Minigrids and Access to Electricity in SAARC

2021

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FOREWORD

Access to modern energy, and electricity in particular, is an indispensable ingredient of socio-economic progress and well-being. However, this is a challenging task, demanding adequate technical, financial, social and regulatory support. Minigrids can be a key enabler for achieving almost all the SDGs, including the eradication of poverty, health, education, clean water and combating climate change. The SAARC Region has very diverse type of climates in different areas, hence different sources of renewable energy generation such as wind, solar and small hydel etc., are available, which can be combined to form a minigrid. Utilizing these renewable energy sources can electrify many energy-poor rural communities in the SAARC Member States resulting in socio-economic uplift of the people.

This study covers the most pressing technical and non-technical aspects and details of mini grids. Case studies from the Member States have been detailed in the study report to show the importance of the mini grids for energy access in the SAARC region. The policy aspects and cost competitiveness of energy access through mini grids make an integral part of the study. Additionally, the study comprises of realistic technological innovation based on the modern Information and Communication Technologies (ICT).

(Dr Nawaz Ahmad)
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LIST OF ACRONYMS

Abbreviation	Full Form
ABC	Anchor Business Community
AC	Alternating Current
ACCSAP	Afghanistan Climate Change Strategy and Action Plan
ADB	Asian Development Bank
AEDB	Alternative Energy Development Board (Pakistan)
AEPC	Alternative Energy Promotion Center (Nepal)
AGM	Absorbed Glass Mat
AHEC	Alternate Hydro Energy Centre (India)
AI	Artificial Intelligence
AKRSP	Aga Khan Rural Support Programme (Pakistan)
AMDA	Africa Minigrid Developers Association
ANDS	Afghanistan National Development Strategy
ANN	Artificial Neural Networks
ANPDF	Afghanistan National Peace Development Framework
ARE	Alliance for Rural Electrification
ARE	Alternative and Renewable Energy Policy (Pakistan)
AREMTI	Afghanistan Renewable Energy Market Transformation Initiative
AREP	Afghanistan Renewable Energy Policy
AREP	Alternative Renewable Energy Policy 2013 (Bhutan)
AREU	Afghanistan Renewable Energy Union
ARISE	Accelerating Renewable Energy Integration and Sustainable Energy (Maldives)
ASERD	Afghanistan Sustainable Energy for Rural Development
ASPIRE	Accelerating Sustainable Private Investment in Renewable Energy (Maldives)
B2B	Business to Business
B2C	Business to Consumers
BDT	Bangladesh Taka
BEA	Bhutan Electricity Authority
BERC	Bangladesh Energy Regulatory Commission
BMC	Billing, Metering, And Collection
BNEF	Bloomberg New Energy Finance
BOO	Build, Own, Operate
BOOT	Build, Own, Operate and Transfer
BPC	Bhutan Power Corporation
BREP	Bamiyan Renewable Energy Program (Afghanistan)
CCI	Council of Common Interests (Pakistan)
CDC	Community Development Council (Afghanistan)
CEB	Ceylon Electricity Board (Sri Lanka)
CESL	Convergence Energy Service Limited (India)
CREDA	Chhattisgarh Renewable Energy Development Agency (India)
CREF	Central Renewable Energy Fund (Nepal)
CSR	Corporate Social Responsibility
DABS	Da Afghanistan Breshna Sherkat (Afghanistan)

DBFOOT	Design, Build, Finance, Own, Operate and Transfer
DC	Direct Current
DDG	Decentralized Distributed Generation
DDUGJY	Deendayal Upadhyaya Gram Jyoti Yojana (India)
DESI	Decentralised Energy Systems of India
DFID	Department for International Development
DG	Diesel Generators
DGPC	Druk Green Power Corporation Limited (Bhutan)
DISCOM	Distribution Company
DoRE	Department of Renewable Energy (Bhutan)
DRE	Decentralized Renewable Energy
DSM	Demand Side Management
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
ECS	Electricity Consumer Society (Sri Lanka)
EESL	Energy Efficiency Services Limited (India)
EFA	Energy for Access
EMS	Energy Management System
EPC	Engineering, Procurement and Construction
ESCO	Energy Service Company
ESMAP	Energy Assistance Management Program
ETFC	Electricity Tariff Fixation Commission (Nepal)
FiT	Feed in Tariff
FY	Fiscal Year
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GoB	Government of Bangladesh
GOGLA	Global Off- Grid Lighting Association
GoIRA	Government of Islamic Republic Afghanistan
GoM	Government of Maldives
GoN	Government of Nepal
GoSL	Government of Sri Lanka
HH	Household
HOMER	Hybrid Optimization of Multiple Energy Resources
HSU	Humboldt State University
HRE	Hydropower and Renewable Energy Project (Pakistan)
IDCOL	Infrastructure Development Company Limited (Bangladesh)
IEA	International Energy Agency
IFC	International Finance Corporation
INDC	Intended Nationally Determined Contribution
IoT	Internet of Things
IPDS	Integrated Power Development Scheme (India)
IPP	Independent Power Project
IRENA	International Renewable Energy Agency
KII	Key Informant Interview

KTOE	Kilo Tonne of Oil Equivalent
kW	Kilo Watt
kWh	Kilo Watt Hour
LCOE	Levelized Costs of Energy
LECO	Lanka Electricity Company (Private) Limited (Sri Lanka)
LEDS	Low Emission Development Strategy
LES	Localized Energy Systems
LFI	Local Financial Institutions
LTGEP	Long Term Generation Expansion Plan (Sri Lanka)
MFI	Microfinance Institutions
MGs	Minigrids
MGEAP	Minigrid Energy Access Project (Nepal)
MGP	Mera Gao Power (India)
MHDF	Micro Hydro Debt Fund (Nepal)
MHP	Micro Hydro Power
ML	Machine Learning
MNRE	Ministry of New and Renewable Energy (India)
MoAF	Ministry Of Agriculture and Forests (Bhutan)
MoEA	Ministry Of Economic Affairs (Bhutan)
MoEWRI	Ministry of Energy, Water, Resources, and Irrigation (Nepal)
MPEMR	Ministry of Power, Energy and Mineral Resources (Bangladesh)
MPPT	Maximum Power Point Tracking
MPRE	Ministry of Power and Renewable Energy (Sri Lanka)
MRRD	Ministry of Rural Rehabilitation and Development (Afghanistan)
MW	Mega Watt
NABDP	National Area Based Development Programme (Afghanistan)
NDC	Nationally Determined Contribution
NEA	Nepal Electricity Authority
NEPRA	National Electric Power Regulatory Authority (Pakistan)
NEPS	National Energy Policy and Strategies (Sri Lanka)
NGO	Non-Governmental Organization
NIWE	National institute of Wind Energy (India)
NPA	Non-Performing Assets
NPP	National Priority Programme (Afghanistan)
NREP	Nepal Renewable Energy Programme
NRSP	National Rural Support Programme (Pakistan)
NSP	National Solidarity Programme (Afghanistan)
NWP	Numerical Weather Prediction
NZD	New Zealand Dollar
NZMFAT	New Zealand Ministry of Foreign Affairs and Trade
O&M	Operation and Management
P2P	Peer to Peer
PAYG	Pay-As-You-Go
PDD	Power Development Department (Ladakh, India)
PLF	Plant Load Factor
POISED	Preparing Outer Islands for Sustainable Energy Development (Maldives)

PPA	Power Purchase Agreement
PPAF	Pakistan Poverty Alleviation Fund
PPP	Public Private Partnership
PV	Photovoltaic
RAPSS	Remote Area Power Supply System (Bangladesh)
RE	Renewable Energy
REB	Rural Electrification Board (Bangladesh)
REDF	Renewable Energy Development Fund (Bhutan)
REP	Rural Energy Policy 2006 (Nepal)
RER2032	Renewable Energy Roadmap for Afghanistan 2032
RERED	Renewable Energy for Rural Economic Development (Sri Lanka)
RERL	Renewable Energy for Rural Livelihood (Nepal)
RESCO	Renewable Energy Service Companies
RET	Renewable Energy Technology
RGoB	Royal Government of Bhutan
ROR	Run of River
RVEP	Remote Village Electrification Programme (India)
SAARC	South Asian Association of Regional Cooperation
SAP	Strategic Action Plan (Maldives)
SASEC	South Asia Sub-Regional Economic Cooperation
SDG	Sustainable Development Goal
SEC	SAARC Energy Centre
SECF	Sustainable Energy Challenge Fund (Nepal)
SEforAll	Sustainable Energy for All
SESI	Sustainable Energy Systems International
SHS	Solar Home System
SIDS	Small Island Developing States
SME	Small and Medium Enterprises
SMS	SAARC Member States
SPEED	Smart Power for Environmentally sound Economic Development (India)
SPI	Smart Power India
SPP	Small Power Producers
SREDA	Sustainable And Renewable Energy Development Authority (Bangladesh)
SRSP	Sarhad Rural Support Programme (Pakistan)
T&D	Transmission & Distribution
TANESCO	Tanzania Electric Supply Company Limited
ToU	Time of Use
TPRM	TP Renewable Microgrid (India)
TREP	Tokelau Renewable Energy Project
UNCDF	United Nations Capital Development Fund
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNHCR	United Nations High Commissioner for Refugees
UNIDO	United Nations Industrial Development Organization
USAID	U.S. Agency For International Development
USD	United States Dollar

UT	Union Territory
VAT	Value Added Tax
VDC	Village Development Council
VESP	Village Energy Security Programme (India)
VGF	Viability Gap Funding
W	Watt
WB	World Bank
WBREDA	West Bengal Renewable Energy Development Agency (India)
XOF	West African CFA franc

EXECUTIVE SUMMARY

SAARC Energy Centre (SEC) commenced this study "Minigrids and Access to Electricity in SAARC" to enhance the deployment of minigrid systems in each of the SAARC Member State(s) (SMS). The study seeks to present the up-to date information and analysis of the minigrid status, challenges and trends in the sector and proposes recommendations to overcome the barriers.

The specific scope of the study included research and analysis on the status of minigrid systems exploring technical, policy, financial and socio-economic aspects in each of the SAARC Member States and identifying country-specific conditions that shall ensure sustainability of minigrid systems. The scope also included analysis of actual case studies to depict their broad success factors.

The outcome of the study is limited to secondary sources and discussions with key stakeholders in each SMS. The analysis and data collection are based on public sources of information such as industry studies, journals, publications, and various research databases.

The study begins with a general overview of minigrid systems detailing the global status of minigrids; technical and operational aspects of a minigrid system; use of conventional and renewable energy technologies; cost trends; business models; and latest innovations in the minigrid sector. Technical aspects detail the structure of a minigrid, technical configurations used and key steps in design of minigrid systems. Innovations including Artificial Intelligence (AI), smart meters, Demand Side Management (DSM) and Internet of Things (IoT) devices used to improve power management, integration, and system efficiency of the minigrid have been discussed. The chapter also discusses the operational issues related to minigrid projects and integration of minigrid with the centralised national grid.

Further, assessment of the status of minigrids' deployment in each of the SAARC Member States has been conducted based on the multi-dimensional framework comprising of nine parameters. These include overall status, national strategy for electrification, policies and regulations, technical aspects, business models, minigrid tariffs, financing, opportunities, and barriers. Secondary data as well as information collected through discussions with stakeholders in each country has been used to carry out the assessment. The assessment provides a comparative analysis on minigrids development in each country and provides cross-learning potential that could be exploited in the SAARC Member States for scaling up minigrids' deployment.

The study later discusses seven specific case studies, with a view to deep dive into several key aspects of minigrid including key factors for minigrid development and associated barriers. Following cases have been drawn across the SAARC Member States and globally with each showcasing a unique feature:

1. ***Bamiyan solar Photovoltaic (PV) minigrid, Afghanistan:*** first-of-its-kind 1 MW solar PV-diesel-battery minigrid system in Afghanistan using state of the art technologies and concepts
2. ***Microgrids with interconnected Solar Home Systems (SHSs), Bangladesh:*** a new approach to interconnect SHSs into smart peer to peer (P2P) microgrids, monetizing excess solar energy with mobile money in real time

3. ***Solar PV minigrid set up under Smart Power for Environmentally sound Economic Development (SPEED) project, India***: a 30-kW solar PV-battery system with load limiters and prepayment facilities used for the first-time and innovative structuring of the business model to de-risk project proponents
4. ***Baglung minigrid, Nepal:*** Six Micro Hydro Power plants (MHPs) ranging from capacity of 9 kW to 26 kW interconnected to form minigrid to provide reliable electricity to households
5. ***Solar PV hybrid minigrid, Tokelau:*** One MW solar PV with battery storage to provide at least 90% of this pacific islands' electricity needs in a year from solar power and reduce diesel consumption
6. ***Bambadinca PV Minigrid, Guinea Bissau:*** A project of the size 312 kW solar PV with battery & Diesel Generator (DG) set installed under public-community partnership model to increase access to electricity
7. ***MHP minigrid, Khyber Pakhtunkhwa Province, Pakistan:*** A 36-kW MHP installed by Pakistan Poverty Alleviation Fund (PPAF) with support of German Development Cooperation in a remote and off-grid area to provide electricity to 580 people.

Above case studies highlight lessons as well as barriers for successful minigrid development. Access to and demand for electricity is the prime driver for minigrid development while enterprise load enables a minigrid to support its operation over time covering operating expenses. Innovations in technical design and business models as well as active engagement of community have proved to be instrumental in improving viability and increasing consumers adoption. Other challenges related to minigrid sector include absence of technical and project management skills, risk perceptions among financiers towards introduction of new technologies and low adoption rate of consumers.

Based on the outcome of the above research, the study concludes with summarising key prospects, drivers, and barriers, with specific recommendations for accelerating deployment of minigrids in *each SMS.*

SAARC Countries	*Drivers/ Opportunities*	*Barriers*	*Recommendations*
Maldives	▪ Net zero GHG emission by 2030 ▪ Promotion of hybridization of diesel grids with RE ▪ Program on hybrid projects	▪ Need of energy sector plans on hybrid RE ▪ Limited sources of financing ▪ Lack of experience and private sector involvement	▪ Develop energy sector expansion plans ▪ Promoting PPA mechanism ▪ Conduct technical and vocational training
Nepal	▪ 2.12 million people lack electricity access ▪ Interest for minigrids in rural areas ▪ Existing govt. & donor programs on minigrid projects	▪ Existing minigrids cater to basic needs ▪ High minigrid tariff ▪ Policy for interconnection not clear	▪ Develop minigrid considering future loads ▪ Measures to reduce minigrid tariffs ▪ Design minigrid implementation plan
Pakistan	▪ 45 million people without electricity ▪ Issue of load shedding ▪ RE policy prioritizes minigrid solutions ▪ Lower minigrid tariff compared to grid	▪ Lack of institutional support ▪ Absence of minigrid policies ▪ Lack of private sector investment ▪ Dearth of technical expertise	▪ Develop least cost electrification plan ▪ Set in place minigrid regulations ▪ Replicate success stories from SMS i.e. SOLshare model ▪ Establish financing programs
Sri Lanka	▪ Govt focus on 100% electrification through centralized grids ▪ Opportunities for minigrid in outer islands running on diesel generators	▪ Limited scope for minigrid due to govt focus on centralized grid approach ▪ Electricity trans. & dist. restricted to CEB only	▪ Develop policy to support enterprise development using RE minigrids ▪ Promote and implement RE hybrid minigrids in outer islands

Figure 1 below provides this summary. The study has also suggested the following specific overall recommendations/ action plan to foster cooperation in the region to achieve the above:

1. ***Regional minigrid cooperation mechanism***: a platform to facilitate coordination and exchange of good practices and learnings among the SAARC Member states. The mechanism could operate through a task force consisting of officials from each SMS and will allow interaction and discussions on regular basis as well as provision of technical assistance.
2. ***Specialized course on design and operation of minigrids***: short term specialized course on minigrid design and operational aspects that can be offered to relevant stakeholders of minigrid sector in the SMS for their capacity building. The course would build on

contemporary thinking and technologies available and used in the minigrid sector. The course may be offered by recognized technical institutions in the SAARC Member States.

3. ***Finance facilitation desk/ unit***: an online e-platform to connect minigrid project developers, services providers, and financiers/investors. The facilitation desk would support the deployment of minigrid projects by helping project developers secure financing more efficiently and supporting investors and lenders to build stronger project portfolios.

SAARC Countries	Drivers/ Opportunities	Barriers	Recommendations
Afghanistan	▪ 70% population without electricity ▪ Plans to set up 25 minigrids ▪ Strong enterprise demand	▪ No national minigrid policy ▪ Private sector growth restricted ▪ Safety and security issues	▪ Develop least cost electrification plan ▪ Capacity building of key stakeholder ▪ Creation of B2B network
Bangladesh	▪ Minigrids for remote off-grid islands ▪ National target of 10% RE in the mix	▪ No specific minigrid policy/ strategy ▪ High minigrid tariff ▪ Land availability	▪ Policy for minigrids in remote areas ▪ Upgrade, connect existing minigrids and buy electricity
Bhutan	▪ Mandate of 60% land as forest, discouraging transmission lines ▪ Increased demand for electricity and reliability of supply in remote areas	▪ No dedicated policies for minigrids ▪ Lack of technical/ other expertise ▪ Private sector not active in minigrid	▪ Formulate minigrid policy & targets ▪ Capacity building programs ▪ Replicate success stories from SMS, i.e. Nepal interconnected hydro minigrid
India	▪ 5.5 million people lack access ▪ Need for reliable & quality supply in remote public institutions ▪ State policies driving private sector interest	▪ Lack of clarity on grid arrival issue ▪ Financing O&M and upgradation ▪ High minigrid tariff	▪ Finalize draft national minigrid policy ▪ Develop innovative business models ▪ Promote grid interactive minigrids

SAARC Countries	Drivers/ Opportunities	Barriers	Recommendations
Maldives	▪ Net zero GHG emission by 2030 ▪ Promotion of hybridization of diesel grids with RE ▪ Program on hybrid projects	▪ Need of energy sector plans on hybrid RE ▪ Limited sources of financing ▪ Lack of experience and private sector involvement	▪ Develop energy sector expansion plans ▪ Promoting PPA mechanism ▪ Conduct technical and vocational training
Nepal	▪ 2.12 million people lack electricity access ▪ Interest for minigrids in rural areas ▪ Existing govt. & donor programs on minigrid projects	▪ Existing minigrids cater to basic needs ▪ High minigrid tariff ▪ Policy for interconnection not clear	▪ Develop minigrid considering future loads ▪ Measures to reduce minigrid tariffs ▪ Design minigrid implementation plan
Pakistan	▪ 45 million people without electricity ▪ Issue of load shedding ▪ RE policy prioritizes minigrid solutions ▪ Lower minigrid tariff compared to grid	▪ Lack of institutional support ▪ Absence of minigrid policies ▪ Lack of private sector investment ▪ Dearth of technical expertise	▪ Develop least cost electrification plan ▪ Set in place minigrid regulations ▪ Replicate success stories from SMS i.e. SOLshare model ▪ Establish financing programs
Sri Lanka	▪ Govt focus on 100% electrification through centralized grids ▪ Opportunities for minigrid in outer islands running on diesel generators	▪ Limited scope for minigrid due to govt focus on centralized grid approach ▪ Electricity trans. & dist. restricted to CEB only	▪ Develop policy to support enterprise development using RE minigrids ▪ Promote and implement RE hybrid minigrids in outer islands

Figure 1: Summary of Country Specific Drivers, Barriers, and Recommendations

1 INTRODUCTION

1.1 Background

Access to electricity rose consistently from 71% of global population in 1990 to 83% of population in 2010 and to 90% in 2019, shrinking the number of those without electricity access from 1.5 billion in 1990 to 1.2 billion in 2010, and to 759 million in 2019. Expansion of grid infrastructure and deployment of off-grid solar including minigrids are the key reasons for this progress (IEA, Tracking SDG7: The energy progress report, 2021).

Minigrids are described as electric systems, consisting of power generation and distribution network, providing electricity to households, businesses, public institutions, productive and anchor loads (such as telecom towers) in remote settlement or in a town or city. Minigrids can be fully detached from the main grid or connected to it with a provision to isolate themselves from the grid.

Globally, at least 19,000 minigrids are installed in 134 countries and territories, representing a total investment of USD 28 billion, providing electricity to around 47 million people. In the South Asia region, there are around 9,300 minigrids installed, with majority of them based in Afghanistan, India, and Nepal (ESMAP, 2019). However, there is still a strongly felt need for last-mile energy connectivity that is cost-effective and reliable. Often, centralised electricity supply fails to deliver reliable and affordable electricity in the remote rural areas. This impedes energy access in under-served and unserved areas, and hence seriously affects quality of life, livelihoods as well as health and education.

Minigrids have been found to be the cost-effective option for rural electrification when the lower Levelized Cost of Energy (LCOE) of minigrid electricity supply outweighs the high fixed cost of extending the national grid (ESMAP, 2017). In unserved and/or under-served rural areas, minigrids have the potential to provide high quality energy for productive uses to communities.

Such systems score strongly on their potential to promote environment-friendly economic progress, and contribute to realisation of Sustainable Development Goals (SDGs) by reducing poverty (SDG1), improving access to energy (SDG7) and on social indicators such as health (SDG3) and education (SDG4). Minigrids also provide clean electricity services for irrigation and other agricultural activities.

Although there have been success stories of minigrids globally as well as in the SAARC region in the form of enabling policies, business models and innovative project designs, there is a need for a systemic analysis of lessons and experiences to enable informed decision making on scaling up the deployment of minigrids in the SAARC Member States, which has necessitated the present study.

1.2 Objective of the study

The overarching objective of the assignment is to facilitate enhanced deployment of minigrid systems in each of the SAARC Member States. The study will assess the efficacy of a Decentralised, Renewable Energy (DRE) based minigrid or RE combined with conventional energy generation sources to address local social and economic goals, and contribute to realisation of the SDGs. The study will provide stakeholders in the minigrid sector with the most up-to date information and analysis of the market status, challenges and trends in the sector and propose recommendations to overcome the barriers. The study will thus enable policymakers and practitioners in the SMS to be more informed on how to regulate, structure and manage a DRE based minigrid project for providing electricity access to unserved and under-served communities.

1.3 Scope of the study

The scope of study includes the following aspects:

A. Research and analysis on the status of minigrid systems and to explore their efficacy as decentralized means of energy access, powering livelihoods, building climate resilience, and furthering realization of SDGs.
B. Detailing the technical and operational structure of a minigrid and potential opportunities in the SMS.
C. Establish, through a country-level analysis, the key drivers, and barriers for minigrids, i.e., social, economic, technological, and financial etc.
D. Explore cost competitiveness and socio-economic benefits of electricity access through minigrids.
E. Analyse various business models that are in operation in the SMS including business models anchored by community, Renewable Energy Service Companies (RESCO) and/or a lease-to-own asset ownership and an analysis of financial models funded by donors, government, etc.
F. Evaluate potential of minigrid projects to encourage enterprise and entrepreneurship, i.e. enabling consumers who can utilize minigrid electricity to set up their own enterprises.
G. Identify country-specific conditions that shall ensure sustainability of minigrid systems.
H. Finally, provide insights on actual case studies to depict their broad success factors including their role to support growth in the SAARC Member States.

1.4 Limitations of the study

This study does not attempt to provide a comprehensive account of all minigrids in the SMS, focusing rather on elements that can be integrated in the design of minigrids, which would facilitate increased deployment of minigrids across the SAARC Member States. The study should also not be used to conduct detailed techno-commercial assessment of any minigrid project or structure. The study is more of an extensive analysis rather than an intensive assessment.

The analysis and data collection are based on public sources of information such as industry studies, journals, publications, and various research databases. The study undertaken is limited to secondary sources and discussion with key stakeholders in each SAARC Member State.

1.5 Challenges faced and ways to overcome

One of the key challenges faced in this assignment was to identify well documented information on operational minigrids across regions and countries with varying economic, social, financial, and environmental circumstances. The approach taken by the team to overcome this constraint was to identify key success factors or issues governing minigrid projects, develop a framework to analyse their impacts. Thereafter, the team used Key Informant Interviews (KII) and consultations to gather inputs.

A second challenge was in the way of engaging with stakeholders. Due to Covid-19 restrictions during the assignment, extensive field surveys were ruled out. However, the team conducted online engagement with stakeholders to overcome this handicap.

1.6 Structure of the report

The Study report comprises of five chapters and the executive summary, emerging as a best practices' guidebook for minigrid development in the SMS. The Executive Summary highlights the report's key findings and recommendations.

Chapter 1 gives the introduction and the background for undertaking the study. It briefly describes the rationale behind the study, importance, and benefits of minigrids. It also states the objectives for undertaking the study, scope of work, limitations to the study and challenges faced during the study.

Chapter 2 provides an overview of minigrid systems detailing the technical and operational structure of a minigrid system, description of various conventional and renewable energy technologies, cost trends, business models and latest innovation in the minigrid sector. It also details the barriers impeding the development of minigrid sector in general and various impacts of minigrids.

Chapter 3 details the status of minigrid deployment in the SMS. The chapter first introduces the framework for assessment of minigrid status in the SAARC Member States and then highlights the trends in policies and regulations, national strategy for electrification, technical aspects, business models, minigrid tariffs, financing, and barriers to development of minigrids in each of the SAARC Member State. It also discusses the opportunities for development of minigrids in each country and their resultant benefits.

Chapter 4 highlights specific case studies, with a view to substantiate facts and analytical results arrived at in the previous chapter. Cases are drawn across the SAARC Member States and globally such as first of its kind minigrid project in Afghanistan, minigrid project developed under SPEED and later Smart Power India in India, minigrid in Nepal, microgrid in Bangladesh, diesel- solar PV hybrid minigrid in the Asia Pacific and minigrid in Africa.

Chapter 5 presents the overall summary and recommendations to overcome different barriers for deployment of minigrids in the SMS. The chapter will yield, in the context of each SAARC Member State, conditions to accelerate deployment of minigrids and thus finally emerge as a guidebook for minigrid development in the SAARC Member States.

