government partner.

The total cost of this mini-grid project included eight units of distributed power generation, electricity grid, electrical installation in 1,250 homes, bamboo forest, commissioning and training. The total capital cost was accounted for USD 12.5 million whereas the operational cost after the commissioning has turned out to be USD 0.07/kWh.

The project's business model creates a synergy between the community, the state-owned utility company (PLN) and Clean Power Indonesia. The project provides turn-key electrical generation and distribution to PLN for all electricity users in the villages. PLN who owns the mini-grid, purchases all electricity generated by the project under a 20-year Power Purchase Agreement (PPA) for a regulated price of USD 0.15 per kWh. PLN then sells the electricity purchased from the project to the community at its National Electricity Rate (TDL) rate of 415 IDR/kWh (~USD 0.031 cents) as of January 9 2017.

The project will in turn purchase all bamboo feedstock produced by the villages under a 20-year Feedstock Supply Agreement for a linked

price equal to 20% of PLN's electricity tariff paid to the project.

This heavily subsidised tariff allows the local community to realise excess income from supplying bamboo feedstock to the project after paying for the electricity from PLN (see scheme on the left column).

Project outcomes

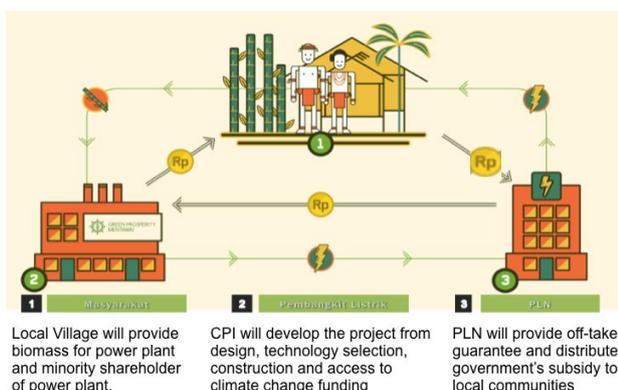


1,250 households directly benefitted from the project. The economic situation of the villages stabilises and grows with the installation of cold storage units, improvements in

agroforestry, and increased electricity access for commercial and productive uses.

As a part of the economic prosperity locally, around 450 jobs were created in the villages roughly meaning 150 jobs in each. The sustainability of the mini-grids is high. Each village will realise about 3,000 tonnes CO₂/year from emission avoidance and carbon sequestration due to new bamboo planting.

As part of the future expansion of the mini-grids, the project is going to spread over to other villages in Mentawai (totaling 43 villages), to other province in the eastern part of Indonesia and to the neighbouring island of Nias. Total capacity that will be developed in the next five years is about 50 MW, all using biomass gasification and bamboo as source of local biomass.



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3.6 Mandalay Yoma Energy: 55 kWp solar-powered mini-grid in Dee Doke South (Myanmar)

About Mandalay Yoma Energy

Mandalay Yoma Energy Co. Ltd. (MYE) delivers renewable energy solutions in Myanmar. MYE provides all services from advice to design, installation, maintenance and financing. From home and commercial installations, to rural electrification and energy consulting, MYE contributes to electrifying Myanmar in the most responsible way - for both its environment and its future generations. MYE works closely with the Government of Myanmar, international NGOs and the local communities from the perspective of bringing economic development to the remote places of Myanmar, and to create a real change that benefits now to the lives of the people.

Context



MYE is the developer of the Dee Doke South project along with other stakeholders namely the Village Electrification Committee (VEC) who are chosen among the villagers, as well as Union and Township Department of Rural Development (DRD), which is the branch of the national government in charge of coordinating rural projects. The project is situated in Meikhtila Township, Mandalay Region, Myanmar. The project running since November 2018 and to be followed by Mandalay Yoma Energy for the next 15 years.



Site identification and selection



Dee Doke village is located in the dry zone of Myanmar, in a really remote area, where the national grid was not expected for a long time. In the wake of the National Electrification Plan (NEP) targeting an access to electricity for everyone in Myanmar by 2030, MYE works hand in hand with the Department of Rural Development (DRD) to boost rural electrification and even more now with the recent partnership with Engie, one of the world's biggest energy utility companies. Side-by-side with

the DRD and local stakeholders, MYE, drawing on a strong solar expertise, conducted feasibility studies to implement a mini-grid system.

The energy demand in the Dee Doke village is on average 688 kWh per month, including the households, the school, the monastery and the library. In addition, the mini-grid system enabled a telecom tower in the area to switch to solar-powered electricity instead of diesel with a monthly demand of 1,340 kWh. On the whole, the electricity demand exceeds 2,000 kWh per month.



Technical design and selection of hardware

For the engineering design, MYE used the information from Dee Doke's current usage and intended usage along with estimated changes in consumption patterns with the availability of electricity. Based on these data, MYE analysed different scenarios with changing fixed and operating costs. With no availability of mini-hydro and wind energy being limited in the region, MYE looked at Solar PV along with batteries.

Though coupling with a diesel generator seemed a good option, the recurring cost of diesel, noise and pollution are major factors that made us choose a second back-up. The back-up system is thus be composed of both diesel generator and Li-ion batteries, which will allow to store the energy produced by the PV. The system has Solar PV generation as the primary source of energy coupled with Li-ion batteries along with diesel genset as backup source.

MYE designed the solar system to meet the current demand of the village and the EdotCo telecom tower of the area, but also anticipated the consumption's growth from households and productive users for the system to be viable. During the field visits, MYE not only focused on understanding what electrical appliances are in use by the different types of consumers, but also aimed at understanding the planned purchases for appliances and goods, in order to anticipate energy demand.

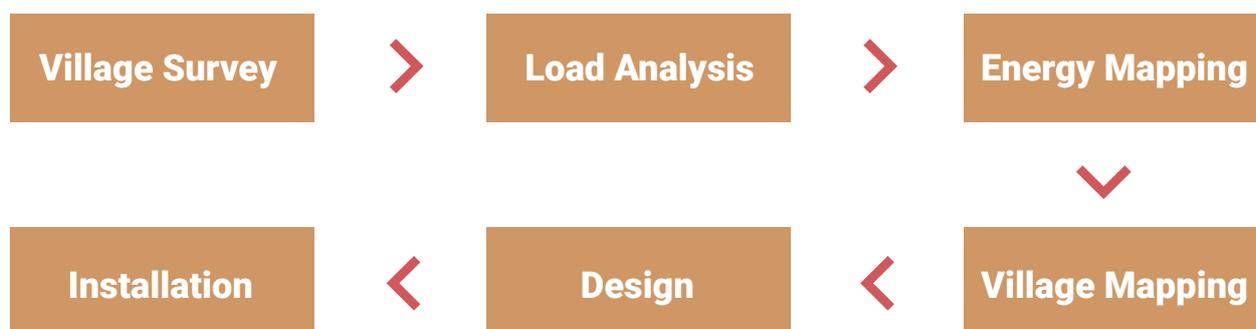
To meet the village demand, a 55 kWp solar-powered mini-grid was set up to provide 24/7 AC power covering all needs of the village. The mini-grid provides single phase and three phase electricity for both domestic and productive use.

Technical Specifications of the Dee Doke South mini-grid

System Details		
Size of PV	55	kWp
Hybrid inverter	50	kW
Battery size	160	kWh
Genset size	60	kVA
Genset running hours per year	400	hours/year
Length of distribution line	4	km

Li-ion batteries were selected given the length of the project and convenience of the batteries with more life cycles meeting the required IEC specifications with 90% DoD (80% usable capacity after 6,000 cycles), their compactness, and very minimum maintenance. All parameters of system will be logged using EMS system to allow easy tracking and reporting of the system health.

Design process



The total time of the project was nine months with three months of in-depth surveys, design and planning, three months of approvals and licensing and procurement and three months of construction.

The whole village engagement process is described below:



Operations and maintenance

The inverter systems are also incorporated with a remote monitoring system, which facilitates checking the plant performance and analysing consumption, as well as taking concrete measures in terms of repair and maintenance if necessary. Monitoring is carried out locally or remotely using an online portal developed by MYE in cooperation with engineers from India and China.

The data available and openly accessible are the real time load, consumption pattern, generation and battery usage as well as daily information on the con-

sumption for each villager. In addition, this powerful tool enables us to reduce drastically the cost of the OPEX which is limited to diesel usage, any maintenance, panels washing (200-400 USD a month).

A regular follow-up is made with the VEC and operators on site concerning the maintenance, the income as well as potential need for technical or financial support for productive uses of energy.



Revenue and financing sources

The mini-grid is owned and managed by MYE. However, a public-private partnership has been adopted with significant subsidy co-financing for the project. MYE works closely with the VEC under the guidance of Union and Township DRD, and provides a turnkey solution leading to a well-functioning mini-grid project. MYE invests in the project within limits set by DRD; builds, co-owns and operates the system until recovery of investment, trains VEC operators and transfers the system to the VEC and DRD.