2 OVERVIEW OF MINIGRIDS

2.1 Global overview of minigrid sector

Minigrid market has grown from very few numbers of projects installed globally in 2010 to 19,000 minigrids in 2019. Most of these minigrids are hydro and diesel powered installed in 134 countries. There are around 7,500 minigrids (mostly solar hybrid) that are planned. As seen in Figure 2, Asia has the most minigrids installed, and Africa has the most minigrids planned. South Asia has a combined total of 9,300 installed minigrids and 2,200 planned minigrids (ESMAP, 2019).

Approximately half of installed capacity of minigrids is from diesel and other fossil fuel powered generators, with hydro and solar accounting for an additional 20% and 13%, respectively. Planned minigrids are expected to utilize energy from renewable sources, with hydro and solar accounting for 46% and 40% of planned capacity, respectively. To reach universal access to electricity by 2030, more than 210,000 minigrids need to be developed and operated globally.

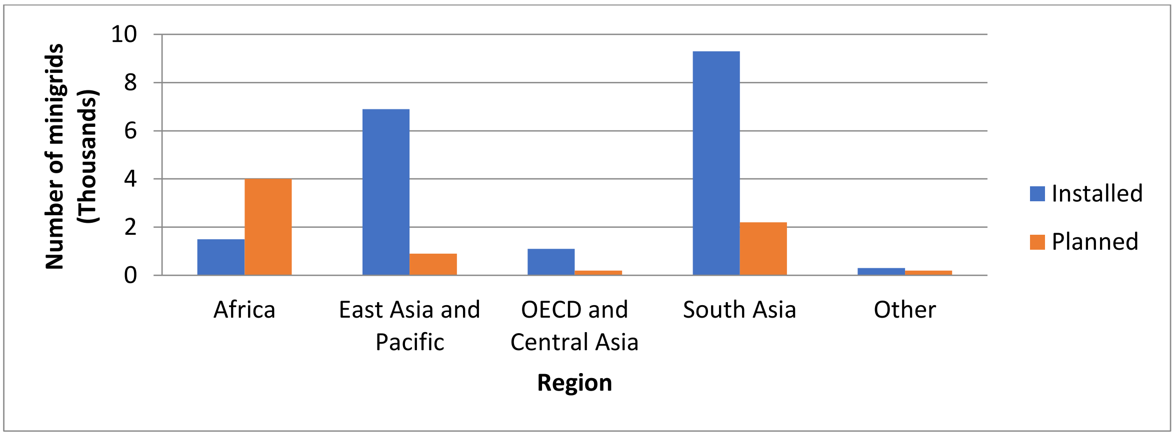


Figure 2: Regional Trends of Installed and Planned Minigrids[1]

Recent stabilisation and lowering of capital costs for minigrid projects, and improvement in quality of service have made minigrids an attractive option to connect un-served and under-served communities, complementing grid extension and standalone home electricity systems to catalyse progress towards universal access to electricity by 2030. In 2019, while the share of population with electricity access grew to an estimated 90%, 759 million people are still without access to electricity. The population without electricity access most likely grew in 2020 in Sub-Saharan Africa. So, considering the current and planned policies and further affected by the Covid-19 crisis around the globe, the 2021 Tracking SDG7 Report estimates 660 million people would still lack electricity access in 2030 (IEA, 2021).

While the potential for minigrids is large, their deployment is rather low as discussed above. The challenges faced by minigrid are not technical in nature but often due to uncertain or underdeveloped policies, financing, or regulatory issues. Therefore, stable policies and favourable economic condition are needed for growth of minigrids. Several policy elements that have been successful in creating an enabling environment for deployment of minigrids globally are depicted in Figure 3.

[1] (ESMAP, 2019)

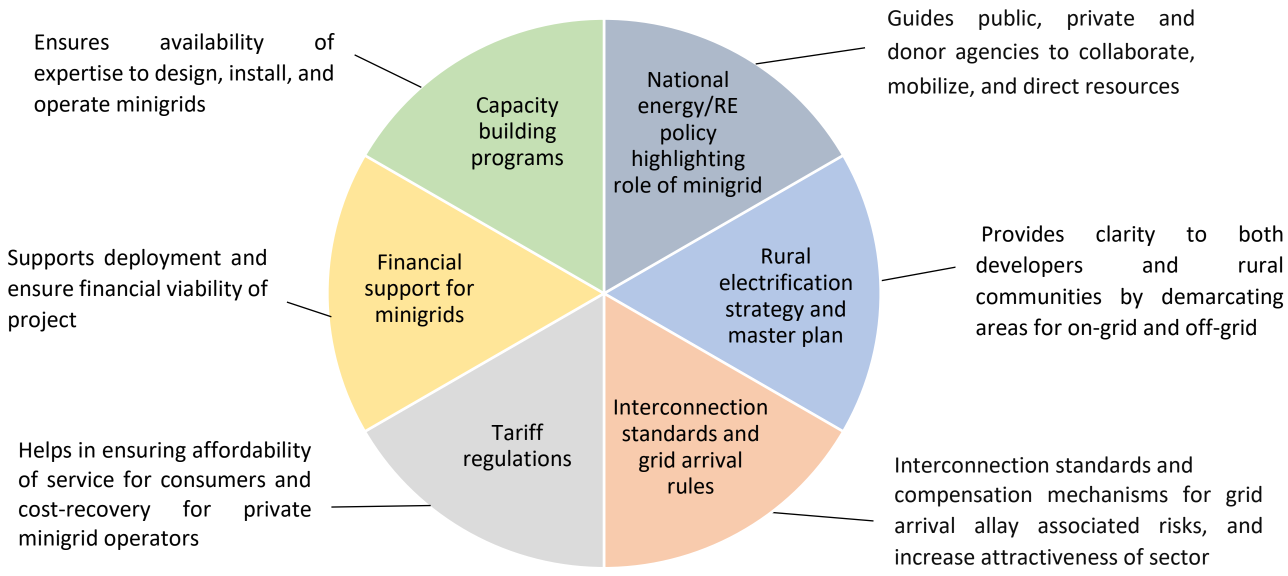


Figure 3: Global Best Policy Elements for scaling up minigrid

2.2 Technical features

The basic technical structure of a minigrid includes components that are grouped mainly under three categories - *production, distribution, and end-user (see* Figure 4*)*. Each system includes various components, which are based on available resources, desired services, and user features (USAID, 2018).

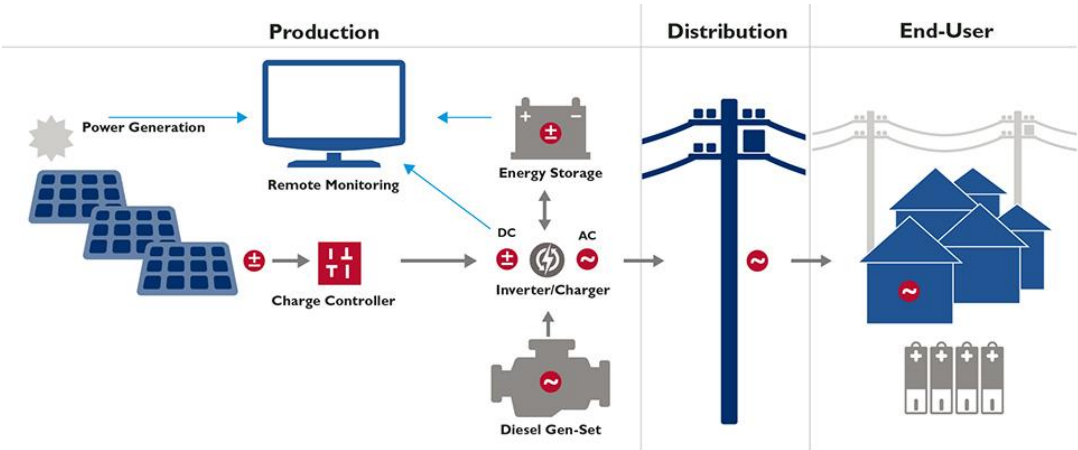


Figure 4: Technical Structure of a Minigrid[2]

Production: The production system comprises of power generation technologies, inverters, charge controller, energy management system, remote monitoring, and energy storage. The production system determines minigrid's overall capacity to provide electricity to end users. Power generation technologies in a minigrid may include a single renewable or non-renewable energy source or

[2] (USAID, 2018)

combination of energy sources (hybrid). Renewable energy sources such as solar and wind are intermittent sources. Therefore, to provide end users with power on demand facility, minigrid must include energy storage (such as batteries). Storage system stores energy at time of low demand and supplies it when resources are not available, or demand is higher than the resource available. Energy storage also adds stability to the system by storing energy for peak consumption.

Distribution: The distribution system transfers power from the production system to end users. It includes distribution lines, transformers, may include transmission lines, and the infrastructure such as electric poles or underground cables to support the electricity distribution network. The distribution system can be either Alternating Current (AC), having either single- or three-phase power, or Direct Current (DC) based network. Different components in a distribution system have different efficiencies, and therefore, the choice of voltage, current and transformers impacts energy losses. However, there are factors such as quality of power, size of the minigrid and user tariff, that usually dictate the option chosen by project developers.

End User Systems: End-user systems are an interface for end users to access, use and monitor electricity from the minigrid. It comprises of electrical connections from the distribution network, remote monitoring component, protection systems to prevent electrical shocks and power consumption metering. The design of end-user systems should always consider consumers' needs and energy uses. However, in a minigrid architecture, the narrative is more complex due to supply constraints: minigrids power stations may not be continuously generating, as a result there is a demand-supply mismatch that often calls for user rationing. Thus, users need to be monitored for excess consumption. At the same time, often usage of electricity is bound to a Pay-As-You-Go (PAYG) system, asking for prepayments. These realities often govern consumer behaviour, as well as business and revenue models.

2.2.1 Three generation of minigrids

Minigrid systems have been classified into three generations. First generation of minigrids are those that were installed more than 100 years ago and were later integrated into the national electric grid. Second generation minigrids were established by local communities or private entrepreneurs to provide electricity to communities in remote off-grid areas. These minigrids are mostly small-scale diesel generators and hydro based and are typical installed in remote areas of emerging countries. Third generation minigrids are technically more advance and complex than the first- and second-generation minigrids. These minigrids include new energy technologies such as solar PV, wind and battery energy storage and are designed to provide electricity 24/7 to the consumers (BNEF & SEforAll, 2020). The technical features of a third generation minigrid are depicted in Figure 5. The salient features of third generation minigrids:

- use new and advance technologies, which are declining in cost, for different components
- provide superior-quality service, often above 97% up-time
- use remote-controlled energy management systems, monitoring platforms, and prepaid smart meters to reduce operating costs and increase revenue collection
- adhere to standard designs for components and processes to reduce manufacturing, installation, and operating costs
- have typically 'grid ready' design to interconnect with the main electric grid, to mitigate investment risk when the main grid arrives

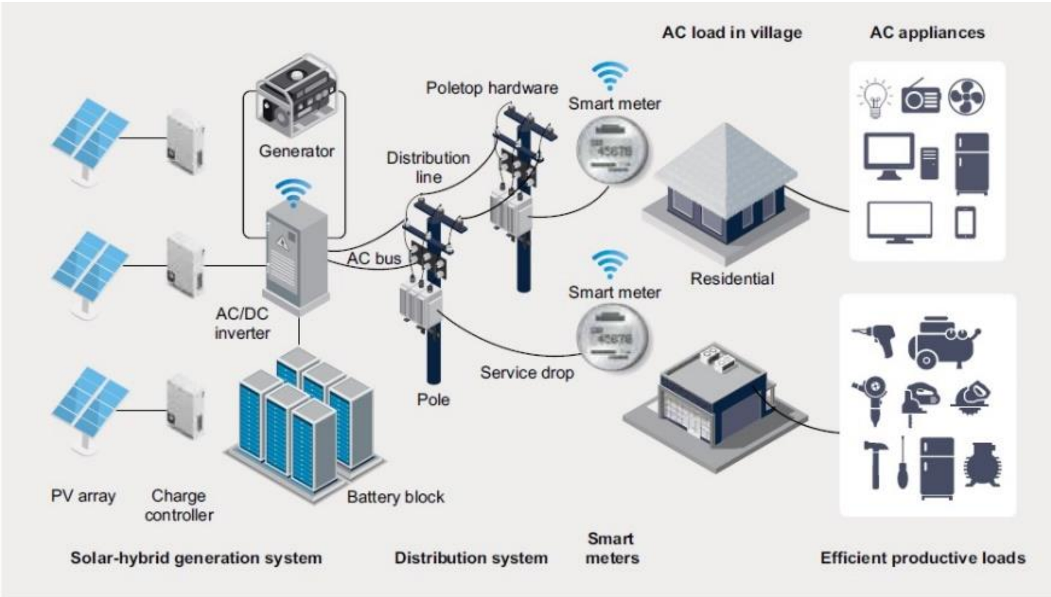
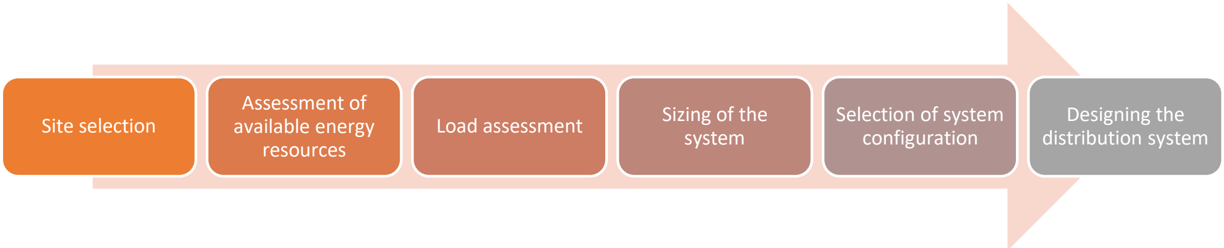


Figure 5: Technical Features of Third Generation Minigrid[3]

2.2.2 Key steps in design of a minigrid system

Successful design is an iterative process, meaning in each step project developers must consider balances in cost, Operation & Maintenance (O&M) needs, ability to provide power on demand, load efficiency and flexibility. There are six key steps in the minigrid technical design process (Section is based on (USAID, 2020)):



Site selection: Various studies have analysed the key parameters required to select a minigrid site. The key parameters for site selection are geographical suitability, energy resource potential, existing economic activity and availability of target customers, population density, power demand, security situation, as well as distance of main grid and risk of main grid arrival (IFC, 2017). The Alliance for Rural Electrification (ARE) study has analysed 11 case studies in South and South-East Asia and reported that two main criteria have emerged for selecting minigrid sites, which are (ARE, 2019): the local economic activity (including the potential for productive uses); and proximity to the main grid or remoteness of the site.

Assessment of available resources: After defining the geographic scope of the project, developers need to assess local energy resources, including their availability, potential, cost, sustainability, and potential conflicting uses. The choice of generation source generally depends on resource availability and cost of technology. During the assessment process, it is essential that project developers interact

[3] (ESMAP, 2019)

closely with local communities to understand valuable information about availability and potential conflicting uses.

Load assessment: A minigrid's size or capacity determines the maximum power output available from the system to meet the consumer loads. Therefore, it is essential to correctly estimate the present and future load requirements of the consumers before designing the systems. The present load requirements are estimated by undertaking a survey of households, businesses, institutions in the village to collect data from potential customers. The data on electrical devices present, their power rating and duration of use is analysed to assess the present power demand in the region. In case, the village does not have any kind of electrical appliances, then the power demand is determined based on the aspirational need of the potential users.

In design and development of minigrids, the ability of the project developer to correctly estimate the future energy demand profile of a user community (such as a village) is one of the key success factors. Incorrect estimation may lead to oversizing of the generation system, leading to lower capacity utilisation and weak cost recovery, making the unit less viable. On the other hand, under-sizing could lead to users not receiving as much electricity as needed, leading to rationing of electricity, dissatisfied customers, and a way for other providers to step in (such as a local diesel minigrid). These developments create potential conflict issues that often destabilise operations of the unit.

Sizing of the system: Developers and planners often use tool such as Hybrid Optimization of Multiple Energy Resources (HOMER) software to model and define system's expected loads, available resources, technical specification, cost to identify the most optimal size of the system. A minigrid that can meet increased demand over time is more financially sustainable. The best size for a minigrid also depends on whether it is likely to connect to the national grid in the future.

Selection of system configuration: Different energy generation technologies favour different configurations. Hydropower, geothermal energy, diesel power and biomass-based power generate AC, so they generally use AC configurations. Solar PV systems produce DC, and wind turbines can be configured to produce either AC or DC. Cost, expected usage, type of end user loads, and plans to eventually integrate into a larger (typically AC) network are factors that influence decision making. DC configurations are typically used for shorter distances, lower voltages and systems generating less power (W rather than kW). AC configurations, which transmit power more efficiently, are more commonly used for longer distances, higher distribution voltages and systems generating more power. DC systems are generally less expensive than AC because AC requires power conditioning equipment. However, the choice of technology mainly depends on the availability of appliances at consumer end. Today, vast majority of consumer appliances require AC supply and also considering minigrid integration into the national grid with minimal system or component replacements, which would not be possible in a DC-based network.

Designing the distribution and control system: Minigrid distribution systems are often more complex than those of standard grids as they may have bidirectional power flows and multiple energy sources. This operational complexity requires extra controls and software. In hybrid systems, each power source requires separate controllers, and the minigrid must have an overall management control to integrate the different power sources. The design of distribution systems should also comply with local codes and standards if it is likely to be interconnected with national grid.

2.3 Conventional and renewable energy technologies for minigrids

Minigrids can be powered with conventional as well as renewable energy technologies or a combination of both. They may use fossil fuel-based generation sources such as DG or Renewable Energy Technologies (RET) such as solar, hydro, biomass, or wind. Minigrids can also be coupled with energy storage systems such as batteries. Diesel Generators are still very popular due to their reduced up-front costs. However, some of the RET such as wind and solar are already competitive with diesel generators in terms of levelized costs of energy (ADB, 2017). The LCOE of solar and wind systems is estimated to be around USD 0.057/ kWh and USD 0.039/ kWh respectively (IRENA, Renewable Power Generation Costs in 2020, 2021). Whereas the cost of diesel systems has been found to range around USD 0.3 to 0.5 per kWh considering subsidized diesel prices (Solano-Peralta, Moner-Girona, van Sark, & Vallve, 2009). The technology-wise share of installed and planned minigrids worldwide is depicted in Figure 6. The description of different power generation technologies in minigrids are discussed below in this section.

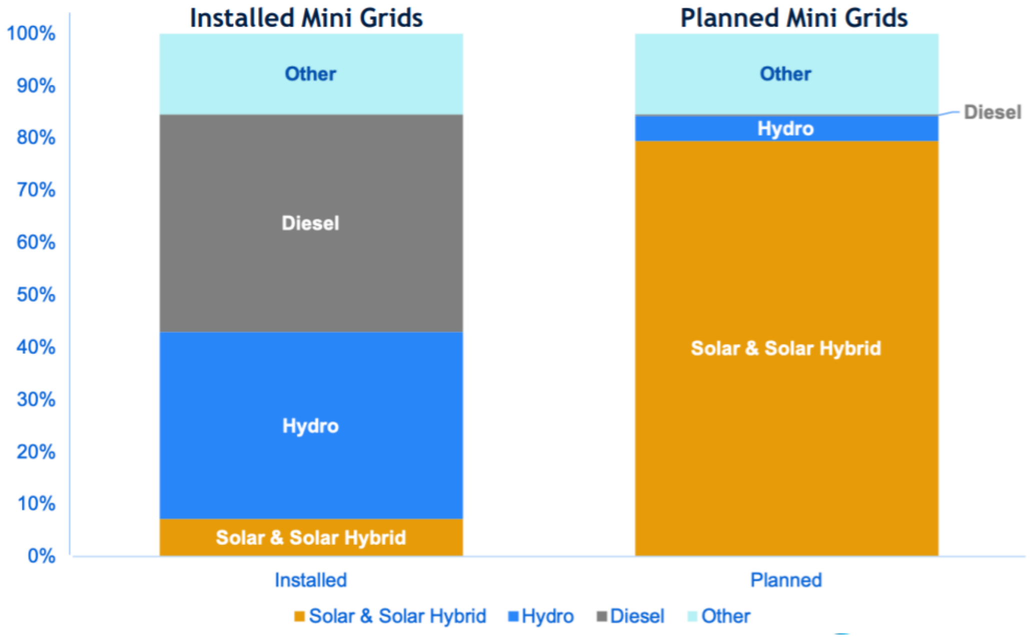


Figure 6: Technology Wise Deployment of Installed and Planned Minigrids Worldwide[4]

2.3.1 Photovoltaic energy systems

Solar photovoltaic systems are one of the most widely used RET in minigrids due to decline in the cost of the technology, its modular/ scalable deployment features and relative ease of installation and operation. The PV systems are often installed along with a back-up option such as batteries since the solar energy is intermittent. The atmospheric conditions such as cloudiness, dust storms, etc. at the location determine the variability of solar radiation at the ground level. This variability leads to a range of energy generation from the same solar PV module. Therefore, sometimes the solar energy generation is more than the power demand, in this case solar energy is stored in the batteries and when solar energy is low, then stored energy is utilized.

[4] (James Knuckles, 2019)

The power output of the PV systems depends upon the number of PV cells/modules installed, which means solar PV systems can be scaled up by adding a greater number of modules into the system. However, it is to be noted that adequate space shall be required to scale up the systems. Solar PV systems are thus able to match any power requirement and suitable for basic energy services to households, such as lights, phone charging, and fans, for a limited number of hours in the day as well as for the high-power service requirement (ADB, 2017). Figure 7 provides the basic layout of a solar minigrid system.

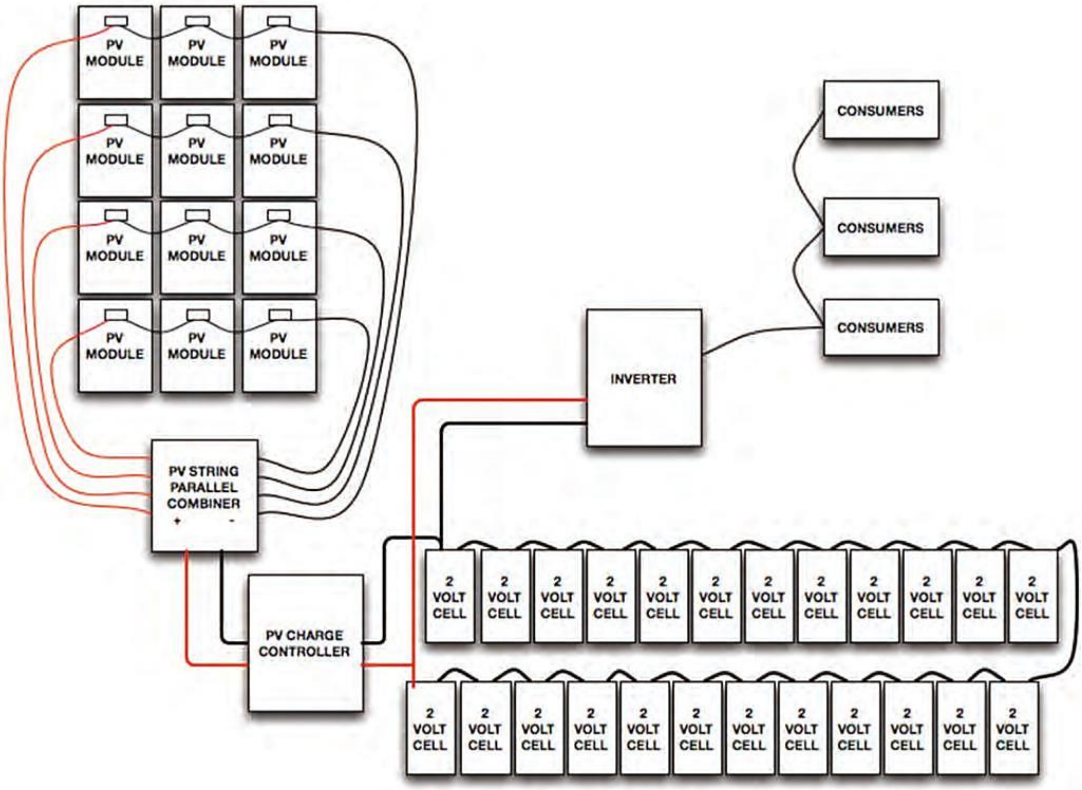


Figure 7: Basic Layout of a Solar Minigrid System[5]

2.3.2 Wind energy systems

Wind turbines transform kinetic energy of the wind into DC or AC current and the necessary power electronic converters transform this energy into DC or AC current at the voltage and frequency of the RE system. The power generated by a wind turbine is proportional to the cube of the wind speed. Therefore, it is important to get wind turbines sited in optimal locations with exposure to the strongest winds. Average wind speed at any site varies a lot within small areas. So, cost effectiveness of this technology is site specific. Wind turbines normally require a high level of maintenance compared to solar PV and repairs and spare parts availability are the major challenges for the wind energy systems. Solar wind hybrid minigrid utilizes solar PV modules and wind turbines to provide level power generation throughout the day as wind starts blowing during late evenings and reaches its peak during the nights and solar PV produce power only during the day.

[5] (ADB, 2017)

2.3.3 Biomass and biogas-based systems

Organic materials, such as wood, rice husk, coconut shell, bark, etc. are used to generate electricity from biomass-based power generation systems. Energy from biomass is reliable as it is free of fluctuation and does not need storage to firm up the capacity or compensate for the intermittency unlike wind or solar power . However, energy generation utilizing biomass resource is challenging because of issues of biomass supply chain. Biomass from agriculture is available only after harvesting period, so there is a need to procure, transport and then store required quantity of biomass within the stipulated time. The agri-residues and other biomass stocks have alternate uses as well such as fodder, cooking fuel, etc. and thus, there is limited availability of biomass for energy recovery, and the prices of residues are also high. Biomass projects generate solid, liquid, and gaseous waste that, if not controlled, can harm the environment. Thus, appropriate measures should be taken to minimize harmful emissions and comply with environmental regulations, which include proper operational procedures and emission control systems.