The total project budget is USD 200,000-250,000. The project was financed through a mix of grant, debt and equity. The mix is as follow:

- **Grant:** 60% (NEP subsidy via the DRD)
- **Debt:** Mandalay Yoma Energy
- **Equity:** Cash from the households and productive users

The tariff for 1 kWh of electricity for the end-users is MMK 400 (~USD 0.26). This represents the source of revenue for MYE. Some productive users with an outstanding consumption benefit from a specific discount.

In addition to maintaining the system, the operator on site, paid by MYE, is in charge of collecting the money from the villagers and of topping-up.

For the villagers, the payback will be between 1-2 years and for MYE, it will take 5-7 years. The project viability is also between 5-7 years based on projected capacity utilisation.

Billing and metering

The consumption is monitored thanks to meters installed for each household, facilities and productive users. The consumers pay upfront connection fees, pay for the installation of the meter and for the upgrade of their meter if necessary. Then they pay for energy usage through their pre-paid meters.

Project outcomes

The beneficiaries of the mini-grid are not only the households (126 connected households representing 724 persons, 72% of the total population) but also the community in general through the school (160 students), the monastery, the li-

brary. People can now use a much larger panel of home appliances such as rice cookers, frying pans, fans, light bulbs and also TV, refrigerator and can simply charge their phones.

In addition, productive energy users are fully benefiting from the switch to solar-powered electricity since this transition is cost-effective (direct savings), there is no more noise pollution (caused by the diesel engine) and they do not need to refill their diesel by going to Meikhtila, the closest town. Four productive energy users are currently running businesses thanks to the electricity from the mini-grid (rice huller, irrigation and carpentry, grinding machine, welding) and potential new businesses are on the way (oil press, irrigation system, stone crushing machine, etc.). Services like grocery shops are also positively impacted since they can now be opened during the evening as well.



The project created around 20 short-term jobs and three long-term jobs (operator, diesel refueling and maintenance, pre-paid metering) and more are expected with the possibilities enabled by solar power.

The Dee Doke's project helps reducing GHG emissions by saving 22.5 tonnes of CO₂ emissions, 830 kg of NO_x emissions and 2 kg of SO₂ emissions annually. The business model used is perfectly replicable and has already been implemented in eight other villages. MYE is now scaling up the business with a target of 40 new mini-grids in 2019/2020 and aims to reach 500 mini-grids within 3-5 years. On the current sites, the annual savings reached 1,142 tonnes of CO₂ emissions, 8.5 tonnes of NO_x emissions and 102 kg of SO₂ emissions.

The currently running mini-grids are all located in the dry zone but the scaling-up targets the whole country. The demand is indeed huge since an estimated 58% of Myanmar's population, approximately 30 million people, are not connected to the main power grid.

After the implementation of this project, MYE noticed how important it is to involve the villagers and the VEC as much as possible. Since they have the best understanding of the processes and ways of thinking and doing in the village, they are of course a fundamental stakeholder. Since they live on site, it is obviously very valuable to train them so that they are almost fully autonomous.

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3.7 Yoma Micro Power: 31.2 kWp solar-powered mini-grid in Sagaing Region (Myanmar)

About Yoma Micro Power

Yoma Micro Power (YMP) builds, owns, operates and maintains small-scale power plants and mini-grids for off-grid customers and rooftop grid-tied solar systems for commercial and industrial customers. The off-grid systems provide electricity to telecommunication towers and the surrounding communities including households, schools, monasteries, clinics, businesses etc. The grid-tied rooftop systems reduce commercial and industrial (C&I) customers' electricity bill with sustainable and green electricity from solar. YMP's mission is to build a better Myanmar for its people by harnessing renewable energy resources.



Context

More than 60% of Myanmar's population do not have access to electricity. The World Bank estimates that Myanmar needs to invest USD 2 billion per year for the next 10 years to be able to achieve its goal of 100% electrification by 2030. YMP was set up to bring in foreign direct investment into Myanmar to build solar power plants and LV distribution networks (mini-grids) in off-grid areas. YMP successfully implemented a 10-plant pilot project in Sagaing Region of Myanmar in 2017 to provide electricity access to rural villages and telecommunication towers before closing USD 28 million in funding in 2018 to build its next phase of power plants with a goal to build 250 power plants within 2019.

The solar mini-grid power plant was the very first plant that YMP commissioned in September 2017. It provided power to a telecom tower, which was using a diesel generator for power supply and to rural households, who had been using solar home systems and a monastery-run diesel mini-grid, but who aspired to move up to a higher tier service capable of running productive appliances in addition to lighting.

By providing solar generated power to the tower, YMP resolved complaints from neighbours about noise from diesel generators running 16-18 hours per day. At the same time, YMP reduced operational costs for the tower company and reduced emissions of greenhouse gases. At the same time, with standard AC electricity from YMP's mini-grid, households could now use rice cookers, irons, refrigerators and other productive appliances that they were unable to use with their solar home systems or with the previous diesel mini-grid.

Site identification and selection

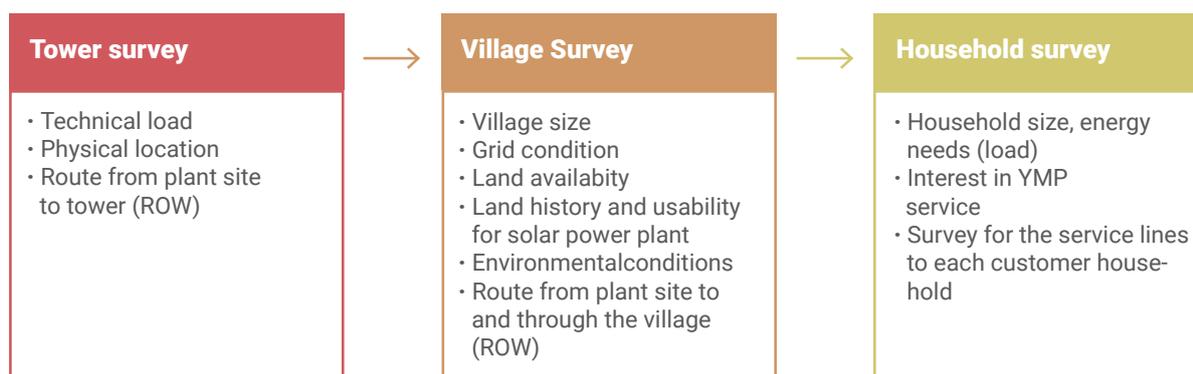
To avoid overlap with the government's National Electrification Plan (NEP), YMP also coordinates with the regional governments and the government-operated

electricity supply enterprises in choosing its locations. This Saint Gyi Village in Wetlet Township of Sagaing Region, Myanmar is an off-grid village by the Ayeyarwaddy River, which is known locally as the Queen River of Myanmar. The village is more than 6 km from the nearest national grid. It has a population of 270 households and with a rural health centre (clinic), a police station and 13 monasteries and ancient pagodas.

For this project, YMP first communicated with the village head and conducted an initial survey of the village to determine the current status of the village's energy needs and their future plans, village size, commercial and business needs for energy besides households. As it turned out, this village was operating a couple of diesel generators that were used to provide electricity for three hours a day in the evening. Additionally, there were rice mills, oil mills and other small machines like water pumps that were being run by individually owned diesel generators that were both expensive and polluting.

After the preliminary survey, YMP performed a more detailed survey to determine each household's needs and desire to connect to a mini-grid built by YMP. With sufficient interest from the villagers, YMP decided to build its solar hybrid mini-grid.

YMP conducted multiple surveys as follows:



Technical design and selection of hardware

The pilot project is a solar-powered hybrid mini-grid in Sagaing Region with batteries and diesel back-up. YMP offers electricity to rural businesses and communities.

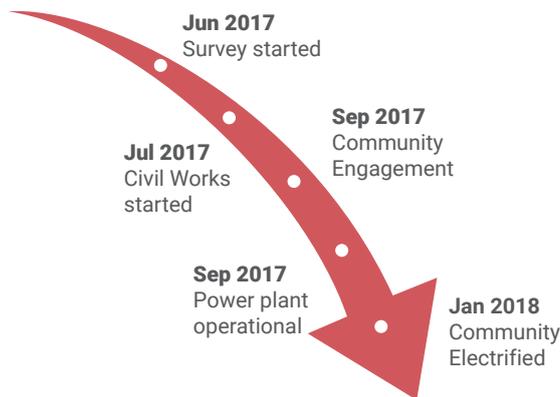
Based on the telecom load and household loads YMP determined to build a power plant with 31.2 kWp of solar, 4,000 Ah VRLA (Valve Regulated Lead-Acid) battery at 48V (192 kWh) and a 20kVA diesel generator for backup, that provides 230 V single-phase AC or 415 V three-phase AC energy depending on the customer's needs. Due to the stringent uptime requirement of 99.95% for telecom towers, YMP designed power plants include a diesel generator for backup, although under normal circumstances the daily power needs are serviced with solar and the battery.