Biogas is a renewable fuel produced by the breakdown of organic matter such as food scraps and animal waste by microorganisms in the absence of oxygen. After biogas is captured, it can produce heat and electricity for use in engines, microturbines, and fuel cells. Stored biogas can provide a clean, renewable, and reliable source of baseload power in place of coal or natural gas. Similar to natural gas, biogas can also be used as a source of peak power that can be rapidly ramped up. The supply chain issues such as poor collection, improper segregation, and transportation of waste are barriers for utilising waste in biogas production.

2.3.4 Hydro based minigrids

Hydropower is the most established RET for electricity generation and also one of the RE power sources for autonomous minigrids. Storage system and run of the river are two main design types for hydro projects. Mini and micro hydropower is a proven, long lasting, and robust technology with low levelized cost of electricity. However, design of a hydropower plant for a minigrid project uses unique design and construction techniques requiring a considerable amount of specialist knowhow. Study of onsite resources and geological features is important along with the flow measurement over a certain period of time. The energy output from the run of the river hydro based minigrids is seasonal as it depends on the river flow.

2.3.5 Diesel generator sets

Diesel generator sets are the most common electricity generation method used in remote minigrids due to their low initial capital investment. Despite their high costs of operation, which is due to high prices of fuel and ongoing maintenance requirements, DG sets are still essential for supplying power to different loads, which are disconnected from the main grid. This is because DG sets are capable of automatically regulating power output to match the demand. Diesel generators are the cheapest power-generating option for islanded systems due to their lower initial investment cost per rated kW (ADB, 2017).

Minigrid running 100% on diesel fuel has the advantage of being theoretically dispatchable on demand. However, the isolated and sometimes inaccessible conditions in rural areas make the delivery of fuel to run a system for several hours a day very difficult. Moreover, while diesel generators can be used for lighting for a nominal daily price, they are an expensive source of electricity if used to run enterprises, since diesel is taxed in the SAARC Member States. Finally, gensets are noisy and polluting, and have severe health impacts. Each litre of diesel fuel consumption produces, on average, 2,664 g of CO_2. (Aaron Zvi, n.d.).

2.3.6 Hybrid systems

Minigrids based on 100% renewable energy, except for hydropower and biomass (if continuous supply is ensured), must rely on storage batteries to provide service to customers without any interruption. Hydropower minigrids can provide reliable electricity throughout the day due to the continuous flow of water.

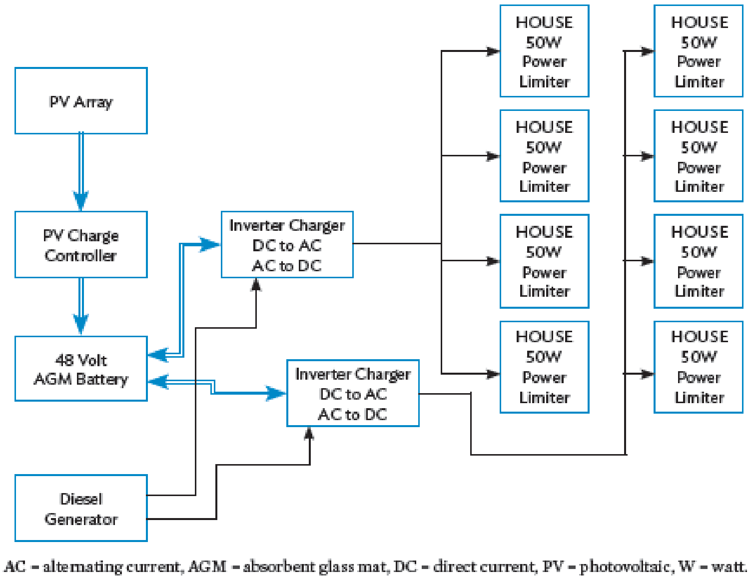


Figure 8: Layout for a Hybrid Minigrid System[6]

To provide reliable quality of service, RE minigrids need to have larger generation capacity in comparison to fossil fuel or hybrid systems, which will increase energy price. Thus, depending on the load profile, installing diesel generators along with RE is an effective way to decrease costs, reduce emissions and provide high-quality energy services. Renewable energy minigrids, in future, will increasingly use hybridisation of multiple sources such as solar/wind, solar/hydro and others, which are the least-cost long-term energy solutions capable of delivering the best services. Figure 8 provides a typical layout of hybrid minigrid system.

2.4 Cost of minigrids

The costs of renewable minigrids, and minigrids in general, have declined steadily over the past 10 years. The costs have fallen low enough that the technology is gaining interest as an alternative to conventional method of grid extension. Technological advancement and cost declines for solar PV and battery energy storage have made the economics of solar hybrid minigrids highly compelling compared to diesel-only systems (IRENA, 2016). However, costs vary greatly by region and are affected by regulatory, transport, and operations and maintenance costs.

[6] (ADB, 2017)

2.4.1 Capital cost of minigrid

The capital costs of minigrids include cost of project development, generation and distribution assets and logistics. In developing countries, the total cost of installing a solar-diesel-battery hybrid minigrid in an off-grid setup is extremely high for many rural customers. The capital cost for solar hybrid minigrids is in the range of USD 1,420/kW to USD 22,689/kW, with the average and median costs as USD 6,193 and USD 4,849, respectively (BNEF & SEforAll, 2020). Figure 9 provides the breakup of capital cost for a solar-diesel-hybrid minigrid system.

The generating components of the minigrid system accounted for 54% of total capital costs. The components with the largest share of overall cost were batteries (15%), distribution system (14%), PV modules (11%), inverters (5–9%), powerhouses (7%), and meters (4%). The variations in taxes and duties, wholesalers and distributors margins, and other costs incurred in setting up minigrid across countries explains much of the variation in minigrid component costs.

The costs of key minigrid components have fallen by 62–85% between 2010 and 2018, partly because of economies of scale outside the minigrid sector. For solar PV, the deployment of utility-scale solar PV parks and rooftop solar home systems drove cost reductions of 85%. The cost of lithium-ion batteries also fell by 85%, which was mainly driven by the increased use in electric vehicles and utility-scale storage projects (ESMAP, 2019). Figure 10 provides the trends in solar PV cost from 2011 to 2019.

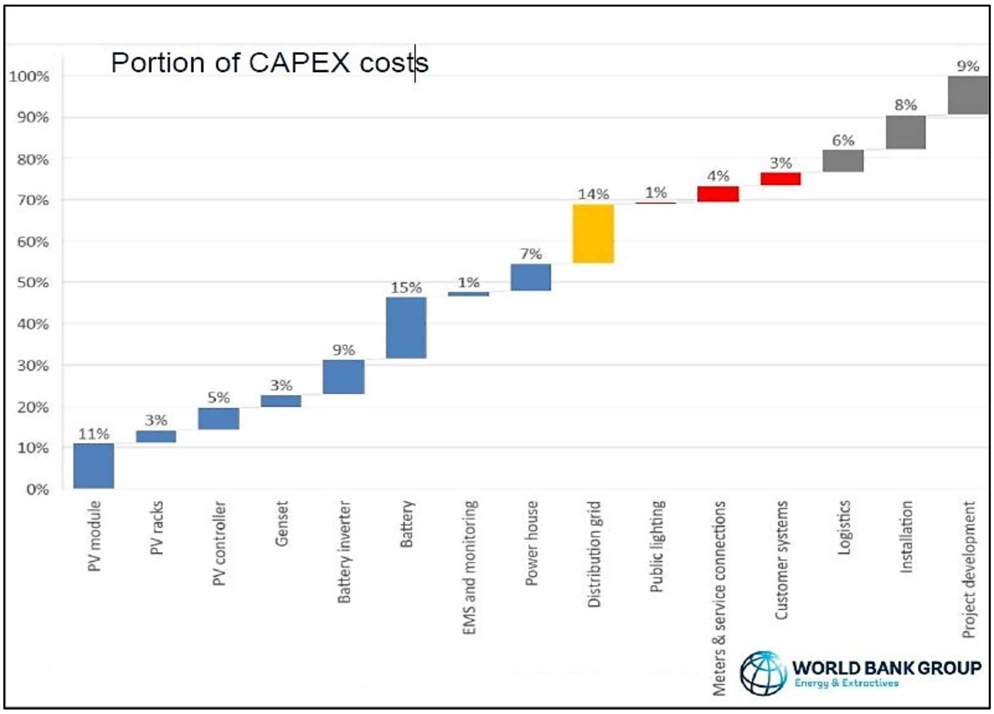


Figure 9: Breakdown of Capital Expenditure for Minigrid[7]

[7] (Chris Greacen, 2019)

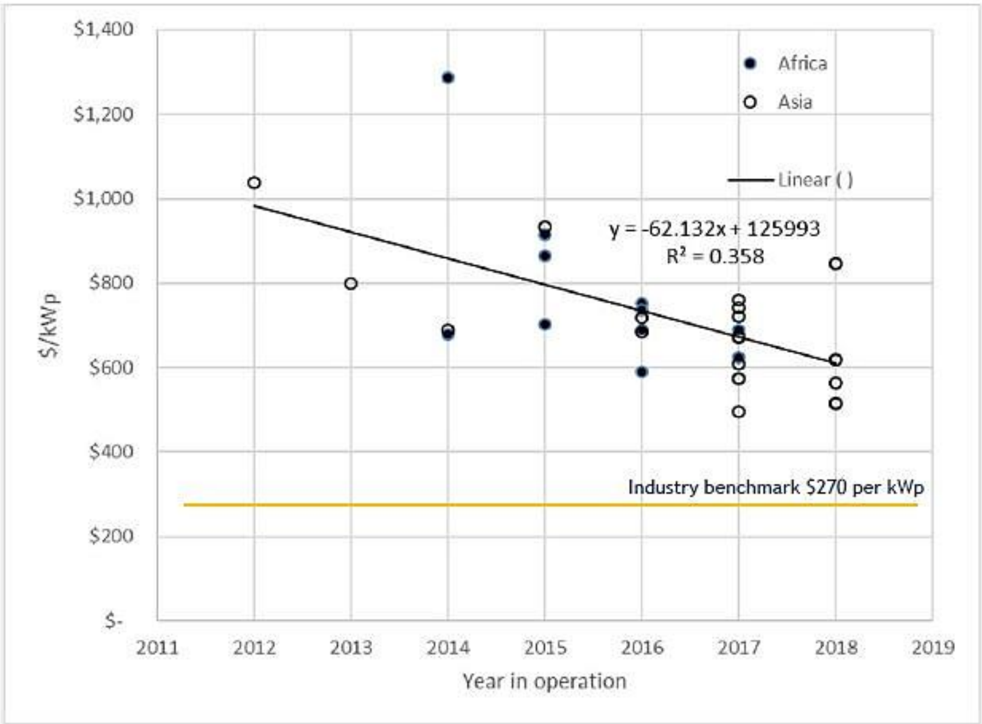


Figure 10: Cost Trends of PV Module from 2011 To 2019[8]

2.4.2 Operating cost of minigrid

Operating costs can be divided into two parts: fixed and variable costs. Fixed operating costs generally includes regular operations and maintenance, insurance premiums, and equipment replacement. Variable costs include fuel costs that can vary from time to time.

According to the Energy Sector Management Assistance Program (ESMAP) and the Rocky Mountain Institute (RMI), operating costs account for 35–40% of the total lifetime cost of a typical minigrid (BNEF & SEforAll, 2020). Remote monitoring, smart meters and control systems have now allowed developers to monitor and optimize performance of minigrids from far off distance and help to reduce operating costs.

Replacement costs of batteries form a large part in the operating cost of minigrids as battery banks need to be replaced after 3–10 years, depending on the type of battery. The growing use of lithium-ion batteries will help in reducing the replacement costs, as lithium-ion batteries have about twice the number of charging cycles before failure compared to conventional lead-acid batteries. Lithium-ion batteries are, however, more expensive storage option, when compared to lead acid batteries.

2.4.3 Levelized cost of energy of minigrid

LCOE is the go-to economic metric most often used to compare different power-producing systems. LCOE is usually applied to determine the minimum price that must be paid for electricity generated and sold from that plant. The LCOE combines a minigrid's capital and operating costs over the lifetime of the minigrid into a single cost per unit of energy.

[8] (Chris Greacen, 2019)

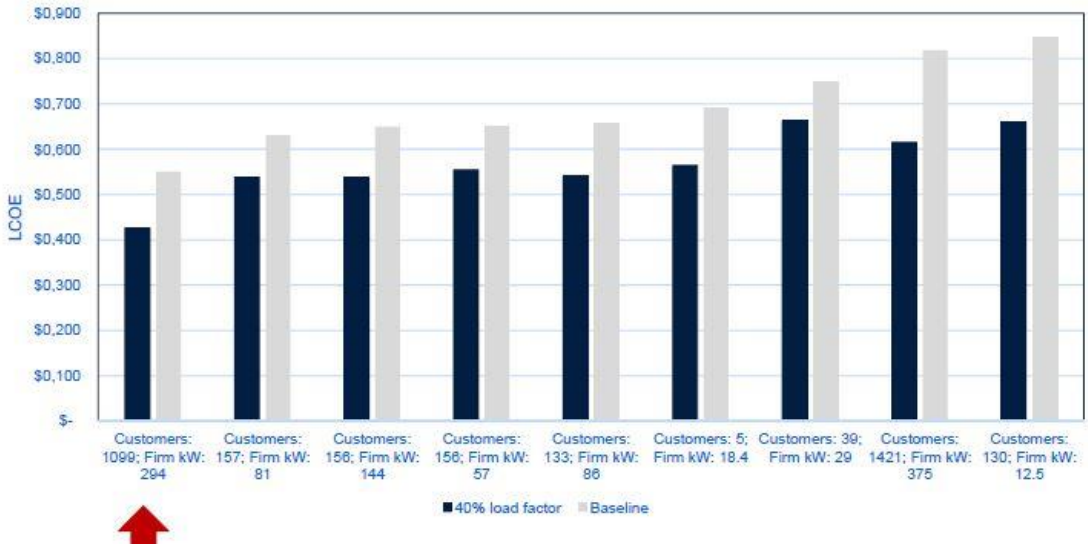


Figure 11: Result of ESMAP Analysis for LCOE Considering Different Load Factor[9]

ESMAP has analysed selected solar and solar hybrid minigrids in Africa and Asia to study the LCOE of minigrid electricity under different scenarios. As per ESMAP study, the LCOE for minigrids ranges from USD 0.55 to 0.85 per kWh. Bloomberg New Energy Finance (BNEF)/ Sustainable Energy for All (SEforAll) study has also analysed the LCOE for various types of minigrids currently in operation across the six case study countries. The study shows that LCOE of solar hybrid minigrid operating in isolated areas and serving productive loads ranges from USD 0.49 – 0.68/ kWh.

LCOEs have been found to be consistently lower for minigrids that serve productive-use customers than for those that serve residential customers. This is because productive-use customers such as agricultural processing facilities and enterprises tend to use daytime electricity, which correlates better with the generation profiles of PV systems, increasing the utilization rate of the minigrid and leading to a lower LCOE. It was found that when a 40% load factor was achieved through significant daytime consumption by local enterprises and commercial setups, the LCOE fell by 25% compared with the base case (see Figure 11) (Chris Greacen, 2019).

Increasing productive uses of minigrid electricity creates a win-win-win-win scenario for minigrid developers, rural entrepreneurs, communities, and national utilities over time. It reduces the LCOE, which increases the minigrid developer's margins and therefore financial viability. Entrepreneurs and communities benefit from affordable minigrid electricity, creation of new jobs and increased economic activity. Although electricity generation from renewable energy usually entails high fixed costs and related risks, renewables can play an important role in minigrids as prices have decreased considerably within the last few years. Figure 12 depicts the unsubsidized costs of 100% renewable energy minigrids from 2005 to 2035. The 100% renewable energy minigrids are a cost-competitive solution in comparison with small gasoline and diesel generators.

[9] (ESMAP, 2019)

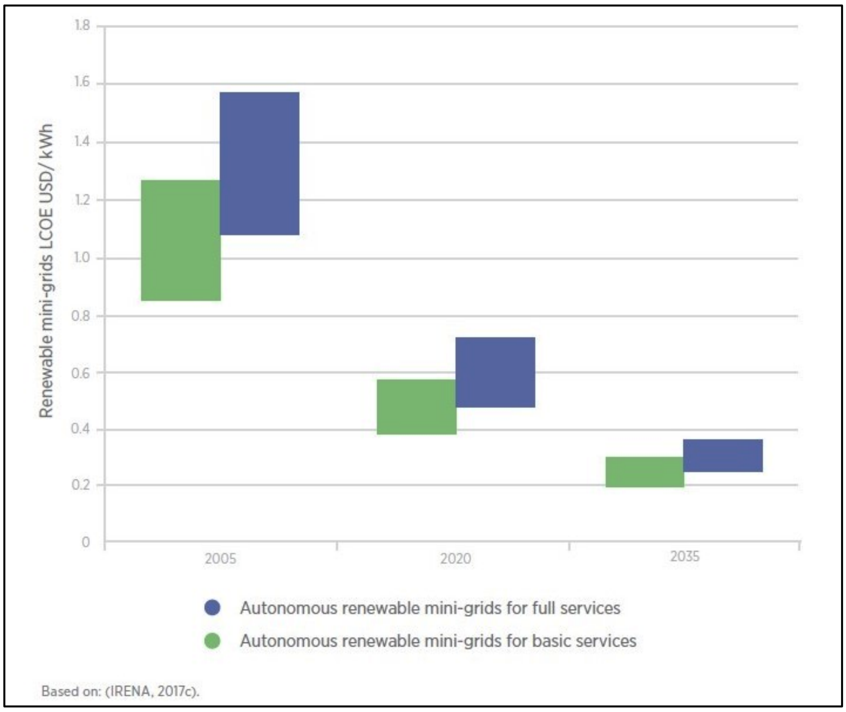


Figure 12: Unsubsidised Cost Ranges for Renewable Minigrids from 2005 To 2035 [10]

2.5 Service delivery models

Service delivery models of minigrids vary depending on their ownership, regulatory frameworks, financing, operation, and management. It is basically the method, by which minigrids are delivered - who is responsible to design and install minigrids, who will finance the minigrids, own, and operate them. The most popular and scalable delivery models are (USAID, 2018):

2.5.1 Community based model

In this model, local communities own and maintain minigrids and usually receive external help with regard to financing, design, and installation. Usually, developer provides technical assistance and public entity, or donor provides financial assistance. After the installation of minigrid, the community is responsible for tariff collection and O&M. The general schematic of community-based model is provided in Figure 13.

This business model is common in developing countries where private companies and utilities lack the capacity or incentive to electrify remote communities. This approach of business model is more likely to succeed alongside programs that promote productive uses of energy such as creating or growing enterprises. This will increase communities' demand and ability to pay, making the minigrid more sustainable financially. The community driven model is very common in South and South-East Asia. The West Bengal Renewable Energy Development Agency (WBREDA) in India creates local cooperatives and beneficiary committees to serve as its partner in minigrid development. More than 23 minigrids are owned and operated by communities throughout West Bengal as of 2016 (USAID, 2018).

[10] (IRENA, Innovation Outlook Renewable Mini-Grids, 2016)

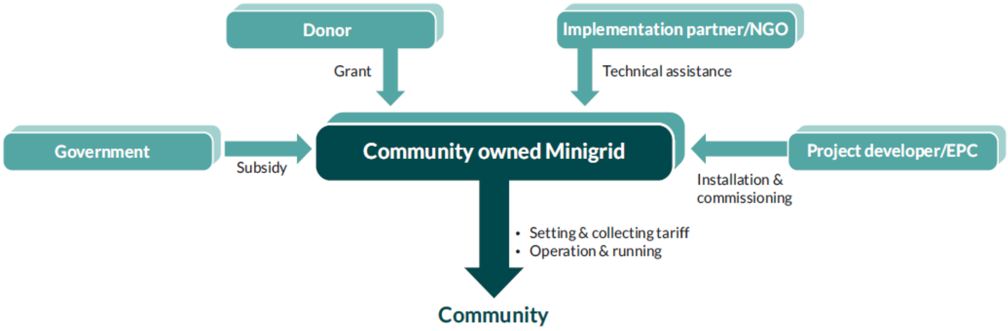


Figure 13 : Simplified Community-Owned Business Model[11]

2.5.2 Private sector model

The private energy service companies construct, operate, and maintain the minigrids, and financial assistance often comes from private equity and commercial loans. This type of business model is most common in countries with supportive policies and simple licensing procedures where investors can access credit, financing and subsidies and bilateral donors and/or non-governmental agencies provide technical assistance. Figure 14 shows the general schematic of private sector-based business model.

Regulations governing minigrids determine the type of business model for a project. Private sector must follow rules governing technology, taxes, quality assurance and other aspects of minigrids in the countries with minigrid regulations which can be expensive. With poorly designed regulations and failing to enforce them, private sector may refuse to participate in minigrid market due to high transaction cost. On the other hand, deregulated environments can cost investors more if private companies must navigate informal regulations affecting the tariff to be paid by consumers, which is often very high.

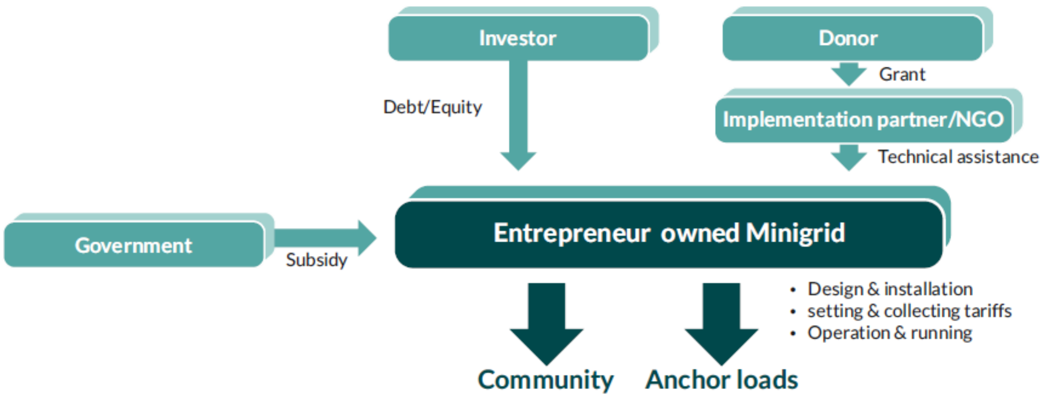


Figure 14: Private Sector Based Business Model[11]

For small scale remote projects, being usually not profitable, involving private sector in minigrid can be challenging. However, creative approaches such as anchor load approach, community clustering approach and private-private partnership can make minigrid investment financially attractive.

[11] (Smart Power India, First Edition)

i. Anchor load approach (Anchor Business Community (ABC) model)

Minigrid developer pre-identifies reliable commercial clients with predictable energy demand such as telecommunication tower to supplement demand in beneficiary community in this approach. Diversification of source of revenue can make risky project financially viable and investors can forecast and plan more effectively. Prioritising anchor customer needs over community energy needs may be risky in this approach if anchor customer goes out of business and stops purchasing the power from minigrid. However, with careful planning, this approach can result in successful minigrid project. Decentralised Energy Systems of India (DESI Power) used anchor load approach to develop viable minigrid project (USAID, 2018). The schematic of ABC model is provided in Figure 15.

ii. Community clustering approach

In this approach, villages with similar needs are grouped together for a shared minigrid project. The developer can use a single management structure either by connecting the communities together or by clustering the communities. Community clustering approach may also facilitate financing as funding is more readily available for larger projects. Chhattisgarh Renewable Energy Development Agency (CREDA) in India uses this approach to operate and maintain successful minigrid projects in remote areas (GNESD, 2014).

iii. Private – private partnerships

One or many private companies work together on a minigrid project sharing the responsibility of generation, distribution, and others. This approach protects assets in the event of one party's bankruptcy. In Tanzania, many small power producers use this approach (USAID, 2018).

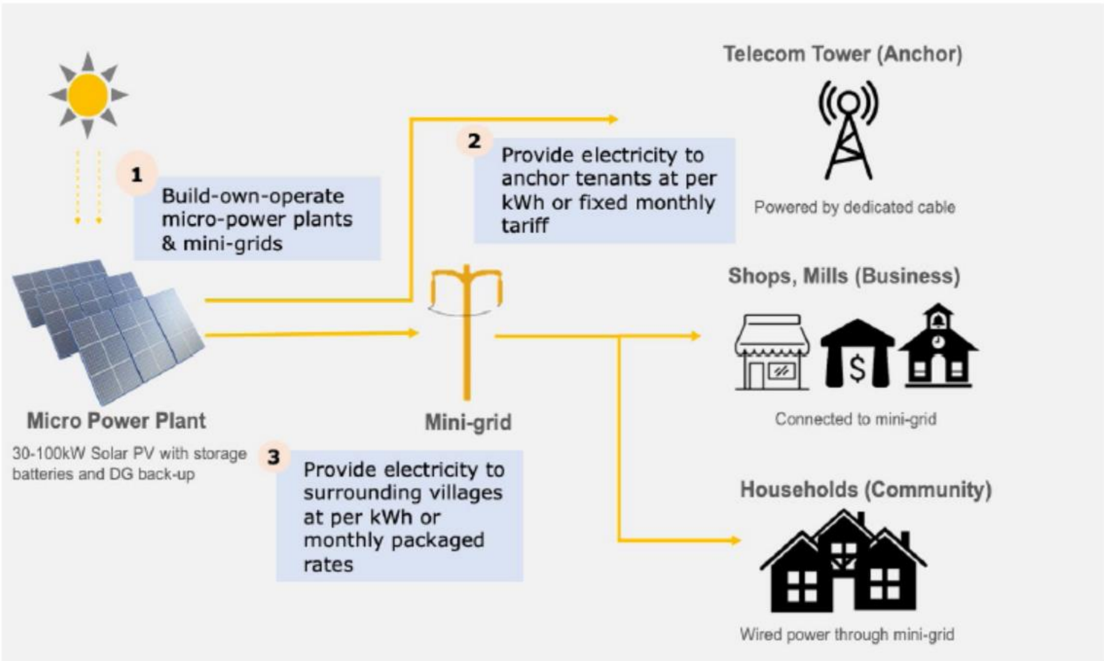


Figure 15: Schematic Diagram of ABC Model[12]

[12] (ARE, 2019)

2.5.3 Utility based model

National utilities operate minigrids in similar manner as the national grid but on a smaller scale. The utility sometimes contracts the local energy service companies to supply and install minigrids. In this model, subsidies are often used to keep tariffs affordable in remote areas. Usually, tariffs are set equal to that of national grid although cost of minigrid is higher.

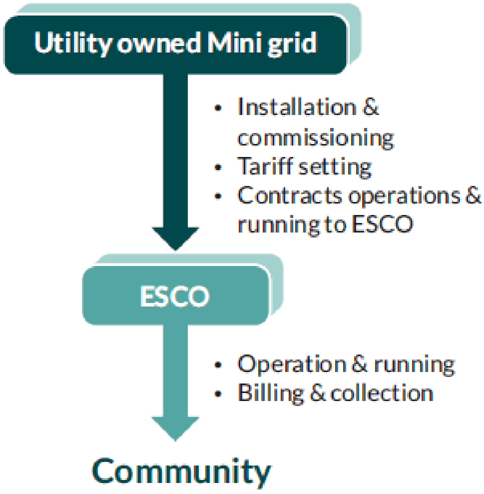


Figure 16: Utility Based Business Model[11]

This model is efficient when government supports minigrid development as part of its national electrification strategy. Traditional national utilities without a minigrid strategy tend to prioritize grid extension. Figure 16 provides the schematic diagram of utility-based business model.

Da Afghanistan Breshna Sherkat (DABS) in Afghanistan has implemented a 1 MW solar-diesel minigrid in Bamyan province that utilizes pay-for power mechanism, which could be run by local utilities (CIF, 2014).In Sri Lanka, Electricity Consumer Society (ECS) supplied electricity to rural households in villages that had not yet been connected to the main grid of the national utility (the Ceylon Electricity Board [CEB]). With the arrival of CEB grid, more than 100 of the isolated minigrids went out of existence, while three ECSs converted their minigrids into main grid connected Small Power Producers (SPP) (ESMAP, 2018).

In Bihar, a state of India, two electricity distribution companies - North Bihar Power Distribution Company Limited (NBPDCL) & South Bihar Power Distribution Company Limited (SBPDCL) are collectively running around 373 microgrids. The average size of each microgrid is around 10-20 kW. The microgrids have been developed and are being maintained by L&T Construction, a private project developer. The project has electrified around 44,000 households, spread across 240 villages. The monthly fee for households has been kept at INR 60 (USD 0.78[13]) and for poor households, the monthly fee has been reduced to INR 30 (USD 0.39) (M Ramesh, 2019).

Tanzania Electric Supply Company Limited (TANESCO) has implemented successful utility based minigrid model that uses cross subsidization and contracts with local energy service companies.

[13] 1 INR = 0.013 USD as on 27th October 2021

TANESCO charges a uniform tariff throughout the country to subsidize minigrid operations (USAID, 2018).

2.5.4 Hybrid business model

Local community, private entity and utility collaborate to implement and manage minigrid projects in this business model. Project developers usually use this model when one stakeholder lacks specific expertise and form joint ventures or use contracts to share ownership, reducing the need for capacity building. The schematic diagram of this business model is provided in Figure 17.

Although hybrid model can be an effective approach, it can be difficult to be set up due to the involvement of multiple actors. An example of a common hybrid model can be utility building and owning the minigrid, community managing the minigrid and private company providing technical assistance. The WBREDA in India provides a good example of partnership between a government agency and local communities where a state agency implements minigrid projects and local cooperatives manage them (GNESD, 2014).

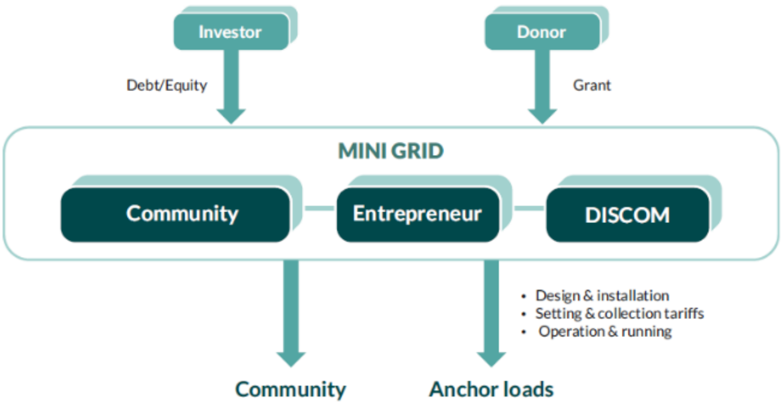


Figure 17: Hybrid Business Model[11]

In another hybrid model, private company generates and sells power to the utility through Power Purchase Agreement (PPA) and the utility distributes the electricity. Utility can also generate and sell power to local utilities for distribution to customers. Mwenga Hydro Ltd. in Tanzania generates the power and sells it to the rural power development company which distributes the electricity (USAID, 2018).

2.6 Operation and management

Operations and management are critical components of renewable minigrids or minigrids in general, and attributable as one of the key reasons why minigrids have failed to sustain over time. Operational issues for minigrids can be differentiated into two components, the standard operation and maintenance issues, which apply to minigrids as they apply to any electricity generation and distribution asset. However, minigrids also have an important additional aspect in Billing, Metering, and Collection (BMC) operations, which are part of the revenue collection architecture.

The second aspect of operational issues deal with management of the minigrids. This is more related to the overall health and sustainability of the minigrid over time. Minigrids often have persistent management issues, due to their almost-inevitable low overhead budgeting. Lower overheads imply that minigrids often cannot employ quality manpower to run the operations. Remote operations, which are innovative and IT-enabled, tend to fall short of solving interpersonal issues and any technical issues that are beyond the scope of the IT infrastructure, necessitating physical interventions. Finally, management of minigrids also translate to managing customer expectations in the long run, which are always aspirational in nature. Some of the other operation and management issues for minigrids are related to supply of fuel, which applies to diesel, biomass, and hybrid minigrids, management of intermittent loads, and management of revenues.

2.7 Integration of minigrid with the centralized grid

The integration of minigrid with the centralised grid has been a challenge for several DRE minigrid sites for several reasons. In certain regions, there is a lack of national standards, codes and regulations concerning the interconnection of minigrids into the centralized grid. The integration of a minigrid also faces technical difficulties due to discrepancies in design standards of minigrids.

Despite the above challenges, central grid and the minigrid have often coexisted as presented below:

- In-country or provincial regulations that allow minigrid to merge with central grid, has supported the coexistence of minigrid and central grid. An excellent case in point is the minigrid policy of Uttar Pradesh in India in which two exit routes have been identified at the advent of central grid arrival that is, the developer can either feed power to the grid or can sell the project to the discom after grid arrival. However, the tariff at which minigrid developers will sell power to the grid will be determined at the time of exit/integration with the grid, but the calculation methodology has not been specified in the policy. Therefore, the developers have opted to stay away from this policy because of the uncertainty over commercial terms of agreement (Priyavrat Bhati & Mandvi Singh, 2018).
- Sri Lanka has developed procedures to acquire existent minigrids and integrate them with the national grid as last mile connectivity. As a result, majority of erstwhile minigrids are now wheeling power to the central grid, or the asset has been fully integrated with the central grid (ADB, Sri Lanka Energy Sector Assessment, Strategy, and Roadmap, 2019).
- In Bhutan, minigrids that have lower cost of power (compared to a threshold value of BTN 5.81 (USD 0.077)[14] /kWh) are allowed to sell power to the centralised grid (IRENA, 2019)

Technical requirements for interconnecting minigrids with central grid can be of theoretical as well as practical relevance for minigrid design and operations. While in certain instances the two can be allowed to operate in parallel (especially in regions where the centralised grid is inexpensive but sporadic), there needs to be precautions (such as islanding) in design of minigrid architecture protecting the local minigrid in the event of a load shedding or brown out in the main grid. Other options (such as in Sri Lanka) are to generate and wheel the minigrid power to the central grid and connect the minigrid's distribution network with the nearest sub-station or create a bus bar for local distribution using the minigrid network.

[14] 1 BTN = 0.013 USD as on 27th October 2021, same exchange rate has been used to convert BTN to USD in this report

2.8 Latest innovation and improvements

Minigrids normally involve hybridized systems with a considerable share of renewable energy supply for electricity generation. However, renewable energy technologies are characterised by their intermittency that is difficult to predict. These conditions involve a challenge in terms of plant operation and management because of the required flexibility to maintain a regular system operation and stability. The minigrid faces further challenges in terms of rising energy demand, demand patterns and a lack of actual data analytics for the optimised operation and management of the system.

For these reasons, the minigrid energy sector is starting to innovate new solutions that include amongst others: Artificial Intelligence, smart grids, smart meters, and Internet of Things devices. These solutions aim to improve power management, integration, and system efficiency of the minigrid. Furthermore, DSM is another innovation that is being considered by minigrid developers to implement the strategies of actively influencing electricity demand to match electricity generation.

Smart grids are developing solutions that allow, for example, to trade electricity with the consumers in minigrid applications with the utilisation of demand-supply matching algorithms. Artificial Intelligence or Machine Learning power controls come into play to undertake the matching process, so that the minigrid systems are able to perform as an integrated system. Obviously, a critical point to consider for the application of these type of innovations, especially in rural environments, are internet connectivity constraints which may hamper the viability of such solutions.

2.8.1 Smart metering & Internet of Things

The meters are needed to measure and track electricity consumption for billing. The metering technologies are of two types - conventional meter and smart meter. Advanced Metering Infrastructure (AMI) combines smart meters, communication networks, and data management allowing a bidirectional communication between operators and consumers for the billing of the customer. This is undertaken without any manual intervention and allows at the same time to monitor the operational status of the minigrid remotely. The real time monitoring process and analytics allow to undertake a predictive load assessment and forecast future electricity demand. This is important as it will allow to manage the loads more efficiently or even decide on potential future actions that maybe required in the minigrid to ensure an optimal system operation.

However, smart meter needs to be integrated in the given energy system infrastructure and thus have to be tailored for the specific customer metering needs. For this purpose, IoT platforms are starting to become a preferred solution based on the data process capabilities with a variety of smart meters. Furthermore, IoT allows to set up custom visualization dashboards, where user alerts and notifications can be configured to communicate at the same time with other applications or platforms. Overall, the IoT could add on further automation and intelligent operation of the minigrid.

Figure 18: Example of IoT Smart Metering Platform[15]

2.8.2 Forecasting & Machine Learning

The electricity generated by renewable energy technologies such as solar PV and wind have one of the major drawbacks in its variability and the fact that the weather and forecasted generation cannot be guaranteed at any time.

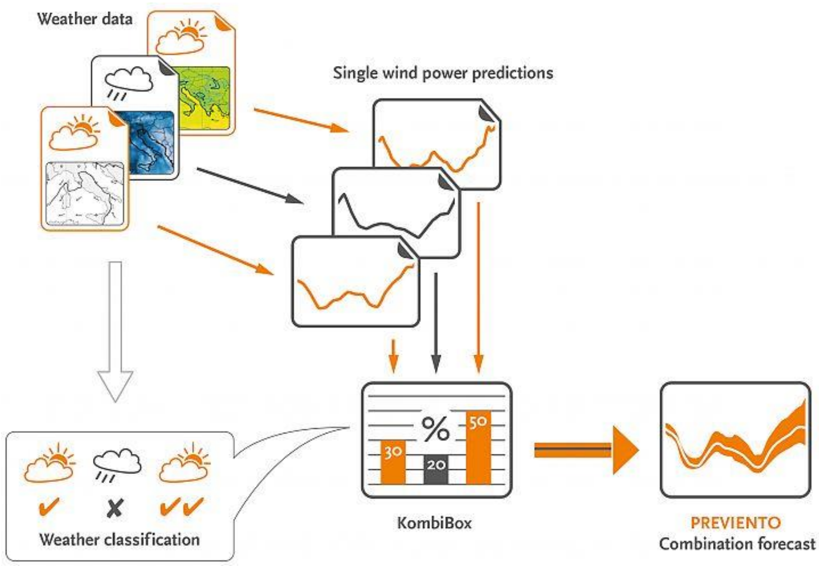


Figure 19: Weather Forecast Process[16]

This intermittency is challenging not only from the energy dispatching point of view but also in terms of its O&M and actual system regulation. Several techniques are currently being developed for wind and solar forecasting that include Numerical Weather Prediction (NWP) and Machine Learning (ML) techniques such as Artificial Neural Networks (ANNs) etc.

The NWP prediction models are normally operated by weather service companies that basically collect measured weather data, which they utilised to predict solar irradiation, wind speeds, ambient temperature, etc. This data allows then to estimate the power output with physical equations or

[15] (SteamaCo, 2020)
[16] (energymeteo, 2020)

statistical tools such as ANNs. Some of the power forecast providers are Meteologica S.A., Meteogrid, Entec Solutions, and Vaisala.

2.8.3 Artificial Intelligence

Artificial intelligence is defined as the capability of a computer or robot to undertake tasks that would normally be done by humans as human intelligence would be needed. With the help of AI, machines can learn from experience, adapt to new changes and perform human-like tasks. The rapid evolvement of power systems, smart meter infrastructure, communications, distributed energy resources and storage solutions result in complex and integrated power networks with a communication network system. These result in an enormous generation and exchange of data by the smart components. However, conventional computational techniques do not have the capability to manage and process these levels of information, therefore AI techniques are starting to be implemented for such a task. In the renewable energy context, AI is starting to be utilized in the O&M to improve the operational efficiency of the plants.

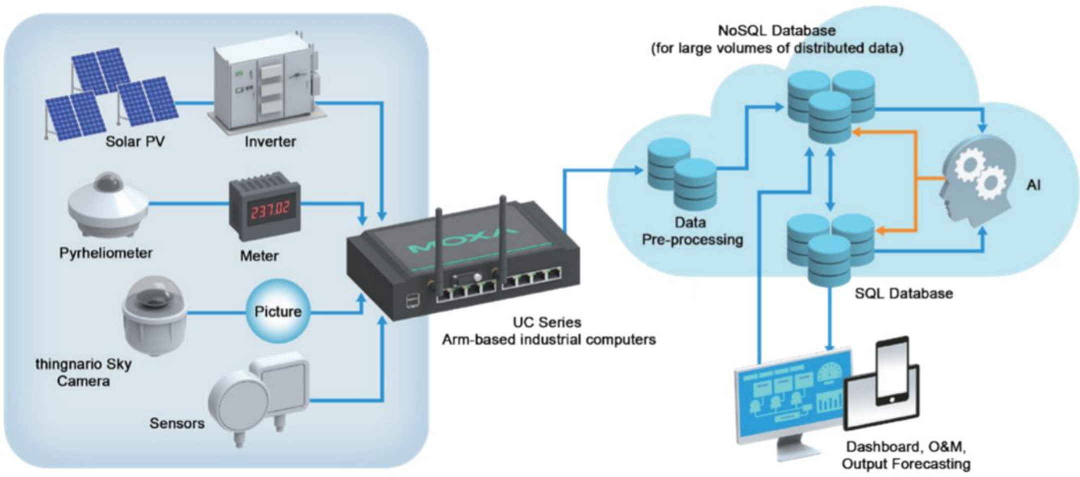


Figure 20: O&M AI Forecasting Tool[17]

The AI allows to assess large volumes of data from diverse real-time sensors where a prediction of the power to be generated in a minute timeframe would be forecasted. This estimate would then be compared against the actual power generation by the renewable energy plant. If a large discrepancy is tracked by the AI, the system will send an alert signal to the operators to perform preventative maintenance. This will not only avoid potential system component breakdowns but also minimize potential underperformance losses and labour cost reduction.

2.8.4 Demand side management

The renewable energy minigrid and energy systems are exposed to stability and reliability as a result of the intermittent nature of the source. The approaches for solving these challenges are various such as storage solutions, load curtailment and DSM. However, energy storage solutions tend to be costly and load curtailment would impact the user in terms of expected energy services. The objective with DSM is amongst others to encourage customers to alter the consumption profile. In the minigrid context, through DSM, the option of variable tariffs would displace electricity consumption from peak

[17] (MOXA, 2019)

demand periods that would help to reduce electricity costs. This would avoid the need of system capacity upgrade and at the same time have a more levelled demand over the day. Other DSM option in the minigrid context could involve charges when inefficient equipment is utilized. This would favour the customer utilizing energy efficient equipment. The DSM load management technique can be classified as:

i. Load levelling

It optimizes the electricity demand so that reserve capacity is minimized over periods of high demand. This can be undertaken through following levelling methods (see Figure 21):

- Peak clipping: This basically involves the reduction of the consumption during peak demand periods
- Valley filling: For low demand periods the "filling" with consumptions that are displaced to that period. For example, mobile charging equipment
- Load shifting: This option involves the displacement of the loads from peak to valley times
- Load conservation: This would involve the application of efficiency measures to reduce the customer electricity demand

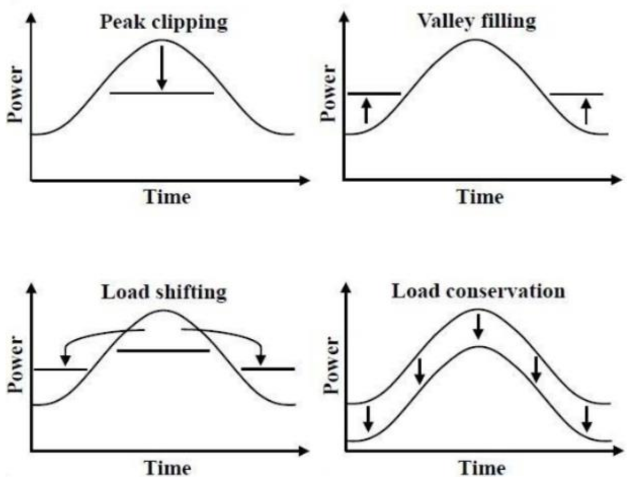


Figure 21: Load Management Techniques[18]

ii. Load control

This compromises a system or program that allows to modify the user end loads in response to specific events (e.g., network issues, high electricity prices, etc.). The load control in the minigrid context would involve a retailer that would have the option to switch on or off potential customer loads.

[18] IEEE FOUNDATION

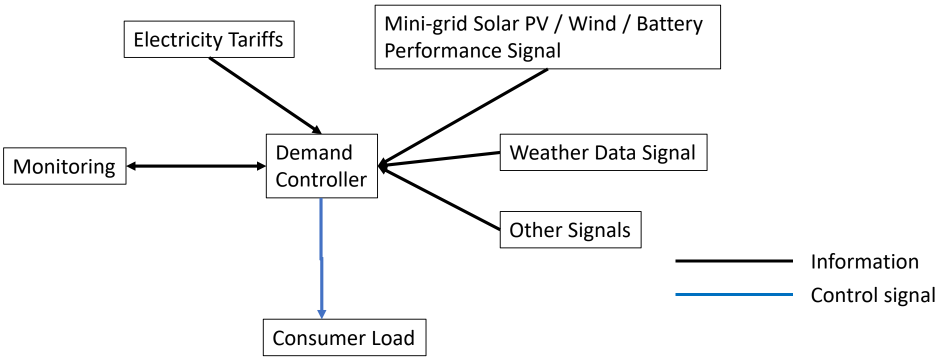


Figure 22: Load Control Process

Usually, there is an interruptible load contract between the user and retailer with some incentives or compensation in return. Normally the retailer does not physically interrupt the electricity supply for the customer, instead it provides the user with an advance notice requesting the load curtailment. Under the scenario of not complying with request this would potentially lead to penalties or even customer load interruption. The current load control technologies do allow the switching of the loads to be undertaken:

- Automatically: the switching responds in an automatic manner to a specific signal
- Manually: the switching is undertaken in response to a specific event or information

The switching may be undertaken locally or in a remote manner by a program triggered by a given signal. The actual switching of the loads may involve:

- Load Cycling: the loads are switched on and off based on a timing schedule
- Load Reduction: the loads are reduced to defined pre-set values
- Load switching: basically, switching off the load

The key demand management strategies and technologies have been summarized in Figure 23 below.

DSM Strategies	***DSM Technologies***
Use of efficient appliances	*Current limiters*
Scheduling of commercial loads	*Time switch, GridShare*
Managing residential consumption	*Load limiters, smart meters*
Consumer education	*Prepaid meters, Advance metering infrastructure*

Figure 23: DSM Strategies and Technologies

2.9 Impacts of minigrid

The impacts of minigrid projects can be experienced across at least eight of the seventeen Sustainable Development Goals in addition to SDG7 - access to electricity. Figure 24 depicts the various SDG levels relevant to minigrid impacts (BNEF & SEforAll, 2020).

Electricity access: Around 47 million people have been provided access to electricity through 19,000 minigrids installed across 134 countries globally (ESMAP, 2019).

Reliable and quality electricity: Today, minigrid developers are designing systems that can provide 24/7 electricity. Use of remote monitoring systems, smart meters, load limiters have led to increase in the quality and the reliability of minigrids. For example, it has been observed that the average uptime of minigrids owned and operated by Africa Minigrid Developers Association (AMDA) members have exceeded 97% (ESMAP, 2019).

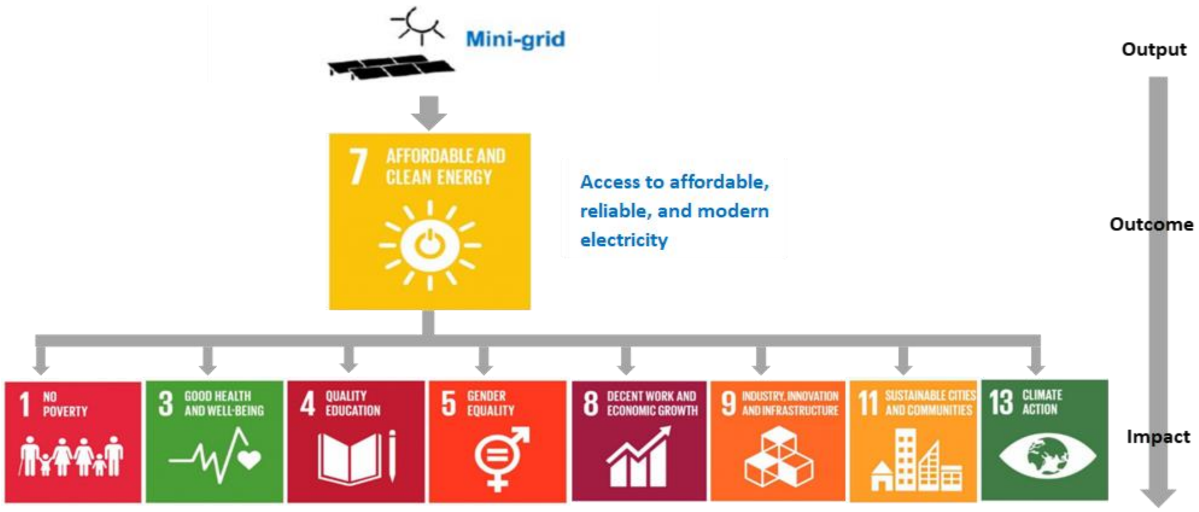


Figure 24: Impact of Minigrids[19]

Economic development: Modern minigrids are designed such that the payback periods are less than 12 months for more than 30 income-generating machines and other equipment. As a result, it improves financial viability of developers as well as create jobs and enhance livelihoods in communities (ESMAP, 2019). As per Global Off-Grid Lighting Association (GOGLA) data, USD 4.9 billion has been generated as additional income because of off-grid solar projects (BNEF & SEforAll, 2020). In another example, an African minigrid project developer, RVE.Sol has set up Kudura minigrids in East Africa to provide electricity as well as drinking water to populations whose mean per capita income is just about USD 3 per day. The project has positively impacted 2,100 Kenyans directly. The fee-based PAYG model has reduced energy costs in these households by almost 75%, as reported by one of the investing entities in the company (Acumen, 2021).

Cleaner environment: A renewable energy powered minigrid avoids noise and air pollution caused by diesel-based generators, thereby contributing to a cleaner local environment. ESMAP has estimated by 2030, 10–15 GW of solar PV could be installed using 50–110 GWh of mostly lithium-ion batteries and energy efficient appliances, which is expected to result in 1.5 billion tons of carbon dioxide emissions avoided (ESMAP, 2019). However, there are hazards and pollution associated with disposing of these batteries which needs to be addressed.

Improved health and education: Use of minigrids has resulted in improved health indicators for women and children from the replacement of polluting energy sources such as kerosene lamps. Further, in the current context of the Covid pandemic, minigrids energising rural health clinics has paved way for a functional clinic capable of storing Covid vaccines and other medicines. Minigrids have also resulted

[19] Figure recreated by the Consultant based on Figure 88 given in (BNEF & SEforAll, 2020)

in improved education indicators through access to reliable household lighting and school power supply.

Benefit to national utilities: Modern minigrids are typically designed as grid ready as well as promote productive uses of electricity and create local economic development. Thus, when the main grid arrives at the site, there is already significant demand for electricity and consumers have greater ability to pay, hence increasing the economic viability of the main grid's extension.

Private sector participation: Private-sector participation in the minigrid market has increased as the economics of minigrids are becoming more attractive. Several industry associations across countries and regions have been initiated such as AMDA which comprises of 27 minigrid developers (each operating a portfolio of commercially viable minigrids) in Sub-Saharan Africa, CLEAN network in India is a network of 200+ members across India and is considered as the industry body for the DRE space.