YMP utilises the inherent modular nature of solar power plants whereby the capacity of the power plant can be increased as the demand increases. So, the sizing of the plant was done to achieve near 100% plant utilisation. The choice

of VRLA batteries was driven by the need for zero maintenance and lower cost requirements. Due to lack of skilled labour in the village, all the equipment and systems are designed or chosen to be low or zero maintenance. Since it was a pilot project with an uncertain outcome, it was also necessary to keep the initial cost as low as possible.

As for design tools, YMP utilised a combination of HOMER, PVSyst and home-grown tools to determine the appropriate sizing of PV, batteries, inverters, the diesel generator etc. Component selection was based on YMP's quality requirements and pricing considerations.

Implementation Timeline



YMP utilised aerial bunched cables instead of bare conductors as they are safer, albeit several times more expensive than bare conductors of equivalent current carrying capacity. The cables may also prevent unauthorised tapping of electricity through “hooking”.

YMP also utilised more efficient LED streetlights with IP65 ingress protection instead of compact fluorescent lamp streetlights used across Myanmar whether connected to the national grid or mini-grids.

Operations and maintenance

YMP designed the power plant and mini-grid to be unmanned and remotely monitored, to reduce OPEX costs. YMP's approach is to build power plants and mini-grids in a cluster concept. Each power plant employs a local caretaker for cleaning and basic maintenance functions, while each cluster is covered by an O&M engineer, who may be responsible for maintaining 4-5 plants. YMP built this mini-grid to be grid-ready and met or exceeded the national grid code.

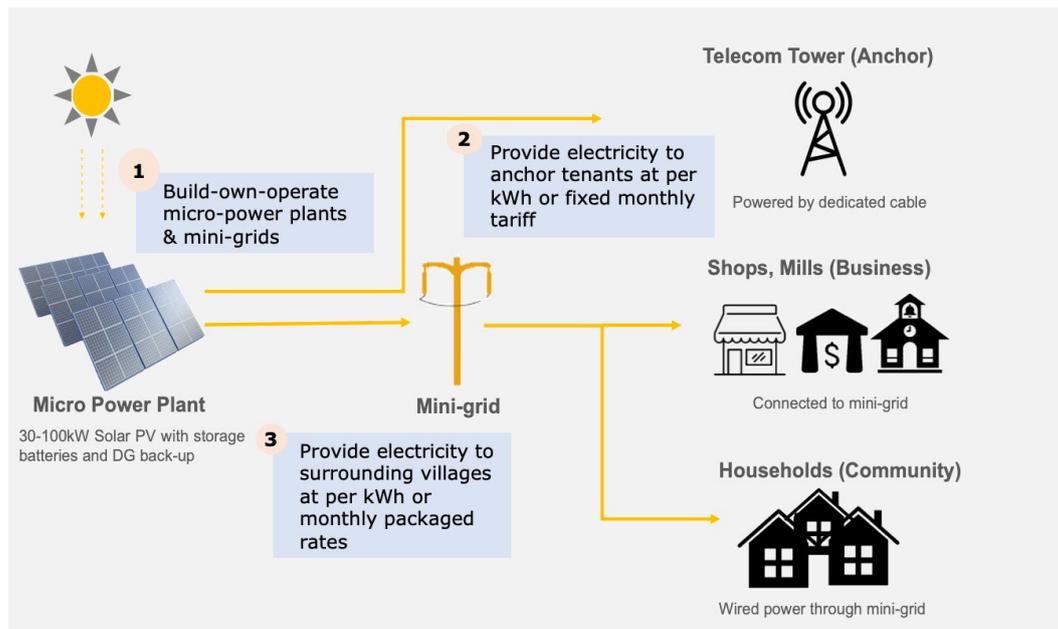
Revenue and financing sources

The project is 100% equity funded with the shareholders of this project being Yoma Group, IFC (World Bank Group), Norfund, and Mr. Alakesh Chetia.

YMP utilised the ABC (Anchor-Businesses-Communities) business model for this project, as shown below. In this model, YMP worked with three different types of customers, starting with off-grid telecom towers as an anchor customer and surrounding rural businesses and communities. YMP made the entire investment necessary for the project. Customers simply pay for electricity they consume besides a one-time connection and installation fee.

YMP's goal with this project was to build commercially sustainable mini-grids without grants or subsidies, so that scale may be achieved for larger impact. Throughout the world, mini-grids have been built with grants and subsidies, limiting their ability to scale. With solar based mini-grid technology becoming fairly standard, business model innovation was a key objective of this project.

YMP successfully demonstrated the viability of building commercially sustainable mini-grids with this project while delivering 100% uptime to its telecom customers, rural businesses and households. As a result, the telecom customer signed a long-term PPA with YMP to receive similar services at hundreds of their off-grid towers. Following that, YMP closed equity and debt financing for USD 28 million (USD 22 million equity and 6 million debt) in April 2018. The breakeven period for a YMP power plant is about seven years, while it will take about 15 years to achieve the returns expected by its investors.



YMP is providing power to the household with various kinds of fixed and metered packages. For the basic income households, YMP provides fixed amount of power for a fixed price. These households can choose from multiple fixed amount packages based on the number of lights, TV and mobile charging usage. Small businesses like mills, shops and other households can opt for 24/7 power supply at a kWh rate that varies for daytime and night-time.

The tariffs YMP charges are based on time of use, at MMK 300 (~USD 0.20) per kWh in daytime and MMK 900 (~USD 0.60) per kWh at night-time. At the minimum consumption level for a household, YMP sees a demand of under 2 kWh per month. The telecom towers are provided with 24/7 electricity service, while the community has various options that include fixed hours for fixed loads for a fixed monthly price to pre-paid metered 24/7 service where their consumption determines their monthly spend.



Billing and metering

For fixed load for fixed hours service packages YMP utilised smart load limiters that cost about USD 20 per household, while for 24/7 service packages YMP utilised pre-paid meters that cost about USD 40 per household.

Rural businesses and households are able to pay for their electricity services through Wave Money – a leading digital money platform in Myanmar. They are able to query their balance and top up using Wave Money at any time.

Project outcomes

Initially, YMP built the mini-grid to cover only about 20% of the households in the village (under 2 km in length) as the villagers were unsure about the quality and level of service that YMP could provide. After the demonstration period, almost the entire village has signed up to receive YMP electricity services and YMP is in the process of expanding the power plant and the mini-grid to cover the entire village.



Today YMP is operating about 90 power plants while on track to build 250 within 2019. YMP has hired and trained more than 50 engineers to maintain its target 250 power plants, besides hiring a caretaker for every plant, thus creating both skilled and unskilled jobs in rural areas of Myanmar. In the pilot, YMP created 20 permanent and 100 construction jobs. Currently, YMP is creating 330 permanent and 2,500 construction in the roll out of further projects. In the future, the aim is to create 2,200 permanent and 20,000 construction jobs.

An off-grid telecom tower in Myanmar uses about 800 litres of diesel per month, which translates to about 125,000,000 litres of diesel burned per year by all the off-grid towers in Myanmar. YMP's solution leads to about 22.5 tonnes CO₂ estimated annual carbon abatement per tower, which will translate to an annual reduction of 5,625 tonnes of CO₂ when YMP's 250 power plants are operational.

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3.8 Gham Power: 52 kW solar-powered mini-grids in Khotang (Nepal)

About Gham Power

Gham Power Nepal is the capacity of lead technology provider and equity investor in the project; Ncell (telecommunications provider) as anchor tenant; financial assistance came from Asian Development Bank (ADB), GSM Association (GSMA) and DOEN Stichting Foundation; local communities in Khotang are the direct beneficiaries and equity investors.

Context

Nepal witnessed its worst energy crisis in the decade preceding 2014. During drier seasons of the year, power cuts averaged at around 16 hours a day. Rural areas faced the greatest plight because of substantially low rate of electrification and the slow progress of grid extensions in remote locations due to rough terrains.

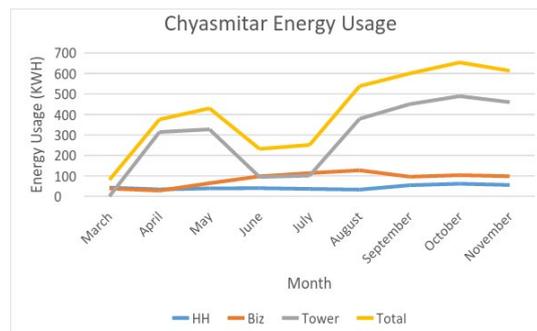
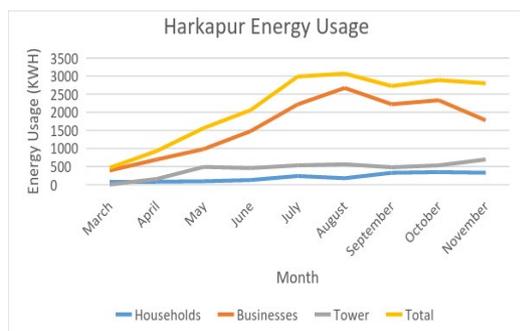
Realising that decentralised off-grid energy solutions were still not adapted in the local context of Nepal, Gham Power teamed up with donors and financiers to install mini-mini-grids in the eastern hilly region of Nepal, where electrification rate remained minimal. Since this was the first mini-grid solar PV hybrid mini-grid project in Nepal, it provided Gham with an opportunity to: generate early success stories and a viable business case for such mini-grids in rural Nepal for private financiers, break the acceptance hurdle that surrounded solar technology at the time for rural settlers, as well as test the right financing mix and business model for 20 similar projects that Gham aims to install before December 2022.