2.10 Barriers to minigrid development

Decentralized systems including minigrids will make up nearly three fourth of the additional connections to meet universal electricity access by 2030 (MGP, 2021). Most of these connections will be from renewable energy. However, development of minigrid sector has been slow due to several barriers for which solutions are still evolving. The barriers can be categorized into four main headings which are:

Policy and Regulatory Barriers: It has been observed globally that when government strategy or policy commitments for minigrids are unclear then it leads to slow development of the sector. Regulations requiring licensing of developers for generating and distributing electricity in a country have also hampered scaling up of minigrid. Other regulatory provisions such as cap on tariffs that can be charged for electricity add further challenges. Most of the installed minigrids globally are not able to compete with the national grid in terms of tariff. So, national grid will always be a threat to the minigrid sector if there is no clear regulation about the integration of minigrids to the national grid after its arrival.

Financial Barriers: Easy access to finance to meet the upfront cost as well as operating costs is a challenge to the minigrid industry. Financing that is available is prohibitively expensive and access to project financing is also limited. Potential private financiers perceive a greater risk to invest in minigrid sector as they have limited experience and exposure. The International Energy Agency (IEA) estimates that over USD 100 billion investment is needed in minigrids sector by 2030 to achieve universal energy access (Agenbroad, Carlin, Ernst, & Doig, 2018). Minigrids often face difficulty in recovering investment or meeting the return expectations of private investors in a short duration of 3-4 years. For this reason, private investors are generally not interested in minigrid projects. Therefore, minigrids require capital subsidies upfront by the government or through other benevolent sources to make them financially viable. As part of the CLEAN study, 49 financial institutions in India were interviewed to understand their perspectives on financing of distributed renewable energy sector including minigrids. Some of the respondents, around 15%, are of the view that project developers and some financial institutions need alternative form of funding, such as philanthropic/CSR/grants/debt, for sustaining the project during their initial years. Financial institutions have also reported that project proposals are often not bankable enough to make investments (CLEAN & Margdarshan Advisory & Consultancy Services, 2020).

Technical Barriers: Minigrids are unique and require custom installations specific to the site. There are also limitations related to technical expertise available among the human resource to deploy minigrid. Intermittency of the renewable resources also adds to the complexity in technical design of RE minigrids. Minigrid system should be designed as grid ready to avoid redundancy of the project after the arrival of the grid, but many countries have not yet issued the interconnection requirements for connecting to main grid.

Economic Barriers: Remote areas or off grid areas have low or unpredictable demand to electricity as well as low-income sources as many rely on agricultural activities which is seasonal. This directly impacts their ability to pay for electricity bills and the revenue generation/ profitability of project developers. Minigrid developers are thus increasingly promoting enterprise development in the areas, which will lead to growth in demand of electricity and help in income generation and hence increase customer's willingness and ability to pay for the electricity consumed.

3 STATUS OF MINIGRIDS IN SAARC MEMBER STATES

3.1 Framework for assessing minigrids status

The section lays out the framework for assessing the status of minigrid development in each of the eight SAARC Member States. The assessment has been carried out using a multi-dimensional framework mapping across nine categories (i) Status of access to electricity and minigrids, (ii) National strategy for electricity access, (iii) Policy & Regulations for minigrids, (iv) Technical aspects of minigrids (v) Business models for minigrids, (vi) Minigrids tariff, (vii) Financing for minigrids, (viii) Opportunities for minigrids and (ix) Barriers to minigrids (See **Error! Reference source not found.**). Secondary data as well as information collected through discussions with stakeholders in each country has been used to carry out the assessment. The assessment provides a comparative analysis on minigrid development in each country and provide cross-learning potential that could be exploited in the SAARC Member States for scaling up minigrid deployment.

Assessment parameters	***Description***
Status of access to electricity and minigrids	As per the general trend observed globally, the closer a country comes to 100% electrification, there is lesser demand for minigrid projects. This section will analyse the status of access to electricity and installed minigrids in the country.
National strategy for electricity access	Government strategies often vary across countries regarding use of minigrids for enhancing access to electricity. This section will assess the national strategy for improving access to reliable electricity and role of minigrids in the strategy.
Policy and regulations for minigrids	There may be a varying degree of policy and regulatory measures adopted across the SMS to support MG development. This section will present the policies and regulations implemented in each SAARC Member State.
Technical aspects of minigrids	Use of innovative technologies in generation, storage, O&M, revenue collection, etc. enhances the viability and therefore attractiveness of MG. This section will discuss the technological focus and advancements in each SAARC Member State.
Business models for minigrids	Maturity of a MG business model ensures that the project is robust in design, therefore more resilient to market dynamics. This section will analyse the various business models that have been implemented in each country.
Minigrids tariff	In most cases, MG tariffs are higher than grid tariffs which is primarily due to power from the grid being subsidised and not reflective of the true costs of power. This section will analyse the MG tariffs in the country and their affordability.
Financing for minigrids	Each country has different level of financing available for MG project which may be donor grant, public loan, commercial loan, equity, and debt financing, etc. This section will discuss the financing landscape available in each country.
Opportunities for minigrids	Each of the SAARC Member States have their unique opportunities for MG projects. These range from access to electricity, high unmet demand, etc. This section will analyse the various opportunities for MGs in each SAARC Member State.
Barriers to minigrids	Key barriers to the sector are policy-level impediments, supply and demand mismatch, low plant load factor of MG, lack of adequate financing. This section will discuss the country level barriers for MG development.

Figure 25: Framework for Assessment of Minigrid Status

3.2 Afghanistan

3.2.1 Status of access to electricity and minigrids

Afghanistan has about a third of its population connected to the electricity grid (ADB, 2020). The country still depends heavily on imported electricity and fuels. Lack of domestic generation remains the key challenge for energy security and energy access in Afghanistan. Energy security and access are high development priorities for Afghanistan.

Since 2001, major efforts have been on reconstruction and expansion of the national electricity grid. Despite these efforts, it is accepted that there are areas in the country that the national grid will not serve in next 20-30 years. This is due to the slow progress of integration of the national grid, which still operates as a few regional grids, which are supported by electricity imported from neighbouring Uzbekistan, Iran, and Turkmenistan, among others.

In addition, secondary information indicates that the current electricity delivery infrastructure is neither reliable nor economically attractive for most consumers. Frequent power outages create discomfort and hindrances, and necessitate power options, especially for commercial and industrial facilities. The delicate security situation in the country has often led to transmission and distribution lines being damaged (due to arson), which have delayed and affected plans for electrification (GardaWorld, 2021). This also implies greater need for localised networks such as minigrids. Thus, the current energy access landscape offers promise for minigrid project development.

Historically, there were many micro hydropower units (about 40 kW or less) that were set up under the National Solidarity Plan (NSP) between 2003 and 2013, although parts of NSP continued under the National Area Based Development Programme (NABDP). Originally targeted for developing 5,000 villages, the NSP implemented about 2,500 village level electrification systems powered by micro hydro units. Several solar home systems were also installed under the programme (Beath, Christia, & Enikolopov, 2015). The management of these units were left to community level institutions called Community Development Councils (CDCs).

However, most of these installations were not managed properly due to lack of technical resources in CDCs, and without any operation and maintenance support, did not sustain for many years. Also, the CDCs did not have the capacity to execute O&M for the assets. As a result, most of the NSP and NABDP projects are in an inoperative state.

The most notable among recent initiatives in the direction of minigrid project development is the United Nations Development Program (UNDP), Afghanistan and Ministry of Rural Rehabilitation and Development (MRRD) supported rural energy programme. The programme is currently operational under the title "Afghanistan Renewable Energy Market Transformation Initiative (AREMTI)" (GCF, 2020). Afghanistan Sustainable Energy for Rural Development (ASERD) (project was funded through bilateral grant funding from Spain and South-Korea) programme laid the foundation for this current programme by developing feasibility studies for 25 minigrid sites in 17 provinces of Afghanistan. Recently, a hybrid solar-hydro minigrid project with a total capacity of 340-kW has been implemented in Dar-i Noor district of Nangarhar Province. The project was commissioned under the ASERD programme and was financially supported by the Republic of Korea and UNDP Afghanistan. This project is expected to provide electricity to approximately 18,000 people (about 3,000 households) and more than 80 Small and Medium Enterprises (SMEs) (UNDP, 2021). The AREMTI programme, on other hand, proposes to implement three (3) solar minigrids with a combined capacity of 2.6 MW, in the provinces of Kandahar, Parwan and Khost. In addition, the programme proposes to develop construction designs for other 5 minigrids in Afghanistan.

There are several diesel-powered minigrids in operation in off-grid areas. While the national utility, DABS operates diesel-powered minigrids in several provincial capitals (not connected to the grid), private operators run diesel generators for providing lighting to rural communities using a rudimentary mini or microgrid structure.

3.2.2 National strategy for electricity sector

At the national level, there is considerable focus on the need for rural electrification in general and the minigrid-based delivery model in particular. Over the past decade and more, from the first Afghanistan National Development Strategy (ANDS), 2008 – 2013, the need for decentralised, renewable energy-based generation was given prime importance. The ANDS clearly highlighted the need and scope for using solar PV and wind-based projects, and that “the relative benefits of this type of energy should be recognized in policies to support their use.” More recently, the second Afghanistan Peace and National Development Framework report (ANPDF), 2021-2025 also highlights the need for electricity access to expand to include all Afghan provinces.

Other policy and strategy documents, such as Renewable Energy Roadmap for Afghanistan (RER2032), also indicate the need for decentralised, renewable energy powered minigrid and microgrids (ADB & ITP India, 2017). RER2032 allocates as much as 720 MW of additional capacity from minigrids, apart from other standalone RE applications. The Afghanistan Climate Change Strategy and Action Plan (ACCSAP) identifies the need to energise rural areas of the country using RE powered minigrids, as one of the Low Emission Development Strategy (LEDS) items for the country.

3.2.3 Policy and regulations for minigrids

From a policy standpoint, it is important to bear in mind that the phase 2003 – 2016 was one of policy action in Afghanistan, where several key national policy and strategy development documents covering a range of sectoral and cross-sector themes were introduced in the country. The policy landscape for minigrid development in Afghanistan is shaped by the Afghanistan Renewable Energy Policy (AREP), 2015 (Government of Afghanistan, 2015).

Although there is no dedicated minigrid policy, as shown in section 3.2.2, the strategy documents clearly outline a role and scope for RE powered minigrids in the country. One of the landmark regulations in the country was the demarcation of all RE projects up to 1 MW capacity, to be set up in rural areas within the purview of the MRRD (AREP, article 4.7). This has contributed to the creation of a nodal ministry for decentralised RE projects that include both standalone grid tied and minigrid applications.

The MRRD, in collaboration with the erstwhile Ministry of Energy and Water (ministry is dissolved as of the present date), had developed a draft National Rural Renewable Energy Policy (NRREP) (2013 – 2014) (Government of Afghanistan, Afghanistan Rural Renewable Energy Policy, 2013). The policy encourages creation of an enabling environment towards full commercial operations of rural renewable energy services. The policy was in line with the ANDS (2008 – 2013) and the policy thrust provided by the National Priority Programmes (NPPs) which were drafted for the country to usher in a regime of balanced growth and development. A total of 22 NPPs were drafted in 2009 covering six strategic themes (Ministry of Finance, n.d.). Among these, rural decentralised development was one key theme – addressed under the 'Agriculture and Rural Development' Cluster. The cluster NPPs highlighted the need for RE based decentralised energy access in Afghanistan.

Around 2015 – 2016, the Afghan government also developed a draft Feed-in-Tariff (FiT) Policy for various renewable energy project categories (e.g. wind, solar, biomass), specific to each Province. However, the policy has not yet been given final shape.

3.2.4 Technical aspects of minigrids

There are several technical aspects of minigrids in Afghanistan that act as key determinants for the choice of a minigrid site, as well as determine growth and development of the sector. These are outlined briefly below.

Size: Available secondary literatures suggest that RE powered, decentralised minigrid projects in Afghanistan tend to be over 100 kW. The minimum size of 25 projects identified under a plan for ASERD in 2017 was 300 kW (2 projects, in Bamiyan and Samangan, both hydro power), while the largest size was 1 MW, to be implemented in the provinces of Khost, Daikundi, Kandahar and Urozgan (mix of solar PV and hydropower) (GIZ IDEA , 2017). The existing Bamiyan solar PV-diesel hybrid unit is also 1 MW capacity. In addition, the national electricity utility DABS runs diesel powered minigrids in provincial capitals, these units are also in the MW scale. At the other end of the spectrum, there are diesel powered micrograms in towns and villages that provide lighting energy to households, which are around 5 KVA – 25 kVA in size.

Enterprise development: While there is a significant share of unmet energy demand in the country, it is also observed that penetration of enterprises in the country is low, primarily constrained by lack of access to electricity (input) and markets (output). The Green Climate Fund (GCF) project document for AREMTI posits that minigrids to be set up under the project shall have strong enterprise and private sector components, to enable the market transformation paradigm (GCF, 2020). Moreover, it is also necessary that enterprises be identified at the design stage, through an enterprise development survey.

Operations and maintenance: Afghanistan is marked by a lack of road and transport networks, which is greater in the rural areas. This reduces access to the minigrid site, which is necessary for O&M and troubleshooting of the minigrid system. The MRRD is intending to develop a minigrid handbook, which will include design and operational guidelines.

Security: Security is a key threat that impedes the growth of minigrids. The more sensitive provinces of the country have had little to no penetration of minigrid systems. On the other hand, the Northern and Central Highland Provinces (Badakshan, Balkh, Baghlan, Bamiyan etc), which are /were relatively peaceful, witnessed maximum number of minigrids being installed.

Figure 26: 5 kW Wind Turbine in Sang-E-Nawishta Village of Kabul[20]

3.2.5 Business models for minigrids

Business models for minigrids in Afghanistan are not prevalent, as the sector is not mature. As discussed in the opening sections, the NSP experience was built on grant-funded projects with the CDCs entrusted with the O&M. More recently, experience with the Bamiyan project, as well as projects proposed under AREMTI, are sought to be grant funded, with private entities operating as contractors entrusted with the Engineering, Procurement and Construction (EPC) and O&M processes. The approach in these recent projects is to secure viability through tariff payments that would cover for O&M expenses at the site.

One of the key aspects of the renewable energy sector in Afghanistan is the creation of the Afghanistan Renewable Energy Union (AREU). Set up in 2013 as a not-for-profit, AREU members have provided inputs for RE sector growth and development as a key stakeholder, undertaking EPC and O&M activities in projects (Afghanistan Renewable Energy Companies Union, n.d.).

In the AREMTI, the approach is framed on the basis of developing Renewable Energy Service Companies centric projects. RESCO projects are invested in and managed by a private renewable energy company and is a business model wherein RESCO entities shoulder bulk of the project's risks. In Afghanistan, RESCO projects undertaken under AREMTI could potentially involve AREU members, who could invest in minigrid projects in RESCO mode.

3.2.6 Minigrid tariff

The Government of Islamic Republic of Afghanistan (GoIRA) had developed a draft Feed-in Tariff policy, which provides province wise feed-in tariffs from RE projects. These tariffs can be considered as a *shadow tariff* for minigrid projects. The tariffs identified under the draft policy are higher than tariffs charged by DABS from national grid consumers in Kabul. However, there are higher tariffs that are charged by DABS in provincial towns where power is supplied from diesel generators.

[20] UNDP Afghanistan

The Bamiyan 1 MWp solar PV–diesel hybrid project (called Bamiyan Renewable Energy Program or BREP), is providing electricity to consumers in Bamiyan town and the average power tariff that was initially charged was as high as USD 1.95 per kWh. However, over time, the cost has reduced and as of 2017 it was USD 0.25 per kWh, a significant improvement. It is also pertinent to note that consumer demand for electricity from BREP has increased as of 2017 (USAID, 2018). This substantiates the view that higher tariffs in minigrid projects might not be a deterrent to energy demand. It is also worth noting that BREP introduced prepaid metering, which was also a first in the country and thus also makes a case for successful implementation of on use of prepaid meters. Importantly, the recently implemented solar PV–hydro hybrid project in Dara-i-Noor district of Nangarhar province has provision for prepaid cards with smart meters, which allows the users to pay for the electricity prior to their use and according to their energy needs (Abdul Haq Omari, 2021).

3.2.7 Financing for minigrids

To understand the financing landscape for minigrids in Afghanistan, it is important to map the key actors financing minigrid or off grid projects in the country. The Bamiyan 1 MWp project, the recently commissioned project in Dar-i-Noor district and under-construction projects in Khost, Kandahar and Parwan provinces and the 5 minigrid projects in design stages are set to be grant financed, with funds provided by development partners. The Afghan government counterpart has provided in-kind support to the project. Other smaller minigrids installed have also adopted a similar approach. However, home and/or farm level standalone solar and other RE projects are financed using private capital, as they meet specific demands for the user, who usually does not have access to banks or institutional capital.

In utility scale projects, also, there are notable success in private sector financing such as the 50 MW natural gas-based power project, which is co-financed by International Finance Corporation (IFC), Govt. of Afghanistan and the Ghazanfar Group (an Afghan industrial house), who also owns the asset (Power Technology, 2016). Another example is the United States Agency for International Development (USAID) supported 10 MW Solar PV power project in Kandahar, which is co-financed by Dynasty Oil and Gas Ltd., an Indian-origin company (Tom Kenning, 2017). Although none of the above two projects are minigrid projects, both are supported by long-term power purchase agreements with DABS, and therefore have revenue assurance. In the Kandahar project, USAID has provided risk coverage due to possible non-payment by off-taker through provisions for risk coverage guarantees. Overall, therefore, the investment in the minigrid sector has so far been wholly grant financed. Recent efforts in the minigrid space, most notably the UNDP & MRRD supported Afghanistan Renewable Energy Market Transformation Initiative project have engaged with private contractors for EPC and O&M services. However, the project does not envisage private co-financing.

3.2.8 Opportunities for minigrids

As mentioned above in Sections 3.2.1 and 3.2.2, the minigrid sector is one of the areas for opportunity in Afghanistan. Potential in the minigrid sector is high due to the following reasons:

Resource potential: Estimates indicate that there are 222 GW of solar, 66 GW of wind and 23 GW of hydropower potential available in the country (Government of Afghanistan, 2015). The solar global horizontal irradiance (GHI) map of Afghanistan developed by the World Bank and IFC has been included in Annexure 2. This potential indicates that RE resource availability is not a constraint for minigrid development. It is also pertinent to note that the resources are evenly distributed across the country (NREL, 2010). While the southern plains and desert areas have excellent solar resources, the mountains have good hydropower potential. Wind power resources are scattered across the country. This indicates that balanced growth of the RE-powered minigrid sector is possible.

Unmet energy demand: This is primarily due to the gap between the demand and supply of electricity in the country. As the evidence of demand for solar home systems and solar powered handheld devices such as lanterns indicates, there is considerable unmet demand for electricity in households and enterprises. While households demand extends to white goods such as television, heating devices, etc., demand in enterprises includes energy for motive use such as power to drive motors, pumps, etc. for mechanical applications. (Ajmal Haidari, 2020). Moreover, the wide use of diesel generators and diesel minigrids in provincial capitals, rural markets and other hubs indicate that there is demand as well as ability to pay for productive use of energy.

While the overall security situation still acts as a potential deterrent, it is expected that Afghanistan would experience a rapid and wide proliferation of minigrid power projects in coming years, as a response to high level of energy demand, especially in rural areas. The success of the Bamiyan case study and other examples clearly show the impact of minigrid projects in supporting economic development. Evidence from Bamiyan's 1 MWp solar PV project indicates that more than 3,500 businesses and enterprises are powered by the solar-diesel hybrid minigrid (USAID, 2018). This bears testimony to the strong enterprise demand in Afghan communities.

Specific opportunities: Within the ambit of economic development, Afghanistan specifically stands to gain from enterprises developed using reliable and cost-effective renewable energy based minigrids. MRRD's target of developing 25 minigrids in 17 provinces of Afghanistan, focusing on rural areas to provide electricity for households and enterprises, indicates a good opportunity for minigrid sector development.

3.2.9 Barriers to minigrids

Although there is significant potential for minigrid development in Afghanistan, there are some serious constraints that act as barriers to minigrid development. These are:

Security: The most potent barrier to minigrid development is the unstable internal security situation in the country. This impedes movement of goods, services, and information across the country. Airlifting is possible but tends to be very expensive, which drives up costs and prices. Finally, skilled personnel do not feel encouraged to relocate to a minigrid site.

Human resources: There is a dearth of technical/ engineering colleges and universities in the country, as a result there are few trained engineers. Also, the colleges and universities operate in an isolated manner, largely due to restrictions on foreign travel inside Afghanistan (foreign tourists are largely discouraged from leaving the capital Kabul). Thus, free movement of knowledge is also not possible. Finally, access to internet is also limited to the major cities and towns. Thus, trained human resources for deployment in a minigrid site is also a constraint.

Lack of financial capital: As discussed in the financing section above, there is a dearth of access to finance for project financing in Afghanistan. Moreover, the interest rates are also high, which acts as a deterrent for both term loans for capital expenditure as well as working capital. The specific financial barriers are:

- The financial sector in Afghanistan does not readily provide debt financing for private entities. Micro finance is more easily accessible, but such financing does not meet the demand for project level senior debt financing. The overall debt financing is also weak, with over a quarter of funds lying idle with central and private banks, high proportion of gross Non-Performing Assets (NPA) over 20% and total bank loans to non-financial sectors amounting to only 3.13% of Gross Domestic Product (GDP) (World Bank, 2021). Bulk of loan off-take were for trading and/or service sectors.

- There are no clear guidelines or incentives for private sector financing of minigrid projects in Afghanistan, which acts as a deterrent to private investment.
- In addition, the cost of capital in the country is also high. Private bank lending rates of interest are around 15%, which implies that projects would have to earn at least 17% - 18% per annum on investment to be viable.
- Finally, the internal security situation also acts as a barrier to post-commissioning operation and maintenance including revenue collection. Due to a lack of streamlined transportation across the country, O&M services are more likely to be impacted.

Finally, the AREMTI project has also identified some barriers to their programme, which addresses minigrid sector and its development (GCF, 2020). While some of these are common to the ones identified above, they are laid down below in totality, to give a picture of key shortcomings in the minigrid sector:

- Lack of incentives and guidelines for private sector to participate in rural electrification projects
- Lack of technical standards and guidelines for minigrid development
- Lack of coordination among institutions on long term energy planning and minigrid development
- Lack of financial instruments that can de-risk challenges such as security, financial, currency and defaulting risks
- Lack of awareness, exposure and experience on use and benefits of RE minigrids among government institutions and beneficiaries
- Limited private sector capacities to design, engineer, procure, construct, and operate RE minigrids, business opportunities in different ownership models and absent learning in pilot minigrids
- Insufficient implemented proof-of-concept solar minigrids with successful O&M
- Lack of institutionalized knowledge center, lack of minigrid pipeline ready to install
- Lack of procurement guidelines and consideration of environmental standards in procurement
- Lack of safeguards guidelines and consideration of safeguards standards in procurement

3.3 Bangladesh

3.3.1 Status of access to electricity and minigrids

Bangladesh is one of the world's most rapidly growing developing economies and one of the most vulnerable countries to climate change. The overall rate of electrification in Bangladesh increased from 14.29% in 1991 to 32% in 2000 to 55.26% in 2010 and 92.2% in 2019 (see Figure 27). In the year 2019, 97.8% of urban population has access to electricity while only 88.85% of rural population has access (World Bank, n.d.). During the consultation with Sustainable and Renewable Energy Development Authority (SREDA), it was learnt that the country has achieved 99% electrification as of 2021. Renewable energy, from both on grid and off grid solar, wind, hydro, biogas, and biomass, has

3.05% share in the total electricity generation mix (Sustainable and Renewable Energy Development Autho, n.d.). Solar home system is the most popular form of off grid renewable energy technology in Bangladesh with 34.28% share. SHS provides electricity for lighting, mobile charging, and fan. However, electricity demand of the off-grid community is not limited to these basic needs.

Realizing the above, Government of Bangladesh (GoB) had identified solar minigrid as an appropriate solution to meet the electricity need of the rural community. Twenty-Seven (27) solar minigrids with diesel generators as backup of total capacity 5.66 MW have been installed in Bangladesh as of August 2021. One of them is operated by distribution utility and rest by private companies. Bangladesh's first commercial solar minigrid, PGEL Solar MiniGrid Project, of 100 kW capacity started operating on Sandwip Upazila, Chittagong in 2010 (Sustainable and Renewable Energy Development Autho, n.d.).