Site identification and selection

Harkapur and Chyasmitar, two rural communities in Khotang district with a population of 400 and 250 respectively, were selected based on the potential to prove the cases mentioned earlier. These places were also selected because of their close proximity to Kathmandu Valley where Gham is based. Also, the two communities are three hours' drive away from each other. This proximity expedited the project implementation and other O&M services that ensued later.

Based on the pre-project survey conducted, the total monthly electricity demand for Harkapur and Chyasmitar can be seen in the graphs. The annual electricity demand for Chyasmitar is 5,400 kWh and for Harkapur is 24,000 kWh respectively.



An initial pre-feasibility survey was conducted to select optimal locations for mini-grid installation. Proximity to Gham Power’s headquarters, ease of transporting procured equipment, reliable community partners, presence of productive end use equipment etc. was accounted for when selecting the sites. After initial agreements with the selected communities in Harkapur and Chyasmitar, a load analysis was conducted. Each household was geo-tagged (see figure below) and follow-up questionnaires sought to manually calculate the load requirements of each household. Geo-locating households also helped when designing transmission lines.

Technical design and selection of hardware

Sun path analysis and solar altitudes were analysed to ensure that installation sites received the maximum sunshine hours in a given year. A seasonality chart was drawn to ensure that the mini-grid energy production could meet energy requirements throughout the year while ensuring a high enough utilisation rate to sustain the mini-grid financially. Computer simulations using HOMER software were conducted to validate this.



Installation components were then procured balancing the quality of the components within cost constraints of the project. As such, all component suppliers had international expertise and were well-renowned for quality. Lead-acid batteries were the preferred energy storage options; initial in-house analysis found that night-time consumption of the communities was substantially lower and as such, battery costs were minimised to lower the total project cost.

Technical Specifications:

Solar Plant	Battery Details							Charge Controller	Inverter
	kWp	#	Capacity/ battery	Type	System voltage	DoD	Battery Bank		
52	168	7000 Ah, 12 V	Lead-acid Exide	48 V	50%	336 kWh	201.6 kWh	150 V / 60 A x 17 nos.	48 V / 8 kVA / 100 A x 7 nos.

Operations and maintenance

In 2015, upon installation of the two mini-grids, totaling 52 kWp that powered these two communities, operators were hired from among the communities and trained. This coupled with smart metering technologies enabled Gham Power to track maintenance issues and expedite services when required.



Connected households have been provided with pre-paid smart meters to track energy usage. A pre-set energy ceiling has been levied on all households and mobile money top-ups increase households' capacity to consume more electricity after the quotas have expired.

Regarding tracking and maintenance issues, the system is operated through remote diagnostics and a Schneider control panel that feeds data using internet connection. The calculations of the cost-savings of using these smart diagnostic measures are yet to be undertaken.

Revenue and financing sources

The mini-grids, which were designed to meet the energy needs of 83 households and 32 businesses, are owned by the Special Purpose Vehicle (SPV) which consists of representatives of all key stakeholders along with representatives from the local government. Gham Power also partly owns the mini-grid as a board member of SPV. Gham Power is also the primary point of contact for the SPV if maintenance issues arise.

The primary beneficiaries ranked in the order of energy usage are: businesses (72%), Base Transceiver Station (BTS) towers that were installed at both sites by anchor tenants (19%) and households (9%).

After 10 years of operation, the ownership of the mini-grid will be transferred back to the local community. The project is financed through financial assistance from ADB, GSMA, and DOEN Foundation, equity investments from the community and Gham Power and debt from NMB bank.

Total project cost for both the mini-grids in Harkapur and Chyasmitar is around USD 239,000. This figure represents the capital expenditure of the project. The targeted IRR of the project for private financiers was 10% over a 10-year period.

Billing and metering

Specific packages that were designed as per the usage cost of Light Bulbs (LB), Refrigerator (R), Charging Mobile Phones (CMP), Televisions (T) were provided to end-users. –

The monthly costs of these packages are:

- NPR 250 (~USD 2.20) for 3LB and CMP
- NPR 500 (~USD 4.40) for 3LB, CMP and 1T

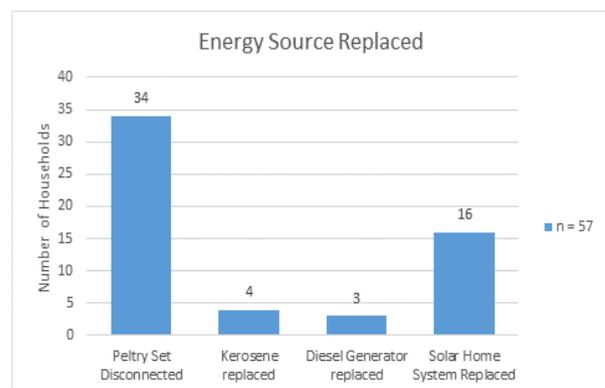
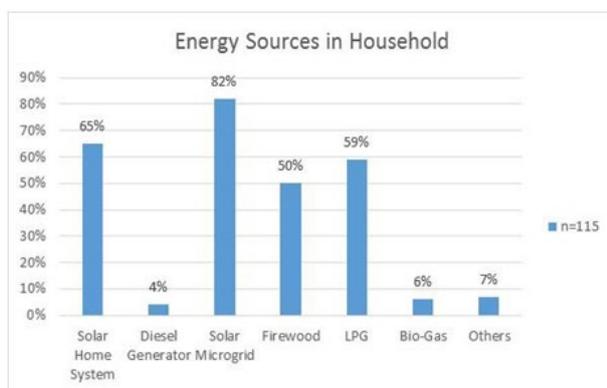
- NPR 3,000 (~USD 26.41) for 3LB, CMP, 1T and 1R
- NPR 3,000 - NPR 5,000 (~USD 26.41 - ~USD 44.02) for businesses depending upon usage

Energy tariffs can be remotely paid via mobile money applications and this substantially reduces the cost for end-beneficiaries. The practice is successful given the fact that the community receives services as per their choices and the payments and repayments become easier. With the convenience of the service, the rate of willingness to pay for the electricity is also quite high.

Project outcomes

At Harkapur, which is de-facto trade center for the wider community, productive end use devices have been introduced en masse. Grinding mills and smaller cold storage facilities were adopted and this decreased the harvest loss for the wider region. Modern technological solutions like computers and printing machines have been commercialised by businesses in the region for income generation.

This has displaced traditional practices such as manual printing. Kerosene, Liquefied Petroleum Gas (LPG) and firewood accounted for the majority of energy supply before the mini-grid was installed. Upon installation, 36% of the people reported that the mini-grid, was their only source of energy, while 82% reported the mini-grid as their primary source of energy. A survey conducted after a year of installation found that 40% of beneficiaries use electricity for longer periods of time than before. Combined, this helped displace 35.7 tonnes of CO₂ at Harkapur and 15.3 tonnes of CO₂ at Chyasmitar per year.



To ensure financial sustainability of the project, a telecommunications partner (anchor tenant in this case) agreed to install BTS towers at both the project sites. This increased the cumulative mobile coverage in these communities from 84% to 96% and adoption of smartphones has seen similar upward trend (40% points increase). Internet facilities were introduced for the first time at both sites due to this. Another partner, a mobile money vendor lent support by agreeing to share its mobile application for repayment





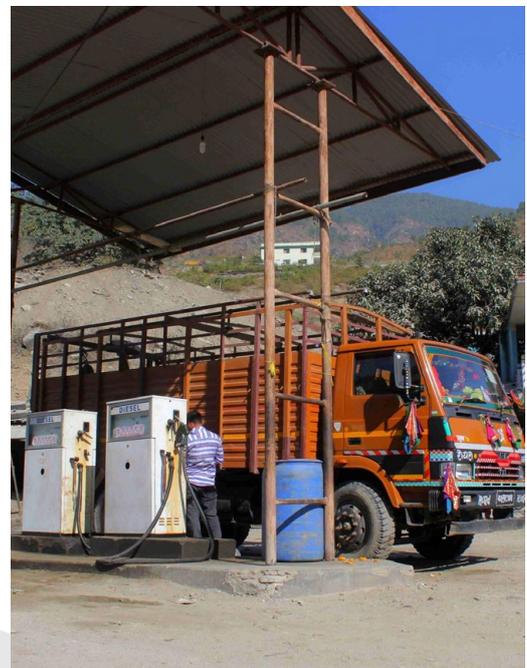
collection. This has increased financial access for some beneficiaries who were previously unbanked.

Direct job creation from the mini-grid includes operators and staff for the BTS tower, as well as the mini-grid itself. Additionally, entrepreneurship development classes hosted to train locals on the productive end use of electricity helped the community, which has seen a steady increase in the number of businesses opening up. Pre-existing

businesses like bakery shops added capacity to previous business lines and this has helped youths find greater job opportunities. About 200 jobs were created due to the mini-grid projects. The most interesting development has been seen in the number of youths migrating abroad for job opportunities, a trend that plagues all of Nepal's rural communities. This trend has drastically fallen over the past three years for these two communities.

The two mini-grid sites demonstrated starkly distinct outcomes. While Harkapur has a capacity factor close to 90%, Chyasmitar's stands in the 20-30% range. This taught us to take a more phase-wise approach to installation, since the capacity factor dictates the financial sustainability and it is extremely difficult to get an accurate load estimate for rural areas. Hence, ensuring a high utilisation potential for communities remains the key focus moving ahead.

One approach Gham Power has taken is to integrate decentralised productive end use appliances at project sites before the installation. Another approach has been to select locations which have larger business presence (e.g. remote tourist destinations with pre-established hotels and lodges). Either way, understanding the seasonality of productive end use loads, the demand side and its effect on revenue is key in being able to scale up mini-grids. The generation systems are grid compatible.



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3.9 RERL and Subas & Sujan Electric Service Center: 29 kWp micro-hydro mini-grid in Simli Khola (Nepal)

About Rural Energy for Rural Livelihood

Rural Energy for Rural Livelihood (RERL) is a joint initiative of the Government of Nepal and UNDP and has been operational since July 2014. It is implemented by the Alternative Energy Promotion Center (AEPIC), the nodal governmental agency mandated to promote renewable energy in the country. RERL is supporting AEPIC to remove barriers for upscaling renewable energy systems and productive energy uses in Nepal.

About Subas & Sujan Electric Service Center

Subas and Sujan Electric Service Center (SSESC) was registered in the fiscal year 2017/18 under the Company Registration Act of Nepal. Motiram Roka, the proprietor, was closely involved in construction of the 29 kW Simli Khola micro-hydropower project in western Nepal as an official of the Users' Committee. Later, when the community decided to lease out the plant to a private entity for the daily operation and management, he established SSESC and was selected through a competitive process.



Context

The 29 kW Simli Khola micro-hydropower project (MHP), an isolated mini-grid, is located at the Sanibheri Rural Municipality in western Nepal, where the people are mostly engaged in subsistence agriculture, livestock rearing or foreign employment. The mini-grid was commissioned in 2009.

Before installation of the MHP, people in Simli, in general, had to rely on kerosene wick lamps for lighting their houses in the evening, only the better off families could afford solar home systems, while the cooking energy demands of all households



were met by burning traditional biomass sources such as fuel-wood and agricultural residues. With the rise in income and social well-being, the locals wanted to have electricity services at their homes for better illumination, charging phones and watching television. The community thus had a strong desire to develop and own a MHP mini-grid.

Site identification and selection

The Simli Khola MHP project, located in Ward No. 9 of Sanibheri Rural Municipality in Rukum (West) District of Karnali Province, which is around 1.5 hours' drive from Rukumkot, the district headquarters. The 29 kW plant was installed in 2009 and received large part of the cost as government's subsidy through the Alternative

Energy Promotion Centre (AEPC), governmental agency mandated to promote renewable energy in the country. The primary reason for the selection of the site was strong community demand for access to electricity.

Technical design and selection of hardware

The initial service area of the MHP in Simli during the survey and design phase covered 291 households, in line with the government’s subsidy policy of distributing 1 kW to 10 households, basically for lighting and operating small household appliances, the MHP was found to be technically feasible to produce the required 29 kW to meet the demand of the coverage area. It was assumed that the spilt energy during the daytime would be enough to power few commercial activities in the marketplace. The design parameters of the MHP is given in the table below.

Source	Simli Khola
Design discharge	69 litres per second
Head	72 m
Headrace canal	1,377 m
Penstock pipe	185 m
Turbine type	Turgo
Generator	Synchronous, brushless 30 kVA
Driving system	Direct coupling
Total transmission and distribution line length	10,928 m
Beneficiary households	495

Leasing Out of Daily Management of the mini-grid to Subas and Sujan Electric Service Center

In the beginning, the project was managed by a Users’ Committee, but faced many challenges. Electricity tariff rates were not well-calculated, and payments were not regular. The revenue collection was also disorganised. The average monthly revenue collection was just about USD 318, which hardly covered the staff salaries. There was no allocation towards contingency fund for the repair and maintenance works. All these factors resulted in the mini-grid not being financially being able to withstand and sustain operations. Furthermore, the local Users’ Committee did not function well and lacked the expected managerial skills.

Because of various operational issues mentioned above, the local community realised that there was a huge potential to induce local economic activities if the mini-grid would be better managed. Therefore, the local community decided to lease out daily management of the MHP to the private entity, Subas and Sujan Electric Center, which now guarantees service delivery over an agreed period of time. Under this modality, the project owner (community) selected an interested lease holding private entity through a competitive bidding process. All terms and conditions of the lease agreement were placed maintaining transparency, accountability and impartiality for the overall management. This leasing out of daily management model was done under a unique Community Private Partnership (CPP) approach.

Operations and maintenance

After the intervention of the lease holding company, the MHP provides uninter-

rupted electricity for 22 hours a day against 12 hours previously. This has resulted in drastic increase in number of enterprises in the market centre. At present, the MHP provides electricity to 495 households and 102 enterprises (productive uses) more than doubling the monthly revenue generation from USD 318 to USD 681. The private operator has established a separate fund for regular O&M to ensure reliable supply.

After the introduction of Subas and Sujan Electric Service Center as a lease holding company for the MHP's operation, the lessee is paying USD 63.63 per month to the Users' Committee and also allocates USD 18.18 every month for repair and maintenance. The daily operation hour has also increased to about 22 hours up from 12 hours before the lease arrangement.

Although Simli Khola MHP is not the first project managed by a private entity under a lease agreement with a community in Nepal, it is the first one operated by a private company and promoted by the AEPC. It received an additional USD 2,636 for repair and maintenance before the agreement was signed. In the past, individual entrepreneurs have leased and operated community owned MHPs with varying degrees of success. As the incentive for reliable electricity supply is very high among private operators compared to communities, the government considers this model as an option to ensure sustainable operation and livelihood improvement mechanism for far flung areas of the country.

Revenue and financing sources

In the beginning, after certain initial design modifications, the estimated total investment on the project was settled to be USD 113,818 of which USD 84,545 (about 75%) subsidy was mobilised from AEPC. To plug the remaining financial gap of rest 25%, every beneficiary household in the community contributed USD 45.45 in cash and 21 days of voluntary labour.

Followed by the intervention and adoption of the CPP model, the proprietor of Subas and Sujan Electric Service Center, the private entity now operates the plant, collects revenue and pays the staff while ensuring continuous service delivery to the beneficiary communities. The Users'

Committee is responsible only for connecting new households and coordinating with other agencies for additional financial or technical support. The Committee is also responsible for monitoring the financial performance of the lease holding company.

The lease holding company has been provided with authority to fix tariff structure to ensure sufficient revenue collection to cover all its expenditures including depreciation cost. However, the company must receive consent from the existing Users' Committee and beneficiaries. Regular expenditures of the MHP include salary for the manager and operators, repair and maintenance cost, bank loan repayment, lease rent to the Users' Committee and miscellaneous costs.

Tariff rates for both domestic and commercial customers	
Domestic	Minimum USD 1.09 up to 5 kWh; USD 0.10 per kWh if > 5 kWh
Commercial	Minimum USD 2.72 up to 5 kWh; USD 0.10 per kWh if > 5 kWh

Billing and metering

Timely tariff collection is one of the reasons behind fair financial status of the scheme. The lease holding company introduced a new financial system that included scientific revision of tariff rates, a new computerised billing system, as well as a reward for timely payment, which has increased payments rates significantly.



The sales revenue of the MHP has increased from USD 318 per month to USD 681 per month after the leasing out to the private operator. Moreover, a new project office in the village centre including a bill payment counter has been set

up where customers can pay after consumption (post-paid). A computer based financial system was introduced. There is a provision of 5% discount for early payment, but 50% penalty for late payments.

Project outcomes

After the CPP has been introduced, the plant factor has improved by 20%. Moreover, the timely preparation of financial audits, additional spare parts and contingency funds for repair works has been guaranteed in a systematic way. Different incentive



packages like providing uniforms and waiver of electricity bills for staff have helped motivate them and keep their morale high having a positive impact on performance and revenue generation.