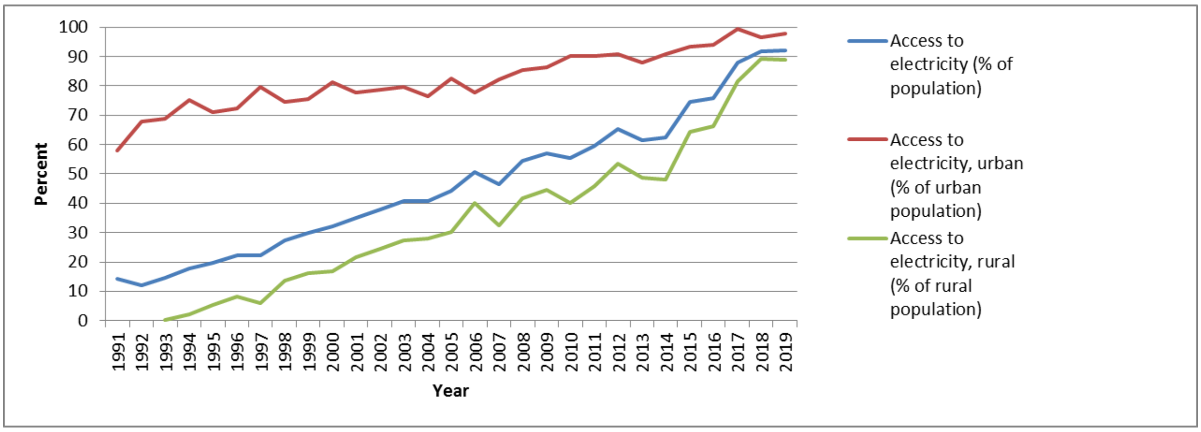


Figure 27: Access to Electricity in Bangladesh[21]

3.3.2 National strategy for electricity sector

The current focus of the Government of Bangladesh is to reach 100% electrification of urban as well as rural areas via national grid only, and there is less focus on minigrids. It has been projected that Bangladesh will achieve 100% electrification by the end of 2021. It was mentioned during the consultation with Power Cell Department that the people having access to electricity through minigrids are not satisfied with the higher tariffs of minigrids. The rural community are demanding electricity access through national grid as the tariffs are low and they can meet their additional electricity demand. Grid-based electrification is promoted to provide electricity to rural communities. Although there are some areas that are remote islands in Bangladesh where providing grid electricity is difficult, but Government is keen to connect them through sub-marine cables and/or river crossing towers. They are expensive options but beneficial in the long run. In the areas where it will not be feasible or distance is too long for submarine cables, then respective distribution utilities are required to identify appropriate solutions for electrification. In this case, the distribution utilities may install minigrids to provide electricity, but the tariff for the electricity will be same as the national grid tariff.

On the other hand, Government of Bangladesh has taken number of initiatives to enhance penetration of renewable energy in the electricity generation mix of the country. Renewable Energy Policy 2008 mandates at least 10% of the total generation to be generated from RE sources by year 2020. Besides

[21] (World Bank, population data, n.d.)

utility programs, the government has initiated programs like the SHS, solar minigrid, solar rooftop, solar irrigation, etc. with an aim to scale up the contribution of renewable energy in the country.

Government has prepared National Solar Energy Roadmap 2021-2041, which included a target of around 10 MW of capacity to be added through solar mini/micro/nano grids during 2021–2030. The roadmap is currently in the draft form and yet to be approved. The roadmap has also mentioned that solar minigrids are most likely to lose financial and technological viability in the long run due to the penetration of national grids in the off-grid areas. For this reason, it was mentioned during the consultations with SREDA and Power Cell Department that solar minigrid target may be removed from the final version of the roadmap (Government of Bangladesh, 2020). The Government has started to connect all existing minigrids to the national grid. Government will buy electricity from minigrid operators at their original tariff and provide electricity to people at grid tariff.

3.3.3 Policy and regulations for minigrids

There is no dedicated minigrid policy in Bangladesh. Infrastructure Development Company Limited (IDCOL) acts as a regulatory as well as financing body, which follows policy guidelines from the Ministry of Power, Energy and Mineral Resources (MPEMR). Annual report of IDCOL 2020 states that IDCOL is pursuing the government to establish a regulatory framework to safeguard private sector investments in solar minigrids (Infrastructure Development Company Limited , 2020).

Policy guideline for enhancement of private participation in the power sector has opened the national grid for commercial use with an objective to introduce and regulate competition by allowing private investment in the power sector, and to establish new commercial power plants and rehabilitate old ones through Public Private Partnership (PPP) (Government of Bangladesh, 2020). The government also published a guideline for Remote Area Power Supply System (RAPSS) in 2007 to facilitate electricity access to un-served areas with private sector investment. A commercial model has been identified under the guideline to implement the minigrid project, but that policy focused on conventional, mainly diesel-based power generation.

Government of Bangladesh has approved Renewable Energy Policy in 2008 with an objective to harness the potential of RE resources and encourage both public and private sector investment. The latest addition to the policy documents concerning the development of renewable energy technologies in Bangladesh is the Draft Eighth Five Year Plan (FY 2021 to FY 2025), which has set the target for renewables including hydropower to supply 5% of the total electricity by the year 2025.

3.3.4 Technical aspects of minigrids

Majority of the installed minigrid in the country comprises of solar PV panels, battery banks, inverters, and diesel backup. The capacity of solar minigrids in Bangladesh ranges from 100 kWp to 700 kWp serving 400 to 1500 customers per grid. The energy produced is distributed through 3-phase, 4-wire distribution system with maximum length of each feeder limited to two kilometres (ESMAP, 2017). Solar minigrids in Bangladesh use local IDCOL batteries.

73.5% of customers are households, and the remaining 26.5% are commercial entities engaged in different income-generating activities and other productive uses. The commercial and institutional entities include shops, workshops (steel, furniture, carpentry), rice mills, sawmills, irrigation pumps, ice factories, telecommunication towers, electrical vehicle charging stations, hospital/clinic, other factories (puffed rice mill, bakery, oil pressing mills), resorts/restaurants, schools, mosque, madrasahs, etc. Many enterprises have been created in these areas because of successful minigrid interventions (Infrastructure Development Company Limited , 2020).

3.3.5 Business models for minigrids

Solar minigrid projects in Bangladesh are mostly based on private sector model i.e., owned, operated, and managed by the project developer. Project developers are franchised a particular area to develop and operate solar minigrid project for 15 to 20 years through competitive bidding. Grant and concessionary loan are provided through IDCOL. A committee comprising of members from Power Cell, Rural Electrification Board (REB) and IDCOL and headed by Power Division official is formed to monitor and supervise implementation of the project including distribution, O&M and setting up tariff. Prepaid metering system has been adopted to ensure 100% revenue collection from consumers in rural areas.

ME SOLshare Limited has installed smart peer to peer solar microgrids in Bangladesh where SHS are connected to each other to form a microgrid. The company was operating 40 microgrids in Bangladesh in 2020 and is expecting to operate 110 microgrids by the end of 2021. The company is targeting to provide power to an additional 1 million through microgrids by the year 2030, including interconnection with the national grid.

3.3.6 Minigrid tariff

IDCOL regulates the tariff of minigrid electricity to be paid by the customers through the implementation agreement that developers sign to obtain the standard financing package from IDCOL. Bangladesh Energy Regulatory Commission (BERC) is not responsible in tariff setting of a system capacity of less than 5MW. The agreement establishes the tariff of all minigrids between BDT 30 and BDT 32 (USD 0.35 and 0.38)[22] per kWh for the first five years of operation and IDCOL's approval is required to increase the tariff. IDCOL does not allow developers to charge different tariffs in the initial 5-year period of operation. Minigrid tariff is calculated by IDCOL based on the forecasts with little room to adjust tariffs once the project is implemented (ESMAP, 2017). The minigrid tariff of the existing minigrids is around BDT 30 (USD 0.35) per kWh while the national grid tariff is around BDT 5–7 (USD 0.058 – 0.082) per kWh. The evolution of minigrid tariff between 2011 and 2015 is depicted in Figure 28.

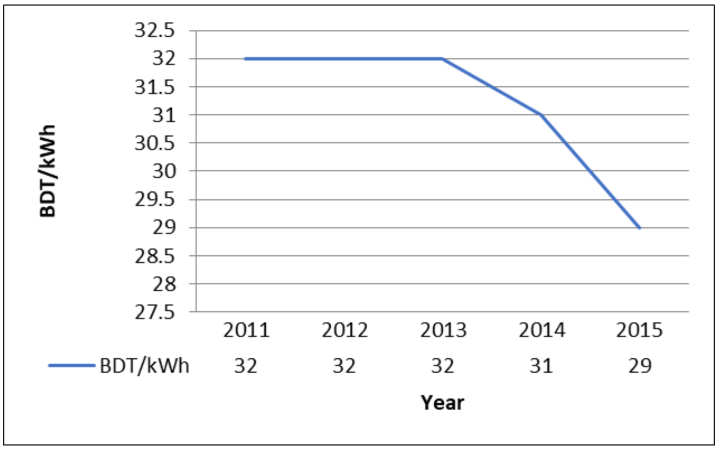


Figure 28: Evolution of Minigrid Tariff[23]

[22] 1 BDT = 0.012 USD as on 27th October 2021, same exchange rate has been used to convert BDT to USD in this report

[23] (ESMAP, Mini grids in Bangladesh: A case study of an incipient market, 2017)

3.3.7 Financing for minigrids

IDCOL is the largest financier of infrastructure and RE projects in Bangladesh. Almost all the solar minigrids in Bangladesh are financed and implemented by IDCOL (Sustainable and Renewable Energy Development Authority, 2021). IDCOL receives funds from government and donors to finance solar minigrid systems and to offer a standard subsidy package to the developer.

Grant of 50% of the total project cost and concessional loan up to 30% is provided to minigrid developers by IDCOL. Remaining 20% comes as developer's equity (Infrastructure Development Company Limited , 2020). Renewable energy equipment and related raw materials for the development of minigrid project are exempted from 15% Value Added Tax (VAT). The banks are allowed to provide loans in rural areas worth up to BDT 150,000 (USD 1,749[24]) for setting up solar minigrids (Sustainable and Renewable Energy Development Authority, 2021).

The first and only minigrid project financed by commercial bank in Bangladesh in Angira solar minigrid, raising 67% through commercial debt taken from Uttara Bank, with the remaining 33% through equity investment. The 50 kWp Angira solar minigrid was set up in 2014 in the Nur Mohammed Market in the Manikganj district. It had an initial capacity of 30 kWp but was upgraded to 50kWp due to customer demand for electricity. While the Angira minigrid is of a smaller capacity than the IDCOL financed solar minigrids, its success could pave the way for larger commercially financed projects (CDKN, 2019).

3.3.8 Opportunities for minigrids

Resource potential: Bangladesh is bestowed with good potential of RE sources, of which solar energy is the most promising one. The study conducted by SREDA & UNDP has reported a 40 GW solar potential for Bangladesh by 2041 considering utility scale, rooftop, and distributed generation projects (Anu Bhambhani, 2020). The solar GHI map of Bangladesh developed by the World Bank and IFC has been included in Annexure 2. Apart from solar, the country has the potential for bioenergy, wind energy, geothermal and limited scope for energy generation from hydro resources. In a study conducted by MPEMR with USAID support, it was found that for wind speeds of 5.75–7.75 m/s, there are more than 20,000 km^2 of land with a gross wind potential of over 30,000 MW. The above potential indicates a good opportunity for minigrid development in the country.

Unmet electricity demand: Even though Bangladesh will reach 100% electrification by the end of 2021, there are remote islands which are off-grid and population concentrations are dispersed. National grid might not be feasible or possible to reach these islands even through submarine cables. In such cases, renewable energy based minigrid might be the best option for providing reliable and quality access to electricity provided electricity tariff is competitive with that of national grid. Providing grid quality electricity from RE sources in those areas will also serve the unmet demand for commercial applications of the rural markets and small enterprises.

Specific opportunities: According to SREDA website, the Bangladesh's total installed capacity is 25,181 MW and the renewable energy installed capacity is 766.45 MW. Bangladesh's vulnerability to climate change necessitates the inclusion of sustainable and renewable energy sources into the country's long-term development plans. Through Nationally Determined Contributions (NDC), Bangladesh has

[24] 1 BDT = 0.012 USD as on 27th October 2021

made commitments to reduce unconditional 5% of Greenhouse Gas (GHG) emissions by 2030 in the power, transport, and industry sectors and a conditional 15% reduction in GHG emissions by 2030 (Government of Bangladesh, 2020). Bangladesh has also committed to increase its share of renewable energy electricity generation in country plans such as Draft Eighth Five Year Plan (FY 2021 to FY 2025), Bangladesh Delta Plan 2100, and National Solar Energy Roadmap 2021-2041. Renewable Energy Policy 2008 mandates at least 10% of the total generation to be generated from RE sources. Minigrid has the potential to become an integral part of Bangladesh's strategy for increasing the share of RE to meet its NDCs.

3.3.9 Barriers to minigrids

The main barriers for minigrid development in Bangladesh are provided below:

- There is no specific policy or strategy of the Government to develop minigrid projects in Bangladesh. As such, project developers are not interested to develop and finance minigrid projects even though there is an opportunity for minigrid development in some off grid areas and remote islands. Private sector companies find this challenging because of high perceived commercial risks pertaining to grid arrival and lack of financing and government support.
- The tariff for solar minigrids is around BDT 30/kWh (USD 0.35[25]/ kWh), which is much higher than the subsidized tariff paid by the grid consumer. This discourages consumers from using more electricity than that required to meet basic needs and thus create resentment among the consumers. This also discourages potential investors to invest in minigrid sector.
- Several solar home systems and solar minigrids have been discarded after the expansion of the national electricity grid to those areas because people were getting grid electricity at lower prices. Thus, highlighting the uncertainty in the operation of minigrids and risks related to arrival of national grid.
- As evident, GoB's priorities are focused on national grid electricity supply, and not on minigrid development in the country as learnt during stakeholder consultations. National Solar Energy Roadmap 2021-2041, still a draft, shows the nation's commitment to increase the share of RE in national energy mix, but minigrid is the least prioritized topic on the roadmap.
- Bangladesh is densely populated country with little land availability and has restrictions on use of agricultural land. Thus, identification of land area for minigrid project development is challenging.

3.4 Bhutan

3.4.1 Status of access to electricity and minigrids

The Royal Government of Bhutan (RGoB) is one of the smallest but fastest growing country among the South Asian countries. The country has aggressively pursued electrification through national grid, decentralised distributed generation (DDG) in isolated, as well as, core protected areas and solar home systems in most remote areas. During the stakeholder consultation with Department of Renewable Energy (DoRE) of Bhutan, it was learnt that the country has reached almost 100% electrification mostly through national grid.

[25] 1 BDT = 0.012 USD as on 27th October 2021

Hydropower projects are the major source of electricity in Bhutan. Other than large hydropower projects, electricity is generated from micro/mini hydro and other renewable energy technologies such as solar, wind and bioenergy. Figure 29 showcases the major electricity generation sources in 2019. Bhutan has also installed 13 to 14 diesel generator sets throughout the country, which are used only as backup power.

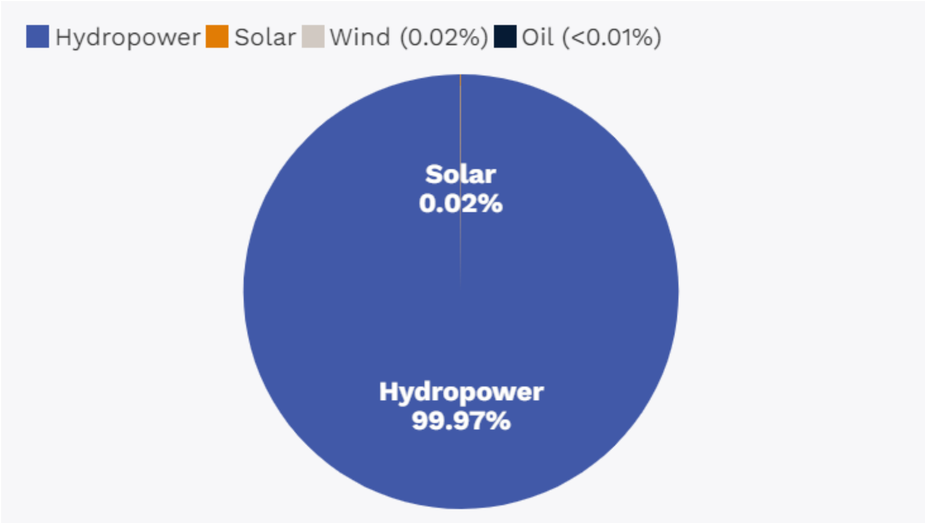


Figure 29: Electricity generation sources in Bhutan[26]

3.4.2 National strategy for electricity sector

Royal Government of Bhutan has planned to expand electricity access in the country through both on grid and off grid electrification in a sustainable manner. The Alternative Renewable Energy Policy (AREP) 2013 of Bhutan sets out a preliminary minimum target of 20 MW by 2025 through mix of RE technologies. Specific targets include 5 MW from solar, 5 MW from wind, 5 MW from biomass. The AREP target does not include generation from micro/mini/small hydro, which shall be developed separately on need basis (Royal Government of Bhutan, 2013).

The country has set no specific targets for electricity generation via minigrids. However, during consultation with DoRE officials, it was learnt that there is a strong interest of the Government to develop minigrids in areas where transmission lines extension is uneconomical, or it leads to deforestation. Bhutan has a mandate to maintain 60% of the country's land under forest covers to preserve its environment. It was also mentioned by the officials that if minigrids are proved to be more reliable and economical then transmission lines could even be decommissioned.

3.4.3 Policy and regulations for minigrids

The energy sector of Bhutan is governed, planned, and coordinated by two ministries, Ministry of Economic Affairs (MoEA) and Ministry of Agriculture and Forests (MoAF). Electricity Act of Bhutan was formulated in 2001 with an objective to promote safe and reliable supply of electricity throughout the country. The act has also highlighted promotion of rural electrification programmes through public and private sector participation to achieve equitable regional distribution of electricity. Rural

[26] (Dawa Gyelmo, 2021)

electrification will be achieved either by the extension of the grid or by the development of off-grid electrification with promotion of renewable energy (Royal Government of Bhutan, 2001).

Alternative Renewable Energy Policy was formulated in 2013 with an objective to promote and develop RE technologies in the country. AREP states that in rural areas where national grid is difficult to reach, community-based initiatives in the form of decentralised distributed generation based on RE sources should be given the priority (Royal Government of Bhutan, 2013).

3.4.4 Technical aspects of minigrids

The common generation technology used for minigrid in Bhutan is hydropower, as can be seen from Figure 29. Other RE technologies such as solar, wind and bioenergy are limited to pilot projects and small applications.

Majority of the minigrids in Bhutan are able to provide sufficient power during off peak hours, but during peak hours, brownouts occur due to demand supply gap. To address this issue, GridShare was developed by the team from Humboldt State University (HSU). It is an approach to alleviate brownouts caused by peak power consumption in isolated, village-scale electrical systems through technology, education, and village-scale collaboration. The GridShare system has been incorporated in a minigrid project in Rukubji village, which helped in providing a more reliable electrical service to the village. A device is installed in every household and business that is connected to the minigrid. The installed device will give indication of the current state of the grid and an enforcement mechanism will limit the load when the grid is overburdened.

During the consultation with DoRE, it was found that new innovative hydrokinetic technologies such as vortex hydro turbine are being explored in Bhutan for generating electricity. Vortex hydro turbine is capable of converting energy in a moving fluid to rotational energy using a low hydraulic head of 0.7–3 metre.

3.4.5 Business models for minigrids

Most of the minigrids in Bhutan have been developed on grant basis. AREP 2013 of Bhutan states that all RE projects for electricity generation including minigrids shall be developed under Build, Own, Operate (BOO) model and mini, micro, and small hydro shall be developed under Build, Own, Operate and Transfer (BOOT) model. It also indicates that all RE projects constructed under the Government funding as distributed power generation source shall remain as the property of the Government and management of the plant shall be transferred to communities, wherever feasible.

3.4.6 Minigrid tariff

The electricity tariff in Bhutan is highly subsidized by the Government. Consumers only pay 50% of the cost of electricity and 50% is paid by the government. As stated in the AREP, Bhutan Electricity Authority (BEA) is responsible to determine the tariff of minigrid projects. During consultation with DoRE, it was confirmed that minigrids tariff is set in consultation with regulatory authority and communities. Minigrid tariff covers only the operation and maintenance cost including the salaries of minigrid operators. Minigrid tariff has been found to be little lower than the national grid.

For projects constructed under Government funding, the tariff should be set such that it meets the operation and maintenance costs only. The rural electrification projects which are not approved by

Department of Renewable Energy shall not be considered for tariff determination (Bhutan Electricity Authority, 2016).

3.4.7 Financing for minigrids

Distributed generation projects have been funded by support from partner governments and development banks. The pilot 600 kW wind project in Wangdue was funded by Asian Development Bank (IRENA, 2019). Government also provides grant as counterpart financing to the rural electrification loan to finance the civil and establishment expenses, but the material costs are financed through the loan (Bhutan Power Corporation, 2020). Private sectors including foreign developers can also invest in RE projects. However, foreign developers are not permitted in micro and mini hydropower projects.

The Renewable Energy Development Fund (REDF) has been established under AREP to provide financial assistance and create a favourable investment climate for RE in the country. For RE projects that are mandated by the Government as per Five Year Plans, the budgetary support from the Government will be utilized. The projects developed under government funding will also get back up support in the form of financing from the government for restoration of the plant during the major breakdown.

3.4.8 Opportunities for minigrids

Resource potential: Bhutan has significant hydro resources along with other RE resources such as solar, wind and biomass. Hydropower is the major resource of RE in Bhutan with theoretical potential of more than 41 GW whereas the technical potential is estimated at 26.6 GW. Likewise, the theoretical solar potential is estimated at 6 TW and restricted technical potential at 12 GW (IRENA, 2019). The solar GHI map of Bhutan developed by the World Bank and IFC has been included in Annexure 2. The stakeholder consultation indicated that Royal Government of Bhutan is interested to exploit this potential for minigrid development in the country.

Unmet energy demand: Although Bhutan has reached almost 100% electrification, reliability of electricity supply remains an issue. Around 58% of households had faced one or more electric power failures/ interruptions lasting at least one hour and the proportion of households that faced more frequent power interruptions is higher in rural areas (64.3%) than in urban areas (46.6%) (IRENA, 2019). During stakeholder consultation, it was mentioned that the government is keen towards the development of minigrid in the country to increase the reliability and quality of electricity supplied to the consumers.

Specific opportunities: Bhutan has a constitutional mandate to maintain 60% of the country's land under forest covers to preserve its environment (SE4All, 2012). Grid extension to every corner of the country may necessitate deforestation. In this case, development of minigrids for the access to electricity can facilitate localization of generation as well as distribution. The reduced length of transmission and distribution lines will alleviate the risk of deforestation. During consultation with DoRE officials, it was learnt that if minigrids are proven to be more technically and economically feasible option then transmission lines could even be decommissioned.

Also, local population in rural areas are showing interest in running enterprises at their own local level and electricity supply via minigrids can provide reliable and quality electricity for productive uses. The use of minigrid electricity will enhance the economic status of the consumers and increase their ability and willingness to pay for the electricity consumed. Thus, government will be able to reduce the high subsidy amount in the electricity sector.

Electricity is the most valuable commodity in Bhutan as it generates more revenue by selling electricity to neighbouring countries. Bhutan is energy surplus economy, but as the economy of the country continues to grow and living standards improve, energy demand and consumption are set to increase. Minigrids can be used to produce RE electricity for local consumption thus enabling the government to export grid electricity for revenue generation.

3.4.9 Barriers to minigrids

Bhutan has no dedicated policy and regulations regarding minigrid development in Bhutan. It is also not clear about the effect on minigrid systems after the arrival of national grid to the area, whether the system remains redundant, or it will be integrated into the grid. The country has set no specific targets for electricity generation via minigrids.

The electricity tariffs in Bhutan are subsidized and public utilities like Druk Green Power Corporation Limited (DGPC) and Bhutan Power Corporation (BPC) claim that they do not obtain a fair return on their assets. In this scenario, private sector participants may be unwilling to make investments in the absence of clear indication of returns to investors. Bhutan has piloted solar and wind minigrid projects only after 2014. The government as well as the private sector lacks necessary technical and financial expertise to develop and operate minigrid in the country.

3.5 India

3.5.1 Status of access to electricity and minigrids

India has made significant progress in last decade in providing electricity access to its population. Its electrification rate has increased very rapidly (See Figure 30). In March 2019, the Government of India declared full electrification of all households. However, as per IEA data[27], the rate of national access has grown from 43% in 2000 to more than 99.6% in 2019 and there are still around 5.5 million[28] people without access to electricity in India (IEA, n.d.).

[27] India has dual electrification targets focusing on electrifying villages (a village is considered electrified if 10% of households have access) and households. IEA methodology focuses on the share of the population with access to electricity in line with the UN SDG tracking framework.

[28] As per the Tracking SDG7 The Energy Progress Report 2021, the access to electricity in India has grown to 98% in 2019 with 30 million people without access to electricity. The Tracking SDG7 Report 2021 has referred to World Bank Global Electrification Database. The World Bank Global Electrification Database derives estimates from a suite of standardized household surveys that are conducted in most countries every two to three years, along with a multilevel nonparametric model used to extrapolate data for the missing years. The IEA Energy Access Database sources data, where possible, from government-reported values for household electrification (usually based on utility connections).

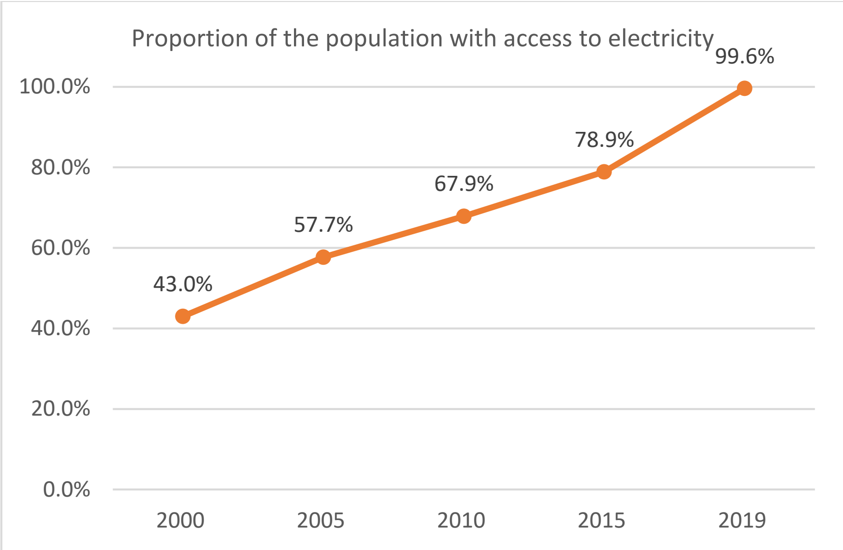


Figure 30: Trends of Electricity Access in India[29]

Minigrids in India have also expanded significantly over the last decade due to increased involvement of private players, local banks, and the government through the Ministry of New and Renewable Energy (MNRE)'s Remote Village Electrification Programme (RVEP) and the Village Energy Security Programme (VESP) for providing reliable and access to electricity to remote villages (Graber, Narayanan, Alfaro, & Palit, 2019). As per the MNRE, 214 MW of off-grid power plants including micro/minigrids had been deployed in India by March 2020 (Centre for Science and Environment, 2020). Figure 31 provides the cumulative growth of off-grid plants in India. Another data source of ESMAP has reported around 2,800 minigrids exist in India, which are powered mostly by diesel, solar, biomass and hydro.