As the MHP now provides reliable power supply, 102 enterprises providing employment opportunities to 140 people are operational in the market. Among these, 24 are owned and operated by women. Though most of these enter-

prises use electricity for lighting, there are others like welding shops, cold storage, press, carpentry, poultries, local hospital, etc. that need reliable and quality electricity supply. The success has forced the lease holding company to schedule operating time of the enterprises and it is planning to accommodate additional demand during the off-peak hours by lower tariff.

Interestingly, household electricity demand has either remained unchanged or even decreased, compared to the initial years, after their consumption is metered, which is explained by the use of lesser numbers of light bulbs and/or the use of energy efficient ones (CFL or LED) to minimise their monthly electricity bills.

The Simli MHP is on its way to sustainable operation and is seen as a success by other MHPs in the district. Other MHP developers/owners visit Simli to learn about their management system. The positive results seen at Simli were due to a concerted effort of the community, lease holder and the AEPC. RERL, a joint initiative of the AEPC and UNDP, organised several workshops and orientation program at the local level to create awareness on different management modalities for MHP and explaining advantages and limitations of each. After the community decided to opt for the CPP model, RERL facilitated each step from publishing bid notice to writing lease agreement and then after for business opportunity assessment, business plan preparation and demand side management (DSM).

Replication of this type of CPP to other parts of the country might help to sustain the micro-hydro projects all over Nepal for reliable electricity supply contributing to economic growth and livelihood enhancement of rural people is both time and resource intensive. Sufficient time and regular support are required for the proper implementation of such partnerships going forward.

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3.10 PowerSource Philippines Inc. (PSPI): 893 kWp biomass gasifier in Rio Tuba (Philippines)

About PowerSource Philippines, Inc. (PSPI)

PowerSource Philippines, Inc. (PSPI) is the first Qualified Third Party (QTP) company under the Electric Power Industry Reform Act or EPIRA Law. PSPI is also the first QTP recipient of the Universal Charge for Missionary Electrification (UCME) subsidy from the National Power Corporation (NPC) and Energy Regulatory Commission (ERC). As a QTP, PSPI provides bundled power utility services including the generation, transmission, as well as distribution for sites considered as remote and unviable for connection to the Distribution Utility (DU)/Electric Cooperative (EC) distribution network franchise.



Context

In 2005, the Rio Tuba mini-grid project was developed by PSPI, which is a populated barangay village in the Municipality of Bataraza, in the province of Palawan. It is about 236 km from Puerto Princesa City, the provincial capital.

The project powers 1,967 households in the village with 24/7 operation basis.

Site identification and selection

Rio Tuba due to mountainous features of Bataraza and underdeveloped roads going to the south portion of Palawan is sometimes inaccessible during bad weather.



Figure: Location of Brgy. Rio Tuba, Bataraza

In Rio Tuba, residents owned and operate small capacity generators to provide electricity for their businesses. However, due to continuous rise in the diesel fuel and maintenance costs, residents suffered on the expensive operating cost to sustain their primary source of income. Rio Tuba falls within the franchise of the Palawan Electric Cooperative (PALECO), but is a distant barangay and is considered unviable for connection to the existing distribution network of PALECO.

Before the PSPI mini-grid project, the village did not have access to electricity. For this reason, PSPI developed a mini-grid for the provision of electricity which will contribute to the social and economic development of its local communities.

Technical design and selection of hardware

In March 2005, after the Government's Department of Energy declaration of Rio Tuba as one of the 428 unviable barangays open for QTPs, PSPI with high economic de-

velopment prospects by providing reliable and adequate electric power supply went ahead with their plan to develop the Rio Tuba Community Energizer Platform (CEP).

PSPI has established a process template for the development of a mini-grid, which can be replicable to other future prospected areas. This process includes the technical design and social responsibilities of the PSPI for the development of the mini-grid project.

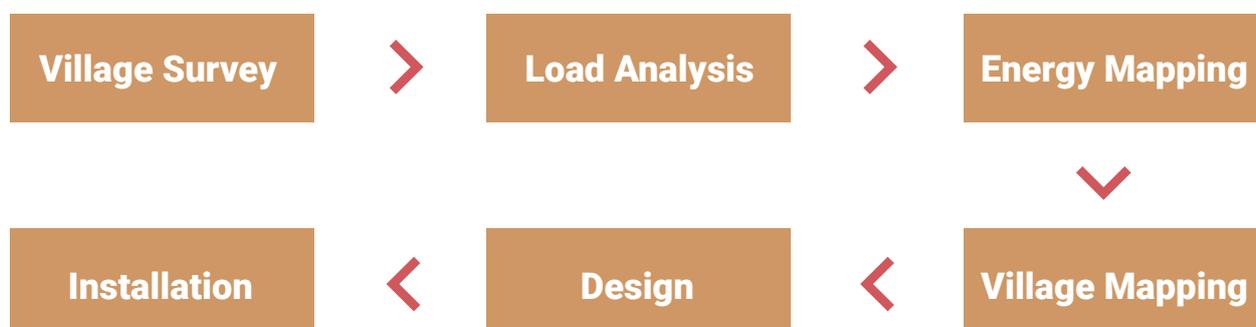


Figure: PSPI Mini-grid Development Process

- 1. Site visit / local interview:** The process of mini-grid project development started with the site visit at Rio Tuba. With the permission of the Barangay Local Government Unit (BLGU), PSPI conducted a site survey and interviews with the local communities at the barangay. Gathered information was then used on the succeeding phase of the process. PSPI identified feasible and strategical location of the mini-grid site – its powerhouse and main office.
- 2. Electrical load analysis (ELA):** ELA demanded the listing of electrically powered equipment and the associated power requirement (kWh) of each household, commercial establishments present in Rio Tuba. The power requirement may differ depending on the utilisation of each component. This gave the total daily energy requirement of Rio Tuba. Having a peak demand of 563 kW, and total energy requirement of 129,600 kWh for a month, the development team sized the mini-grid to reach optimal efficiency.
- 3. Public Consultation:** This is one of the community participations of PSPI to Rio Tuba. The main goals are to improve the efficiency, transparency, and public involvement of the QTP relative to the project affecting the constituents of the barangay.
- 4. Area Mapping:** Area mapping method was used to analyse, design and plan the distribution network of the mini-grid system in most efficient manner. Efficient area mapping will lead to optimal design of the distribution lines capacity considering the demand and the forecasted growth of the area. This will also affect to minimal expansion cost.
- 5. Customer Orientation:** This activity aimed to inform the connecting customers on the service process of PSPI. This included the customer guidelines for electric service connection, as well as the billing cycle of the month, etc. This phase of the process is when the PSPI informed the connecting customers on the initial tariff per kWh to be imposed.

6. **Project Implementation:** This phase of the process includes the construction/installation of the mini-grid facility and its components (generation, transmission, and distribution).

Subsequent to the successful commercialisation of Rio Tuba mini-grid in 2005, PSPI envisioned the inclusion of renewable energy sources to the diesel system. PSPI considered to convert the system into hybrid generation source by incorporating a biomass gasifier. The integration of this component complemented the operation of its existing diesel generators and lessened the dependency on the fossil fuel and carbon emission from the mini-grid.

With the passage of Renewable Energy Law, PSPI applied for Biomass Renewable Energy Operating Contract which was approved in February 2015. PSPI proceed to the installation of the biomass gasifier and commissioned in January 2016.



Recently, a Department Circular No. DC2018-08-0024 was released by the DOE entitled “Promulgating the Rules and Guidelines Governing the Establishment of the Renewable Portfolio Standards for Off-Grid Areas.” This Circular shall be known as the “RPS Rules for Off-Grid Areas” and is hereby adopted in order to contribute to the growth of the renewable energy industry in the off-grid areas by mandating electric power industry participants to source or produce a specified portion of their electricity requirements from eligible Renewable Energy resources.

Compliant to the department circular, PSPI is actively exploring other renewable energy resources available/feasible at Rio Tuba to be incorporated into the system. This includes solar energy by installation of solar arrays, as well as hydro energy which can be sourced from rivers at site.

Operations and maintenance

PSPI employed local residents of the barangay for operations and maintenance of Rio Tuba mini-grid facility. This includes eight linemen to maintain the reliability of the distribution network, four generator unit operators for adequate generation production, billing assistant, finance officer, and cashier responsible for issuance of monthly billing statements and collection respectively. A security guard was also hired for the protection of the facility, and site supervisor for the supervision of the operations of the mini-grid facility.

Revenue and financing sources

The Rio Tuba mini-grid is owned by PSPI. The total cost for the development of the mini-grid project was PHP 25.5 million (~USD 514,000) which covers project components, general and administrative, and other development costs. The project was financed through a mix of debt (70%) and equity (30%). The actual cost during the initial months of operation was PHP 73.478/kWh (~USD 1.481/kWh). Since mini-grid sites like Rio Tuba are small and isolated, electricity rates are typically higher than those connected to the main grid of EC’s franchise.

Rio Tuba is considered as the pilot mini-grid project developed and operated by a QTP. With the support from the Department of Energy (DOE), the mini-grid project commenced while the regulatory and administrative framework for QTP’s is being developed. In this case, it prolongs the duration for the grant of the subsidy from the ERC which was approved in April 2010.

Given the limited paying capacity of its consumers, PSPI set its tariff at the rate of PHP 25.5/kWh (~USD 0.514/kWh) which is lower than the actual cost and thus operated at a significant loss while expecting to recover from the subsidy.

While waiting for the approved subsidised rate, connected consumers of the mini-grid system are affected by the fluctuations in market fuel prices. During this phase, connected consumers paid for the whole cost per kWh which include the fuel price. Upon deliberation and approval from the ERC, the Subsidized Approved Retail Rate (SARR) imposed on the connecting cus-

tomers of Rio Tuba CEP is PHP 8.50/kWh (~USD 0.171/kWh). Also, the true cost of electricity service was computed by the commission which is PHP 34.086/kWh (~USD 0.686/kWh).

Billing and metering

Consumers paid their respective monthly consumption through cash payments. A billing officer issues monthly billing statement which indicates the total kWh consumption of consumers on the billing month and its corresponding bill amount. Linemen conduct monthly meter readings to the residential and commercial kWh meters installed per consumer – the basis of the billing statement.

Project outcomes

During the commercialisation, 1,885 households were connected. Presently, 1,967 customers consist of residential and commercial establishments are connected to the system with 4% demand growth over the years. The provision of electricity in Rio Tuba and the availability of the subsidy to its consumers contributed to the social and economic development of local communities. The 24/7 access to electricity and establishment Community Enhancement Platform model contributed to the enhancement of livelihood, increase productive uses of electricity, as well as enhancement of the community income.



The project created 16 local jobs in Rio Tuba.

The CEP consisted of cold storage and mini-ice plant modules, internet access, and communications

modules, which were housed in container vans. However, some of the facilities (water purifier, ice maker, communication modules) operated only for several years.

PSPI Observations and Recommendations for Sustainability of Mini-Grids

PSPI observed that the subsidies for remote/missionary areas with lesser consumption and revenue potential for investors have significant impact on the sustainability of the project. Being the first QTP company to operate a mini-grid site, PSPI recommends minimising the evaluation period of ERC on QTP investment proposals for granting the Subsidized Approved Retail Rate. Also, to alleviate the regulation for QTP compared to large scale energy projects. This will attract more private sector players to participate in Rural Electrification especially for small-sized capacity projects.

Observations and issues with the biomass gasifier

During the implementation, technical problems were troubleshooted and measures were made by PSPI in order to achieve full operation of the biomass gasifier. Upon the procurement of higher capacity additional appliances like blower, PSPI tested the gasifier and unfortunately, it failed to communicate and operate in parallel with the existing diesel generators in the system. In view of this PSPI deferred the operation of biomass gasifier to further work on the identified issues during the installation and testing of the renewable energy source.

The engineering team also noted the following challenges arose during the implementation of biomass gasifier:

- Complexity of the system,
- Manpower requirement during operation,
- Danger in inhalation of gaseous state,
- Waste and by-products during and post operation, and
- Feedstock storage due to voluminous amount needed for the operation of gasifier.

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3.11 Inno Energy Master's School, Blue Solar and Symbior Solar: 60 kWp solar-powered mini-grid in Koh Jik Island (Thailand)

About InnoEnergy Master's School Project Team, Blue Solar and Symbior Solar

The project team from InnoEnergy Master's School (KTH Stockholm, TU/e Eindhoven, UPC Barcelona and IST Lisboa), regrouped as the Koh Jik ReCharge Team, played a key role in this project by canvassing investors, developing a techno-economic analysis to optimise an existing mini-grid. The team also facilitated negotiations between the community, the government and the investors, as well as disseminating information to the scientific community.



Two private sector developers from Thailand, Blue Solar and Symbior Solar are also involved in the project as funders. The two companies are renewable energy project development companies doing utility and C&I PV projects. Blue Solar is developing Thailand's largest PV plus storage project 42 MWp PV / 54 MWh ESS under a 20 years PPA contract at first year purchasing price of 2.54 THB/kWh (~USD 0.08 per kWh).



Context

Koh Jik Island, Thailand, is a community owned and operated renewable energy mini-grid. A community owned mini-grid has been operating since 2004 (upgraded in 2012), but in 2018, critical system components reached end-of-life. The community of 400 inhabitants is losing reliable 24/7 access to clean electricity. Therefore, the ReCharge project was designed to rejuvenate the mini-grid. The project is funded by private Thai developers (Blue Solar and Symbior Solar), Australian Aid and enabled by

a consortium of European universities. It has been developed step-by-step with the community.

Site identification and selection

The ReCharge project is restoring and improving the mini-grid system on Koh Jik by replacing failing assets, implementing an automatic control system, flexible hybrid AC-DC configuration and network connected digital meters for easier management and monitoring.

The island has no connection to Thailand's main electricity grid. The current

community mini-grid that is powering the island consists of 40 kWp PV, 240 kWh lead-acid energy storage system and 50 kW diesel generator.

Past experience of the community ensured trust in and acceptance of the new project. Community consultations allowed to benchmark new tariff against the old one, assess eventual reaction to the price change and willingness to pay.

Trained members of the community energy company, as well as people's knowledge of how to deal with mini-grids, boost the chances of a seamless transition to the upgraded system. The agreements made within the community, for instance limiting the use of air conditioning units or other high-power appliances, helps to keep the demand within the mini-grid's capacity.

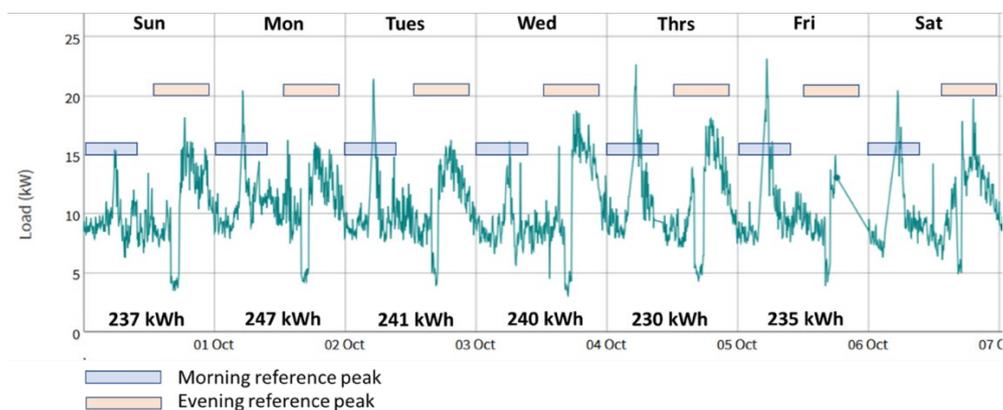
Past experience of the community ensured trust in and acceptance of the new project

Technical design and selection of hardware

The ReCharge project aims at restoring and improving the system on Koh Jik by adding 20-40 kWp of PV capacity and replace existing lead acid batteries with 240-260 kWh lithium-ion ESS.

Li-ion batteries were chosen because of the sharp price decrease over the last years, their lifetime can reach up to 3,000 cycles as compared to the 900 cycles of lead-acid batteries, less maintenance, and environmental friendliness.

With support from Blue Solar, a System Monitoring Unit (SMU) was installed on the island in September 2018. This device logs all parameters from the bi-directional inverter and allows remote access to the monitoring data. The SMU data could be accessed through an online dashboard to any stakeholder and was used to analyse typical load behaviour, an important pre-design step.



The load profile data shows that the average daily consumption is around 230-250 kWh. The daily consumption reveals clear repetitive patterns with a short morning peak and a longer evening peak. Hence, the daily base load could be directly fed by a new AC-coupled PV array. Based on all data, the project team went ahead and redesigned the system using a holistic approach and software such as HOMER Pro, Helioscope and Excel.

In total, six scenarios were analysed based on different battery suppliers/configurations (DC, AC or Hybrid AC-DC), each with two different PV configurations of 20 kW (ground mount) or 40 kW (roof mount). The expansion of the system is restricted by strict physical space constraints. Such constraints eliminate the possibility of running a 100% renewable share scenario and are described as follows:

- Ground mounted physical space constraint (20 kW) - maximum size of array given the available space if new PV were to be installed beside the existing array.
- Roof mounted physical space constraint (40 kW) - maximum size of array given the available space if new PV were to be installed on the roof of a nearby building.

The best performing scenario in terms of cost, lifetime performance and robustness was selected and is described in the Figure and Tables below (40 kW roof mounted case). It consists of a hybrid AC-DC configuration incorporating a small diesel generator and Li-ion battery pack.