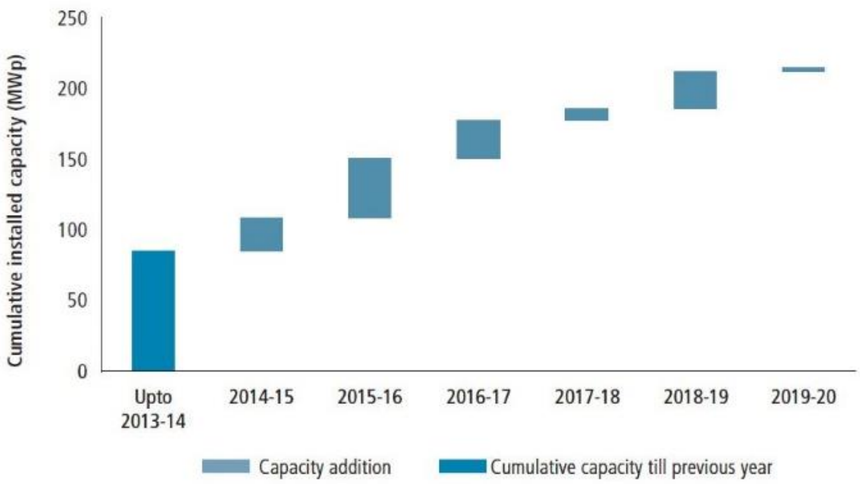


Figure 31: Cumulative Growth of Off-Grid Power Plants in India[30]

3.5.2 National strategy for electricity sector

Currently, Government of India's focus has been to expand access to electricity through grid-based electrification. The government launched *Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY)* in rural

[29] (IEA, n.d.)
[30] (Centre for Science and Environment, 2020)

areas, Saubhagya scheme for grid connectivity to last mile households and Integrated Power Development Scheme (IPDS) in urban areas to provide electricity access. In April 2018, the Government declared that 100 % of the villages had been electrified under DDUGJY. Later, in March 2019, all households (including 96 % in rural areas and 4 % in urban areas) except 18,734 households have been electrified by the States under Saubhagya scheme. Several schemes to enhance energy access of remote villages through renewable energy-based off-grid and decentralised technologies including minigrids have also been launched. The first minigrid project was pioneered in the 1990s when WBREDA installed 25 kWp system in Kamalpur village in Sunderban delta region of West Bengal. WBREDA has further set up more than 20 minigrids based on solar PV with an aggregated capacity of around 1 MWp supplying electricity to around 10,000 households in West Bengal. CREDA, another state agency in India, has electrified around 35,000 households with low capacity (1-6kWp) solar minigrids in Chhattisgarh. Thereafter, minigrids connected to solar PV, biomass, or small hydro, have been implemented in various states, notably Bihar, Chhattisgarh, Lakshadweep, Madhya Pradesh, Odisha, Uttar Pradesh, Uttarakhand, and West Bengal.

Although decentralized energy systems such as minigrids have been instrumental in providing last mile connectivity and reliable electricity, yet the government considers them merely as a stop-gap solution till the grid arrives. Several reports have highlighted that government programme of providing electricity through grid electrification may not be sufficient to provide reliable electricity in remote villages, and therefore minigrids might also continue to operate in grid connected villages having irregular electricity supply (Bhushan, et al., 2019).

3.5.3 Policy and regulations for minigrids

Government of India has taken following key policy measures to encourage minigrid development:

- Electricity Act of 2003 removed the requirements of licenses for developers to generate and distribute electricity in rural areas of India (Ministry of Law and Justice, 2003). Thus, giving minigrids freedoms to operate alongside government Distribution Companies (DISCOMs)
- Ministry of Power's Tariff Policy 2016 allows DISCOMs to purchase minigrid electricity and provides relevant guidelines (Ministry of Power, 2016). Till date very few states have adopted these guidelines.
- MNRE issued a draft 'National Policy for Renewable Energy based Micro and Minigrids' in June 2016, which proposed to install 10,000 new, renewable energy-based micro/minigrid projects of total size 500 MW by 2022 (Ministry of New and Renewable Energy, 2016). Till date, the national policy has not been finalized.
- Several states have also adopted the above central government measures in varying forms, and two have further implemented their own policies and regulations. For instance, the state of Uttar Pradesh in India has introduced two policies - Mini grid Policy, 2016 and Minigrid Renewable Energy Generation and Supply Regulations, 2016. These policies/ regulations stipulate capital subsidy for minigrid project, interconnection with DISCOMs, terms of electricity sale to DISCOMs, permissions for minigrids to become distribution franchisees, among others. Similarly, Government of Bihar in India has notified Policy for New and Renewable Energy Sources 2017. The policy has specified operating areas, interconnection with DISCOM, electricity sale, subsidy for minigrid, among others.

- Further, the Government had sent a notification in the National Tariff Policy in January 2016, to support the concerns of minigrid developers regarding future electrical grid reaching the area of a microgrid before the useful life of the asset. The notification states that the microgrid owner should receive a pre-determined tariff for the rest of the useful life of the asset (Jaffer, 2016). But this has not been made into a regulation yet.

3.5.4 Technical aspects of minigrids

The common generation technologies used for minigrids in India are diesel, solar PV, biomass gasifier, mini/micro hydro and solar-diesel or solar-battery hybrids. Minigrid technology has advanced over the years with the adoption of remote monitoring, load limiters and low cost, efficient technologies. Innovation in revenue collection methods, specifically pre-paid technology, has enabled better returns for minigrid operators. Most of the minigrids today are being designed keeping future energy demand of rural households and businesses in mind. There is a shift from DC to AC, from just households lighting and mobile charging to household and commercial appliances.

TP Renewable Microgrid (TPRM)[31], a minigrid developer, has designed an innovative technology "Utility-in-a-Box", which is a pre-assembled, modular minigrid system. Similar boxes have also been developed by other companies such as ABB, GE, etc. The system is a full turnkey system for minigrid operators, including the complete hardware, the end-to-end installation, and a comprehensive after-sales service package. The system can meet the demands of larger and greater number of loads. The cost of the technology is USD 1.85 per Watt, which is significantly lower when compared to another low-cost provider (Institute for Transformative Technologies, n.d.).

3.5.5 Business models for minigrids

A wide variety of business models have been adopted and promoted by government agencies and private developers in India. The community-based model is the most common business model that has been adopted by most publicly supported minigrids developed by WBREDA or CREDA. Mera Gao Power (MGP), one of the private minigrid players, has promoted an innovative business model providing low-cost microgrid power solutions to rural India. The emphasis of MGP is to provide service-specific microgrids designed to meet the lighting and mobile charging requirements of rural people. The customer base primarily includes poor households and enterprises which are billed on a pre-payment basis.

The anchor-business-community model, widely adopted and promoted by OMC Power - a renewable energy service company– in India, is another model which prioritises large 'anchor' loads such as commercial and industrial followed by businesses and households. This model works well in villages with considerable commercial/industrial loads. Gram Power, another private minigrid developer, has evolved 'pay as you go' model to electrify remote rural villages in India using advanced technologies where provision of electricity is made on demand.

Other set of business models include those that cater to the varying needs of the local people with emphasis on creation of local entrepreneurship by engaging with the community and encouraging development of local commercial activities. Smart Power India, a large-scale renewable energy

[31] TPRM is a partnership between Institute for Transformative Technologies (ITT), Tata Power and the Rockefeller Foundation to provide power through mini grids to 25 million people across 10,000 rural villages in India.

initiative created by the Rockefeller foundation, has been field-testing new technologies and business models that can take decentralized renewable energy from an off-grid alternative to a mainstream component for widespread rural electrification.

Further, operational diesel based minigrids are being converted/ hybridised into solar/ wind/ diesel minigrids in large and densely populated islands and hilly/ remote regions of India. WBREDA is developing a 500-kW solar-wind hybrid project in Sagar Island of Sunderbans. Central government is promoting hybridisation of diesel gensets with renewable energy in Andaman & Nicobar and Lakshadweep islands where majority of the power generation comes from diesel-based units.

Convergence Energy Service Limited (CESL), a newly established subsidiary of Energy Efficiency Services Limited (EESL) is solarizing the existing diesel minigrids in Zanskar valley in Union Territory (UT) of Ladakh, in collaboration with Power Development Department (PDD), Ladakh and Autonomous Hill Development Council, Kargil. The proposed solar-diesel hybrid minigrid projects are driven by the Vision-2050 for UT of Ladakh, which aims to harness the potential of renewable energy in the state and thus becoming 1st state in India running on 100% clean energy. CESL is exploring international carbon finance market to monetize GHG reductions from such projects.

Mlinda, another project developer, is installing scalable and replicable model of minigrids to increase access to energy and has already installed 39 minigrids in 40 villages by March 2020. The project has connected 4,918 families and empowered 1250 small enterprises across states of Jharkhand and West Bengal. The minigrids are designed to meet domestic as well as agricultural needs. The consumers pay upfront connection fees and then pay for energy usage through pre-paid meters (Mlinda, 2018).

Minigrids are being promoted to provide electricity for public institutions in health care and education sector and for enterprise development in rural areas following the PPP approach where the Corporate Social Responsibility (CSR) funds/ government grants/ local area development schemes are being matched with private sector equity and community contribution to install and operate minigrids.

Hamara Grid Private Limited, a minigrid developer, has initiated a project designed on the above model wherein the District Administration (Public), the minigrid project developer (Private), and the Village Development Board (People) are proposing to work together to electrify 1000 villages spread over ten districts in the Northeast. The project will integrate clean, high quality, and reliable energy with livelihoods, agriculture, health, education, and other public infrastructure such as streetlights.

Husk Power, a minigrid developer, builds village scale minigrids using rice husk gasifiers, capacity usually ranging between 30 and 200 kW. The firm has replicated this minigrid model in several projects. The company works only in locations where at least 250 households agree to take connection. DESI Power, on the other hand, has focused on productive use of power and used husk-based systems to displace diesel-based electricity supply to micro-enterprises. It has also used anchor loads to improve the financial viability of the business. SunMoksha, clean energy technology provider, has developed technological solutions for microgrid and irrigation sectors. Smart Nanogrid, one such solution, is a smart-grid and IoT/cloud-enabled microgrid solutions to dynamically manage supply and demand, and manage billing and payment.

3.5.6 Minigrid tariff

A vast difference can be seen across the tariff structures set for both publicly supported as well as privately implemented minigrids. This is mainly because setting up of minigrid tariffs are outside the purview of the current regulatory framework and are determined through negotiations with consumers while also taking into consideration the prevailing socio-economic aspects of a given area. Hamara Grid, one of the project developers in India, establishes electricity tariff for their minigrid project by consultation with district administration and local Village Development Councils (VDCs), and based on the mutual decision and the consumers' ability to pay, the electricity tariff is set. Most minigrid developers today provide 'package deals' for a flat monthly fee instead of charging the end user a cost per unit. This works well for the households/ domestic consumers as this is the amount that was previously spent by them on kerosene. However, these payments are effectively 5-6 times higher on the cost/unit side when compared to what an urban residential consumer is paying for grid electricity. In some cases, such as in case of Hamara Grid, a differential tariff rate for daytime (lesser tariff rate to promote usage of productive loads) and night usage (higher tariff rate as electricity flows through storage) are negotiated.

3.5.7 Financing for minigrids

Most minigrids in India have been financed using capital subsidies provided by Government of India through MNRE or Ministry of Power. MNRE programmes have provided subsidies to meet the capital cost of the projects. Decentralized Distributed Generation programme of Ministry of Power has the provision of not only providing capital subsidies for the project, but also providing some operational costs of up to five years of project operation.

Private minigrid developers have also tapped developmental bank loans, venture capital funds, donor grants, CSR financing and private equity financing, etc. Minigrid developers use these financing tools in different combinations at different stages. At the inception stage, developers typically fund their minigrids with a combination of capital subsidies, grants, and their own equity.

3.5.8 Opportunities for minigrids

Resource potential: India has a large potential for renewable energy deployment. According to National Institute of Solar Energy (NISE), the total potential for solar power alone is estimated to be 748 GW (Ministry of New and Renewable Energy, Solar Energy: Overview, n.d.). The solar GHI map of India developed by the World Bank and IFC has been included in Annexure 2. The estimated potential of small/ mini hydro assessed by Alternate Hydro Energy Centre (AHEC) of IIT Roorkee is 21,135.37 MW (Ministry of New and Renewable Energy, Small Hydro Current Status, n.d.). National institute of Wind Energy (NIWE) has estimated a potential of 302 GW for wind power in the country (Ministry of New and Renewable Energy, Wind Current Status, n.d.). The bioenergy potential is 28 GW utilizing agricultural residues (Ministry of New and Renewable Energy, Bio energy - Current status, n.d.). Further, the government has introduced an ambitious target of 175 GW of RE including decentralized generation by 2022 (Sustainable Development Goals Partnership Platform, n.d.). The huge resource potential and RE target thus provides an opportunity for minigrid development in the country.

Unmet electricity demand: As mentioned earlier in section 3.5.1, there are still 5.5 million people in India that lack access to electricity and most of these people live in remote rural areas. While India generates sufficient electricity and has necessary capacity to meet demand, it struggles to distribute this electricity efficiently and effectively to rural areas. In many places, the power reliability is limited by transmission capacity and electricity distribution companies' ability to perform repair and maintenance of the network in remote areas. Even in grid connected villages there are problems of reliability (hours of supply) and quality (voltage) of electricity. Despite the government's ongoing efforts to electrify last mile households in India, there remains a clear gap between demand and supply. RE based minigrids can provide high quality reliable electricity for lighting and other productive loads in households and has the potential to become an integral part of India's rural electrification strategy, providing last mile electrification.

Further, while the central Government has completed the electrification drive under the Saubhagya scheme, the focus was mainly on households, and therefore, the public welfare institutions, (particularly rural health centres) have been left out of this scheme. These institutions usually rely on diesel gensets. Thus, there is an opportunity for minigrids to scale up in these areas to electrify public institutions and support enterprise development utilizing CSR funds and other health sector related public funds.

Specific opportunities: Minigrid policies in two states of India - Uttar Pradesh and Bihar - have been driving private sector interest in these states to develop RE based minigrid projects for providing last mile electrification, reliable & quality power and push socio-economic development complementing government efforts. An increased consumers' aspirational need for additional appliances also indicates an opportunity for continued expansion of minigrid system capacities.

3.5.9 Barriers to minigrids

The foremost challenge to minigrid development in India is lack of clarity in policies and regulations at the central and state level regarding future grid arrival at the place of minigrid site. This has discouraged many companies from pursuing minigrids in remote areas as they are unsure of the stability of their investment. Health centres, schools, streetlights, and other public good infrastructure have remained uncovered in the state minigrid policies.

The other challenge is to make electricity from minigrids as affordable as grid power and still be able to recover the capital and operating expenditures in a reasonable time frame for sustainable operations. Minigrid power can be 25 times as expensive as power from the grid per kWh, because developers try to recover their investment within only a first few years as well as due to presence of low demand for electricity.

The third challenge for minigrid developers is the lack of a credible and reliable source of finance to meet upfront capital costs and regular operating costs. Minigrids face challenge in financing, due to their longer paybacks, inherently risky business structures, untimely payment by consumers, improper billing and payment mechanism, and the lack of financing entities willing and capable of extending low-cost financing. There is also lack of patient capital[32] available to finance minigrids.

[32] Patient capital is an investment that does not seek to maximize financial returns to investors, but seeks to maximize social impact and to catalyze the creation of markets to combat poverty

3.6 Maldives

3.6.1 Status of access to electricity and minigrids

Maldives is the first country in South Asia to achieve universal access to electricity. In 2008, the country reached 100% access to electricity and further by 2011, 24-hour electricity supply across all islands. Each inhabited island has its own powerhouse and distribution facility, effectively operating as single, isolated island power grids. Almost all the country's current power needs are met through diesel fired generation, although there are no proven reserves of fossil fuels in Maldives. Diesel fuel is imported and transported to the dispersed generating locations.

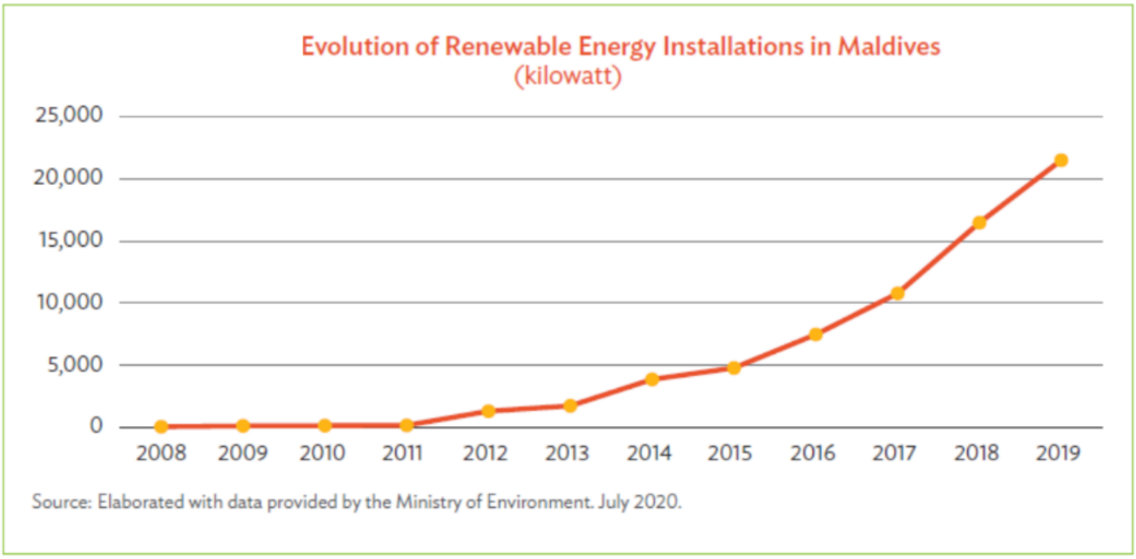


Figure 32: Growth of Renewable Energy in Maldives[33]

The island country has a total of 290MW capacity of diesel generators installed in 186 inhabited islands, around 144 MW of additional diesel genset capacity in Resort islands and 20 MW in industrial islands. Two electric utilities, Fenaka Corporation Ltd. (FENAKA) and State Electric Company Ltd. (STELCO) operate 148 and 35 powerhouses respectively. A very small capacity of 21.5 MW of renewable energy systems has been installed till now across the country. The above **Error! Reference source not found.**Figure 32 shows the trends of renewable energy installations in Maldives from 2008 – 2019 (ADB, 2020).

Most of the solar installations in the country are rooftop solar PV installed under net metering. Recently, solar PV projects in hybrid mode with existing diesel generators are being successfully implemented in several inhabited islands under the Preparing Outer Islands for Sustainable Energy Development (POISED) project of Asian Development Bank (ADB). The project is transforming existing diesel-based energy minigrids into hybrid renewable energy systems in 160 inhabited islands, out of which installations on 48 islands have been commissioned.

[33] (ADB, 2020)

3.6.2 National strategy for electricity sector

The Government of Maldives (GoM) aspires to reach net-zero global greenhouse gas emissions by 2030 with international assistance and private investments. The key priority of the government, in this regard, is to reduce its dependence on imported diesel fuel and invest in renewable energy projects.

Over the past 10 years, government has introduced several strategies and initiatives to scale up the renewable energy applications in the country. Maldives has developed a Strategic Action Plan (SAP), which includes strategies and targets for development of clean energy in the country. The plan targets to increase the share of renewable energy by 20% as compared to 2018 and install a minimum of 10 MW of solar PV under net metering regulations by 2023. The plan also targets to reduce distribution losses and plans to establish smart minigrids in selected clusters of islands to address this issue.

3.6.3 Policy and regulations for minigrids

Since 2008, the GoM has supported reduction in global GHG emissions in the wake of a warning that rising sea levels could submerge the entire country. Several policies and strategies were developed and implemented in this regard. In 2012, Maldives Scaling-Up Renewable Energy Investment Plan was developed, which included strategies to scale-up renewable energy in the country.

At present, the policy instruments supporting hybridisation of diesel minigrids with renewable energy technologies are the Energy Policy and Strategy 2016 and the Strategic Action Plan 2019–2023. The Maldives Energy Policy and Strategy 2016 recommends the introduction of hybrid systems that use renewable energy and seeks to encourage private sector renewable energy development.

As stated earlier, the National Strategic Plan also supports the development of minigrids in the country. The plan targets to reduce distribution inefficiency by maintaining distribution loss within 7% by 2023 through establishment of smart minigrids as one of the action items. The Ministry of Environment and Energy is the nodal ministry responsible for policy, planning, and development of the energy sector.

3.6.4 Technical aspects of minigrids

The diesel minigrids combined with solar PV systems have been the main mode of hybridisation in the country till date, although the country has potential for other forms of renewable energy. Under ADB POISED project, solar PV systems are connected to the diesel power plants through an Energy Management System (EMS) for improved management of electricity supply. This hybrid configuration offers short pay back times when compared to current prices of electricity produced by diesel generation sets (ADB, 2020).

A unique, 40 kW grid-connected solar photovoltaic system was installed on Dhiffushi island in November 2016 coupled with the ice-making machine which uses seawater to produce around 1 tonne of flake ice per day. In the daytime when solar energy is more than the demand, the icemaking machine stores excess solar energy by producing ice. The system provides a simple yet sustainable way for local fishermen to preserve fish and save costs (GSEP, 2017).

3.6.5 Business models for minigrids

Under World Bank-supported Accelerating Renewable Energy Integration and Sustainable Energy (ARISE) project, hybridisation of fourteen island grids is being done under public private partnership project framework which was earlier developed by World Bank.

The first project, 1.5 MW PV, was completed in March 2018 under this framework. Additional two sub projects, which include 5 MW PV installations (currently in the construction phase) and a 21 MW project (in tender stage) have been the result of continued efforts of this working model. The projects are being developed on Design, Build, Finance, Own, Operate and Transfer (DBFOOT) model. The project developer enters into a long-term PPA with the existing electricity service provider at a fixed tariff (Duggal, 2021).

The hybrid solar projects under ADB POISED project are being installed in outer islands as grant/ loan model with financing provided from ADB and European Investment Bank. The projects will be owned by public utilities such as STELCO and FENAKA (ADB, 2020).

3.6.6 Minigrid tariff

The cost of electricity production using diesel fuel in Maldives is quite high, with energy cost ranging from USD 0.097/kWh to USD 0.45/kWh, depending on the size and efficiency of the electricity system (CIF, 2019). This is mainly because diesel fuel is imported and transported to the dispersed generating locations in Maldives, which adds to the cost of generation. For domestic consumers, government provides fuel surcharge subsidy and usage subsidy which covers over 50% of the cost of electricity (ADB, 2020). Figure 33 depicts the average electricity tariff in 2013 compared with the generation costs using diesel and solar PV. It supports the fact that investing in solar PV will be beneficial for both the government and the consumers (Ministry of Environment and Energy, 2013).

The solar PV bids in the Greater Malé area under the World Bank-funded Accelerating Sustainable Private Investment in Renewable Energy (ASPIRE) project has demonstrated solar PV tariffs as low as US cents 10.9 per kWh. The introduction of solar photovoltaic technology into a diesel minigrid environment means that the diesel generation provides a back-up as more and more solar PV penetration occurs, thus reducing the cost of generation for the hybrid system. PV tariffs are also expected to continue falling as the market continues to mature, the scale of projects increase, and investor confidence grows.

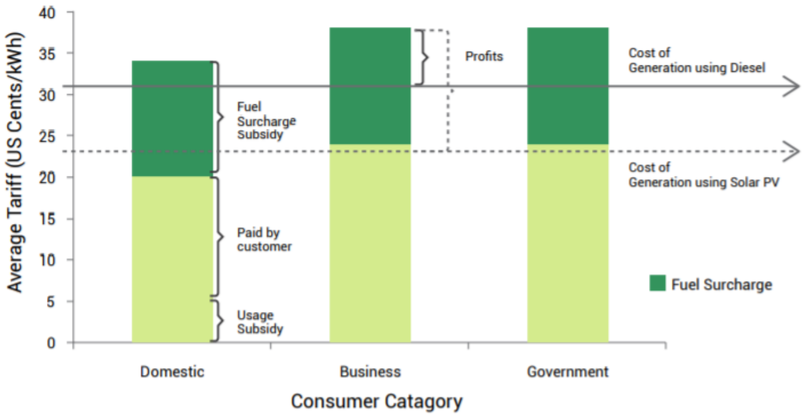


Figure 33: Average Tariff of Different Consumers in Maldives[34]

[34] (Ministry of Environment and Energy, 2013)

3.6.7 Financing for minigrids

Most of the renewable energy projects have been developed under grant or loan component provided from multilateral development banks, donor agencies. The funding for typical infrastructure projects/ programs in Maldives tends to be small grants or loans given the country's size, macro-economic conditions and borrowing constraints. The POISED program has been able to mobilize nearly USD 129 million through grants and loans and has made a sound case for larger funding in Maldives (CIF, 2019). The ASPIRE project of World Bank has resulted in the mobilization of USD 9.3 million since it began in 2014. The private sector investment in the RE sector is in its nascent stage and private developers and lenders are still reluctant to invest in the sector (ADB, 2020).