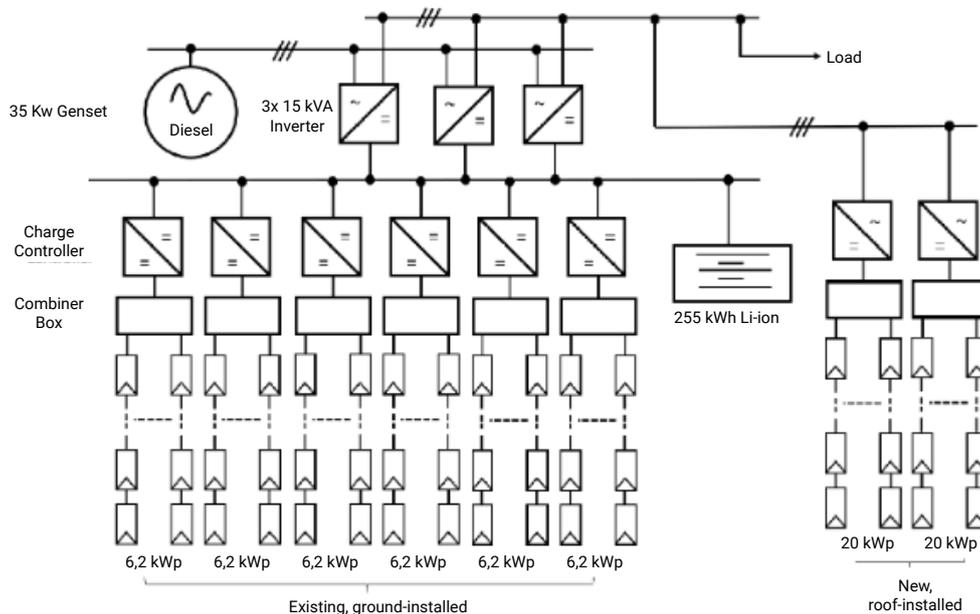


Diagram: PV configurations of 20 kW (ground mount) or 40 kW (roof mount)

The components of the system were chosen based on current system compatibility, ease of procurement and investor preferences. Compatibility between Fronius (grid tied PV inverter) and Victron (solar charge controllers and central inverters) products was supported by field experience of a project advisor. Oversizing of

the PV grid tied inverter adds flexibility for a possible extension of the PV array. The three 15 kVA inverter (one per phase) configuration improves the reliability of the mini-grid in case of an inverter failure. The battery size of 255 kWh is the result of a techno-economic analysis performed with Homer Pro over the project lifetime and is based on quoted prices. The distribution system is AC three phase four wire 380V/220V.

The diesel genset sizing took into consideration the maximum load it will need to cover over 20 years project life. It was also critical not to oversize the genset to avoid extended time periods of low load operation (< 30% of nameplate capacity).

Operations and maintenance

Component	Product	Amount	Specifications
Solar charge controller	SmartSolar 250/100 MPPT Tracer	6	250/100 (V_{max}/I_{max})
PV grid tied inverter	Fronius ECO 25.0-3-S	2 (roof)	25 kW
PV system ground	Sunrise Poly 250 W_p	160	40 kW
	Ja Solar JAP6 265 W_p	66	20 kW
PV system roof		132	40 kW
Battery storage	Undisclosed (lithium-ion)	1	255 kWh
Inverter/charger	Quattro 48/15000/200-100/100	3	15 kVA / 12 kW
	Color Control GX remote control	3	-
Diesel genset	Generic	1	35 kW

Mini-Grid Specifications and Equipment

	Unit	Ground	Rooftop
Li-ion Battery Size	kWh/kVA	250 / 45 ^a	255 / 45 ^a
Diesel Consumption	l/y	9,730	5,385
Renewable Fraction	%	69.6	83.2
CAPEX	USD	196,740	215,970
Fuel Cost	USD/y	8,230	4,560
OPEX (excl. Fuel)	USD/y	5,650	6,890
Cost of electricity (COE)	USD/kWh	0.290	0.280

Final Design Results and Costs of the Mini-Grid

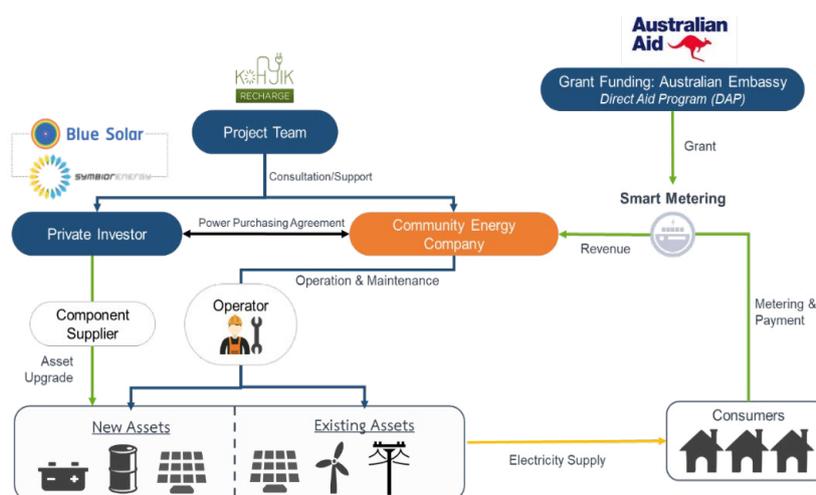
^a Single-phase inverter used with 15 kVA rated capacity hence leading to total capacity of 45 kVA.

The community is still in charge of O&M, but costs are being covered by the investors. Meaning that if a component breaks down within the duration of the contract, the investors are responsible to fix or replace the components. The community is, therefore, risk-free and does not have the burden of unexpected component breakdowns.

The system monitoring unit (SMU) is capable of showing system alarms if fault occurs. The upgraded system will be implemented with more advanced real time monitoring that will be monitored from a central monitoring centre.

Revenue and financing sources

The community energy company owns the assets existing on the island before the mini-grid upgrade. It was responsible for maintenance operations, billing and collecting the electricity revenue, which has now been transferred to the investors until the end of the Build-Operate-transfer (BOT), which is essentially a type of PPA contract. The investors agreed to invest in equipment upgrade under the conditions of the PPA with the community energy company. The PPA is made for a contract duration of 10 years with the option of extending to 15 under the provision of a battery upgrade included in year 11. This means that during the PPA duration, all the generation is handled by the investors.



Project financing for the major system upgrade has been secured from a joint venture between two Thai solar developers: Symbior Solar and Blue Solar under a mix structure of equity and debt. The total project is valued at approximately EUR 155,000 (~USD 172,000).

A grant of approximately EUR 17,500 (~USD 19,400) was received from the Australian Embassy Direct Aid Program (DAP) to order, install and commission 100 smart meters with pre-payment functionalities in the scope of the project. The pre-payment capabilities ensure that electricity prices are paid beforehand and eliminate the risk of non or delayed payments in addition to unlocking endless possibilities of tariff management and energy conservation measures.

The electricity tariff is 13 THB/kWh (~0.42 USD/kWh), subject to fuel price volatility. Although substantially higher than the national tariff, which is 4 THB/kWh (~0.12 USD/kWh), the mini-grid enables the community access to electricity at affordable prices, while providing higher reliability and power quality than other means of electrification. Due to the relatively stable population and its energy needs, the tariff is flat without peak (demand) charges, or other behaviour-shaping incentives.

Billing and metering

The community energy company is still responsible for the metering and billing to ensure that tariffs are collected. Pre-payment billing and metering system are being used. Electricity consumers pre-pay for electricity by buying top-up token from the vending point, they enter the token (20-digit Secure Transfer Specifica-



tion (STS) encrypted codes) using keypads on the meter. The meter's LED screen shows the amount of remaining credits (kWh) and has a built-in relay to disconnect power supply once the credits have been used up.

Pre-payment billing systems support the overall management of the mini-grid by ensuring that revenue is not lost through non-payment and defaults. Pre-payment billing is done through STS enabled metering and vending point of sales. Digital payments through online money transfer are also possible to reduce cash transaction.

Project outcomes

The project allows the inhabitants to conserve the clean, reliable access to energy at the same tariff. Indeed, with the current system degradation, the community was slowly increasing the share of diesel used every day which would have translated in the long-term in an increased cost of electricity (calculated COE at 0.441 EUR/kWh (~USD 0.49) for 100% diesel generation) and a greater dependency on fuel price fluctuations. The inhabitants benefit from a new, more performant system which will allow continuous use of their energy-intensive utilities such as washing machines, refrigerators, rice-cookers to power tools and high-pressure water pumps, etc. The project employs three permanent employees, as well as between five and 10 for occasional maintenance work (panel cleaning, tree trimming, etc.)



Greenhouse gas emissions avoided by the new system were calculated against the assumption of an eventual return to a 100% diesel scenario once again. They translated into 85 tonnes of CO₂ avoided per year, clearly showing the renewable nature of mini-grid systems, even if the 100% renewable fraction is not reached. The potential for replication is huge, especially in ASEAN countries that are also struggling with electrification of rural areas. The project showed that strong community involvement throughout every step, from planning to operations as well as maintenance, is key to realisation of successful mini-grid projects.

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