3.6.8 Opportunities for minigrids

Resource potential: The Maldives has abundant renewable energy resources including solar, wind and ocean power. Solar radiation is in the order of 1,200 kWh/m^2/year, which is considered good for any solar PV project. The solar GHI map of Maldives developed by the World Bank and IFC has been included in Annexure 2. Wind resources are not equally distributed across the country with northern half being relatively richer in wind resource than its southern part. The resource assessment of tidal and in-stream energy has estimated the potential in the range of 28 MW to 106 MW. Among the three, solar PV energy has the most immediate exploitation possibilities in Maldives. The Strategic Action Plan of Maldives targets to increase the share of renewable energy by 20% as compared to 2018 focusing on hybrid solar plants and rooftop solar (ADB, 2020).

Unmet energy demand: Maldives has achieved 100% electrification in each of its islands, providing 24-hour supply mainly through diesel based minigrids. However, the demand of electricity is increasing, and the country does not have any fossil fuel reserves and has to import diesel fuel which has several challenges associated with logistics, as well as with greenhouse gas emissions. The GoM has recognized these challenges and is working to transform its energy sector through utilization of country's renewable energy potential. Government has also set a target to achieve net zero emissions by 2030 through applications of renewable energy technologies.

Specific opportunities: The current cost of electricity in the country is among the highest in South Asia. Annual subsidies to the electricity sector amount to USD 65 million at the end of 2019 (ADB, 2020). Energy sector studies reveal that the cost of energy generation based on renewable energy and fossil fuel hybrids would be significantly lower compared to existing options (ADB, 2014). The transition to renewable energy-based systems has thus sound economic rationale. The hybrid renewable energy systems can also displace a large quantity of the imported diesel fuels which will help in reducing the GHG emissions and thus contributing to the government's target of achieving net zero by 2030. Resort islands running on diesel systems can have the inherent benefits of eco-friendly branding by adopting renewable energy systems in hybrid mode. Outer inhabited islands have less power demand in general but during vacation period, the power demand increases. Incorporating renewable energy-based systems in conjunction with existing diesel minigrids can be used to power the additional demand as well as reduce the consumption of diesel in other days.

3.6.9 Barriers to minigrids

There are several challenges to deploy renewable energy-based hybrid minigrids in Maldives namely, *Lack of concrete energy sector plans:* There is a need to develop robust energy sector plans focusing on hybrid renewable energy projects to meet the increasing electricity demand in the country, lower electricity cost and reduce the import of diesel.

Lack of financing: The investments in renewable energy projects in the country have been driven primarily by grants and loans from multilateral agencies. Due to its relatively small banking system, Government of Maldives is facing liquidity crunch to fund these projects. Commercial bank financing or private sector financing is in its nascent stage since they are still reluctant to accept the risks associated with renewable energy technologies and invest in the sector. Private sector participation is crucial for development of RE minigrids in the country.

Limited expertise and experience in RE technologies: Utility companies in Maldives have mainly implemented conventional energy projects since the beginning of the country's industrialization. Therefore, there is limited knowledge and experience regarding renewable energy technologies, their installation and operation and maintenance.

3.7 Nepal

3.7.1 Status of access to electricity and minigrids

Nepal was facing severe electricity shortage and the country was facing load shedding (power cuts) up to 16 hours per day in households till early 2017 as well as in industries till early 2018 (Sushil Sah, 2019). Economic Survey of Nepal 2020/21 states that the overall rate of electrification has reached 93% (Ministry of Finance, 2021). The yearly trend of access to electricity is provided in Figure 34. The major source of electricity in Nepal is grid connected large hydropower projects. However, Nepal has difficult topography and scattered settlements, particularly in hills, thus extension of national electricity grid for electrification of rural areas would be expensive. Hence, Nepal has been promoting micro hydro for rural electrification since 1980s (Alternative Energy Promotion Centre , 2016).

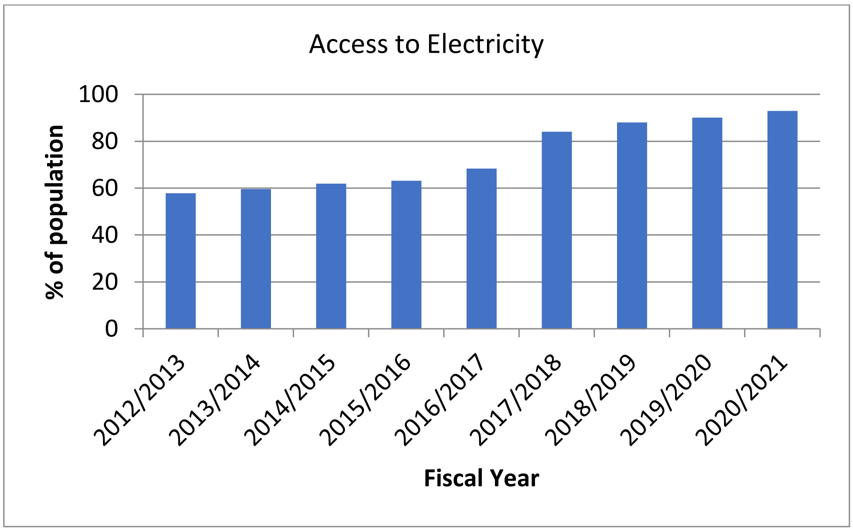


Figure 34: Yearly Trend of Access to Electricity[35]

[35] (Ministry of Finance, Economic Survey 2077/78, 2021)

The solar minigrid in Nepal was piloted by Nepal Electricity Authority (NEA) with support of France in 1989 (Renewable Energy for Rural Livelihood, 2020). After 2011, Government of Nepal (GoN) has been allocating budget and installing solar and solar-wind hybrid minigrids in each fiscal year (Santosh Rai, 2019). Alternative Energy Promotion Centre (AEPC) has different programs for the promotion of renewable energy including minigrid sector focusing on rural electrification in Nepal. AEPC has installed 11 solar-wind hybrid minigrid projects of total capacity 384 kW and 14 solar minigrid projects of total capacity 711 kW until 2020 (includes working, under construction as well as planned projects). AEPC has also developed 1,816 numbers of mini/micro run of the river hydro projects of total capacity 32,778.39 kW in off-grid areas under different programs (Santosh Rai, 2019).

During the stakeholder consultation, it was learnt that since last couple of years less than 50% of mini/micro hydro minigrids have sustained due to different reasons including high tariff, operation and maintenance issues, and natural disasters. Almost 274 mini/micro hydro were damaged by 2015 earthquake in Nepal. Out of 274, 116 projects are under rehabilitation with support from Renewable Energy for Rural Livelihood (RERL) program, Department for International Development (DFID) and GoN fund and 97 projects are rehabilitated and maintained by community themselves (Santosh Rai, 2019).

3.7.2 National strategy for electricity sector

Budget has been allocated to electrify 50,000 households (HH) in off grid areas and 90% subsidy will be provided for solar and mini hydro implementation by local government and community institution, as per the Nepal's government budget for FY 2021/22. Further, the government is also focusing on electrifying remotely located mountain communities and upper hills by implementing Solar Minigrid program (Ministry of Finance, 2021).

GoN has been promoting renewable energy since mid-1970s by provisioning credit facility to install micro hydro and in mid 1980s, mini/micro hydro up to 100 kW has been delicensed and subsidy has been provisioned for electricity generation and distribution. The Fifteenth Plan (Fiscal Year 2019/20 – 2023/24) aspires for a 12% contribution of renewable energy in the total energy consumption and has target of 100% electrification by 2023/24. Similarly, the plan aims to provide access to electricity to the additional 5% of the total populations with 13 MW of micro/mini hydropower, 127 MW of solar and 10 MW of wind energy.

3.7.3 Policy and regulations for minigrids

AEPC is the focal organization for developing and promoting renewable energy technologies including minigrids in Nepal since 1996. Electricity Act 1992 opened the doors for private sector investment in hydropower including mini and small hydro in Nepal. Hydropower plants from 100kW to 1MW did not require license for generation and in off grid areas, the distributor could fix the tariff and charges independent of the Electricity Tariff Fixation Commission (ETFC). The Act also allowed developers to sell electricity to the national grid.

Rural Energy Policy 2006 (REP 2006) is the first policy approved by AEPC, which focuses on increasing access to clean and cost-effective energy in the rural area, thereby increasing the living standards of rural population by creating employment and productivity. RE Subsidy Policy and Subsidy Delivery Mechanism 2016 indicates that the subsidy amount in the renewable energy technology needs to be reduced and readjusted to gradually shift from subsidy to credit model. Subsidy should be based on electricity consumption. The policy has the provision of additional financial support to targeted beneficiaries including households headed by women and marginalized community. The white paper of Ministry of Energy, Water Resource, and Irrigation (2018) has provisioned the policy to establish the challenge fund to develop the 100 kW to 500 kW solar energy technologies at each local level.

Minigrid Special Program Operation Rules has been formulated in the year 2019 to facilitate mountainous and upper hills solar minigrid program and *Ujyalo* Nepal Program. MHP Operation and Management Guidelines provide details on sustainable operation including institutional strengthening for smooth operation of the plants and promotion of productive electricity uses after the installation of micro hydro. Technical standard for grid interconnection 2014 was approved by NEA to buy electricity from an MHP when the national grid passes through its service area. This has opened opportunity for the interconnection of micro hydro to the national grid (Renewable Energy for Rural Livelihood, 2020).

3.7.4 Technical aspects of minigrids

Nepal has minigrid systems generating electricity from hydro, solar and wind resources. Plants with capacity of up to 1 MW have been developed as hydropower minigrids in the country and solar as well as solar-wind hybrid minigrid has capacity range of 8 kW to 150 kW.

The solar and solar-wind hybrid minigrids have battery backup. Most of the minigrid end-user has a prepaid energy meter. South Asia Sub-Regional Economic Cooperation (SASEC) projects of ADB are the first minigrids in Nepal to use prepaid meters (Renewable Energy for Rural Livelihood, 2020). During stakeholder consultation, it was learnt that after the SASEC project, prepaid energy meters are mandatory for all minigrid systems. The solar minigrid installed by Gham Power, Nepal (private sector) also has remote monitoring and control system. The minigrid projects of ADB in Nepal have grid compatible distribution system. Some of the minigrid projects are successfully connected to the national grid.

3.7.5 Business models for minigrids

Nepal Electricity Authority, a government utility actively constructed and managed mini and small hydro plants for many decades but this is slowly phasing out. Hydropower policy of Nepal encourages community, cooperatives, and local bodies to be active in developing smaller hydro projects. Many of the early minigrid systems such as Salleri Chialsa mini hydro and Namche mini hydro in Solukhumbu district were built with support from the communities and they are responsible for operation and management of the system.

AEPC/RERL program aims to demonstrate success of public private partnership model for development of minigrid projects. All RERL supported projects are owned by the community and managed either by cooperatives or as public limited companies.

The World Bank has launched a program “Minigrid Energy Access Project (MGEAP)” which has the objective to increase electricity generation capacity from renewable energy minigrids in selected areas by mobilizing RESCOs. 29kW Simli Khola MHP, Rukum is the community owned privately managed minigrid system. The plant is managed and operated by the single person, and he pays to the community as per the lease agreement (Renewable Energy for Rural Livelihood, 2019).

Dubung Solar microgrid is the first in Nepal built in partnership between the community (user community of Dubung), private sector (Saral Urja Nepal Pvt. Ltd.) and the government of Nepal. The project developer company is jointly owned by user community of Dubung and Saral Urja. Private sector involvement has helped in providing reliable electricity supply (Saral Urja Nepal, 2021).

3.7.6 Minigrid tariff

According to Minigrid Special Program Operation Rules 2019, minigrid tariff should be set in accordance with prevailing tariff rate of NEA; minigrid tariff should not be more than the grid tariff (Alternative Energy Promotion Centre , 2019). Minigrid tariff in Nepal is set in consultation with the community, considering the site of the project and technology of the minigrid. Micro hydro developers set up flat tariff rate in Nepal on the monthly basis without considering the amount of energy usage. During the stakeholder consultation, it was mentioned that average tariff rate of solar minigrid electricity for household (around NPR 15 per kWh (USD 0.12[36] per kWh) is less than that of the enterprise around NPR 20 per kWh (USD 0.17 per kWh). As per the consultation, Electricity Regulatory Commission of Nepal is trying to bring uniformity in tariff rates of grid and off grid electricity.

Dubung solar microgrid project, discussed previously in Section 3.7.5, is charging high tariffs to the consumers as compared to the national grid tariff even after receiving high upfront subsidy for the project. However, the beneficiaries who are able to now utilize electricity for income generating activities are paying their bills on time (Renewable Energy for Rural Livelihood, 2020).

3.7.7 Financing for minigrids

Minigrid financing in Nepal hinges on grants/subsidies from the government and community contribution. Very few projects are privately financed. Agriculture Development Bank of Nepal was the sole financial institution in early 1980's for MHP financing. AEPC in 2011 created Micro Hydro Debt Fund (MHDF) to promote MHPs with credit facility. MHDF enables the communities to repay the high upfront costs over a long period of time and encourages commercial banks to finance micro hydro projects in rural Nepal. Private banks provided credit for 26 MHPs in 12 districts through project financing modality with 50% loan guarantee scheme from AEPC/MHDF. However, due to the discouraging loan recovery performance from those MHPs, AEPC has also been mobilizing Local Financial Institutions (LFIs) like cooperatives and Microfinance Institutions (MFIs) to promote MHPs for rural electrification (Alternative Energy Promotion Centre , 2017).

Central Renewable Energy Fund (CREF) has been established as the financial management mechanism for the RE by AEPC which functions as the core financial mechanism responsible for the effective delivery of subsidies and credits to the RE sector in Nepal. CREF also intends to promote vendor financing mechanism which targets to facilitate the installation of at least 600 renewable energy systems through vendor financing model (Central Renewable Energy Fund , 2017). Vendor Finance Challenge Fund (VFCF) is financed by UNCDF, UNDP-RERL and CREF to support development and growth of the RE market by mobilizing commercial credit, attracting private sector/entrepreneurs and reducing their investments risks.

[36] 1 NPR = 0.0083 USD as on 27th October 2021, same exchange rate has been used to convert NPR to USD in this report

Sustainable Energy Challenge Fund (SECF) is being implemented under AEPC's CREF to provide Viability Gap Funding (VGF) to make marginally feasible distributed RE projects bankable. SECF supports technical, managerial and financial management to new and existing RE minigrid projects.

To attract the private sector in operation and management of minigrids, the RE subsidy policy 2016 has provisioned upfront kilowatt-based capital subsidy and the subsidy for energy consumed to cover part of the operational expenditures. However, the new provision has not attracted the investors due to the perceived risk in investing in community owned minigrids.

3.7.8 Opportunities for minigrids

Resource potential: Among different forms of RE resources, hydropower has the largest potential to provide energy in Nepal. The theoretical potential is 84 GW of which 43 GW is estimated to be economically viable (Alisha Pinto, Yoo, Portale, & Rysankova, 2019). According to the AEPC report, the commercial potential of solar power is 2.1 GW (Water and Energy Commission Secretariat, 2013). The solar GHI map of Nepal developed by the World Bank and IFC has been included in Annexure 2. Hydro, solar and wind based minigrids have typically been developed in Nepal till date. The Government of Nepal is moving towards the universal access to electricity with on grid and off grid electrification projects and has annual plans for development of minigrids based on RE resources. This indicate that resource potential is not a constraint for development of minigrid in the country.

Unmet energy demand: Nepal has to provide electricity access to 7% of its population, mainly on mountainous and upper hilly regions for achieving 100% electrification in the country. Expansion of national grid to those areas is cost intensive as well as time consuming. RE based minigrids, which are able to provide reliable access to electricity at affordable cost have good opportunity for development in these unserved areas of Nepal.

Specific opportunities: The fifteenth plan of GoN aspires for a 12% contribution of RE in total energy consumption by the year 2024. The country has also targeted solar minigrid projects in mountains and upper hills region as mentioned in section 3.7.2 (Alternative Energy Promotion Center, 2019). These specific minigrid programs such as mountainous and upper hills solar minigrid program and *Ujyalo* Nepal Program offer good opportunities for minigrids in Nepal. GoN has allocated budget for detailed feasibility study of minigrid programs around the country and national minigrid plans for *Ujyalo* Nepal Program. Subsidy and debt will be provisioned for RE systems under national minigrid program (Ministry of Energy, Water Resources and Irrigation, 2021).

Nepal Renewable Energy Program (NREP) is dedicated to increase private sector investment in DRE and increase universal energy access. To date, NREP has been preparing for the launch of SECF to catalyze the DRE market in Nepal by providing needs-based awards. It has developed a pipeline of over 70 DRE projects.

3.7.9 Barriers to minigrids

Minigrids have been designed mainly for basic needs without the consideration of future energy demand of households and productive loads. Also, minigrid power is expensive compared to power from the grid because of developers' interest to recover their investment within first few years. The areas served by the minigrid may soon be reached by national grid and due to higher tariff rate of minigrid electricity; customers will keenly connect to the national grid.

Despite the successful interconnection of several MHPs and solar PV projects to the national grid, the policy for grid connection of minigrids is still ambiguous. CREF, although has been operational for some years, it has not been able to attract private investment in minigrid projects. Project developers continue to struggle to achieve financial closure on time as subsidy and their equity are not enough to cover the total project cost and bank financing is difficult to access, if available the cost of financing is very high as the financing institutions perceive high risk to invest in rural communities.

3.8 Pakistan

3.8.1 Status of access to electricity and minigrids

The electrification rate in the country has improved from 55.7% in 2005 to 79.2% in 2019. However, there are still around 45 million[37] people without access to electricity with majority falling in the rural areas (IEA, n.d.). The installed power capacity as on June 2020 stands at 38,719 MW, which was more than sufficient to meet the total demand in the country in FY 2019-20. Despite having surplus power generation capacity, long hours of load shedding persist in several areas of the country (National Electric Power Regulatory Authority, 2020) . The power cuts are more pronounced in the rural areas compared to urban centres (Wheeldon, 2017).

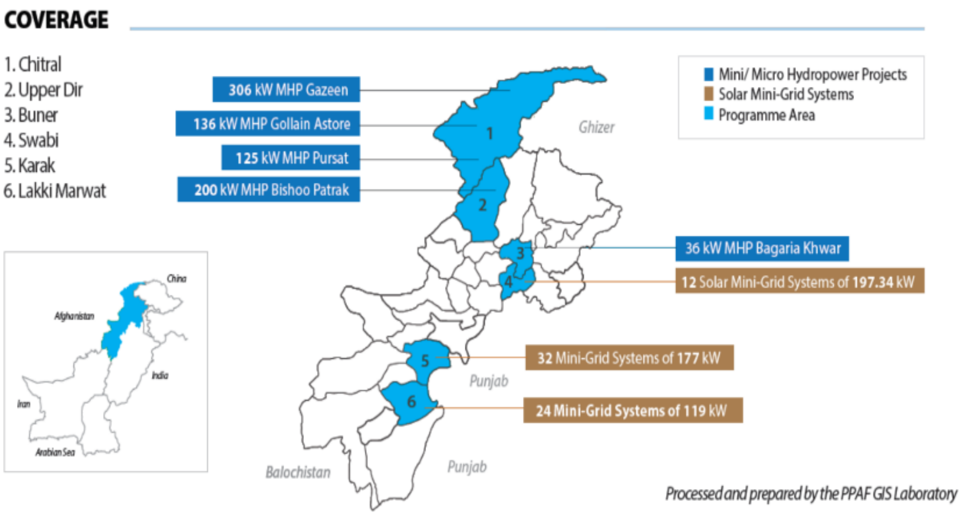


Figure 35: Coverage and Projects Under PPAF KfW HRE Program[38]

The distributed solar industry in Pakistan evolved during the early 2010s at the time of growing power shortages (ADB Institute, 2018). Pakistan Poverty Alleviation Fund has implemented more than 3,800 RE projects of 13.78 MW which include mini & micro hydropower projects, minigrid systems, solar water pumping systems, wind energy projects, solar-wind hybrid, and biogas plants (Nafees Ahmad Khan, 2021). Currently, PPAF is implementing Hydropower and Renewable Energy (HRE) project,

[37] The access to electricity in Pakistan has grown to 74% in 2019 and there are 56 million people without access to electricity as per the Tracking SDG7 The Energy Progress Report 2021. The Tracking SDG7 Report 2021 has referred to World Bank Global Electrification Database. The World Bank Global Electrification Database derives estimates from a suite of standardized household surveys that are conducted in most countries every two to three years, along with a multilevel nonparametric model used to extrapolate data for the missing years. The IEA Energy Access Database sources data, where possible, from government-reported values for household electrification (usually based on utility connections).

[38] (Pakistan Poverty Alleviation Fund , 2021)

initiated in 2013, with funding from German Development Bank (KfW). Five mini/ micro hydro power plants with total installed capacity of 803 kW have been implemented in Chitral, Upper Dir and Buner Districts of Khyber Pakhtunkhwa. A total of 68 solar minigrid systems with installed capacity of 500 kW has been installed in remote and off-grid locations of Karak, Swabi and Lakki Marwat districts of Khyber Pakhtunkhwa (Pakistan Poverty Alleviation Fund , 2021). The coverage and projects under HRE program are shown in **Error! Reference source not found.**Figure 35.

Aga Khan Rural Support Programme (AKRSP) and Sarhad Rural Support Programme (SRSP), two prominent Non-Governmental Organizations (NGOs) in Pakistan have implemented several micro hydropower projects in some regions of Northern Pakistan since their inception (Energypedia, n.d.). Private sector is also active in Pakistan and has developed several off-grid projects in rural Pakistan and has helped electrified households through solar systems.

3.8.2 National strategy for electricity sector

The Government of Pakistan has largely been focusing on electrifying the country through national grid, which mainly centred around urban areas as there is increased demand for power. The emphasis on rural electrification at the national level has remained overlooked in the country because of high distribution costs, very low electricity demand and lower capacity to pay as opposed to their urban counterparts. Hence, these factors make rural areas uneconomical and thus not a priority for distribution companies. Utilities and distribution companies are reluctant to roll out the grid since the "revenues from tariffs would never be able to provide the returns needed to recover the investment" (Energypedia, n.d.). Moreover, for those rural set-ups connected to the grid, insufficient energy access is widened due to inter-province electricity distribution and rural-urban divide (Reon Energy, n.d.).

Though the renewable energy policy of 2006 required the relevant authorities to enact measures for the promotion of off-grid RE including minigrids, not much progress has been made so far (IRENA, Renewables Readiness Assessment: Pakistan, 2018). Alternative Energy Development Board (AEDB) initiated a rural electrification programme in 2005 to provide over 7000 villages in Sindh and Baluchistan with electricity by deploying solar home systems. The project was implemented through a grant from the Government of Pakistan. It suffered a shortfall in funding and could not achieve its targets. The provincial governments have undertaken several rural electrification initiatives based on renewables, using their own resources as well as support from development partners (IRENA, Renewables Readiness Assessment: Pakistan, 2018).

3.8.3 Policy and regulations for minigrids

The Alternative and Renewable Energy (ARE) Policy 2019 provides a comprehensive framework for deploying renewable energy technologies in the country. The policy was approved in-principle by Council of Common Interests (CCI) on 6th August 2020 as per official notification available on AEDB website (Alternative Energy Development Board , 2019) .

The policy has set the target of at least 20% RE generation by capacity by the year 2025 and at least 30% by 2030 in the national grid. The policy has prioritised mini/microgrid, off-grid, Localized Energy Systems (LESs) and Business to Business (B2B) solutions for combating power scarcity realizing their potential in the country(Alternative Energy Development Board , 2019) . AEDB is currently developing the strategy and action plan for implementing the ARE Policy 2019. The private sector companies are allowed to set up power generation plants in the country, however, they are not allowed to set up a distribution system or sell electricity without a prior approval and license from both the national energy regulatory authority and respective distribution company (Saleh, 2019).

3.8.4 Technical aspects of minigrids

Hydropower has traditionally been the most prominent source of renewable energy in Pakistan. Other renewables have only recently come into the mix after the country introduced a set of support mechanisms to foster renewable energy deployment in the mid-2000s. There are numerous off-grid micro-hydropower installations in Khyber Pakhtunkhwa and Gilgit-Baltistan. The solar minigrid systems installed under PPAF HRE project were small scale ranging from 2 kW to 51 kW to meet not only the lighting requirements of the community, but also supporting the village level businesses and local enterprises (Pakistan Poverty Alleviation Fund , 2021).

3.8.5 Business models for minigrids

Minigrid projects, developed by PPAF, AKRSP and SRSP, in the country have followed community-based model for development, operated and managed by the community members. In minigrid projects implemented by PPAF, the operations, and maintenance fall under the purview of committees comprised of members drawn from local communities. Plant operators and technicians are selected from within the local community and are paid through the tariff collected from consumers. Plant operators are also trained on minigrid operation and management.

During the consultations with PPAF officials, it was learned that there has been satisfactory experience working with NGOs/ communities for minigrid operation. SRSP has also deployed similar model for managing micro hydro schemes, which ensures continuous maintenance of all parts and structure of MHPs and regular monitoring of micro catchment area for sustained water flow (Ashden, n.d.).

Nizam Bijli, a subsidiary of Nizam Energy, has rolled out PAYG model using mobile money in off-grid areas to provide affordable solar home solutions. The customers have the option of purchasing systems upfront or on a 12-month, 18-month or 36-month payment plans (all plans include health insurance). The cheapest plan allows customers to buy electricity at a price of USD 0.5 per day (Business Call to Action, n.d.). Another energy provider in rural Sindh, EcoEnergy, is providing Pay-As-You-Go solar solutions, allowing individuals to pay only for what they need and can afford. Monthly payments are typically comparable to what villagers spend on energy. A typical household spends an average of 14% of their monthly income on energy. The solar kit is remotely disconnected when credit expires (IGC, 2019).

3.8.6 Minigrid tariff

National Electric Power Regulatory Authority (NEPRA), as the sole power market regulator, has been determining tariffs for electricity in the country since 1998. The cost of electricity for end-consumers has been on the rise owing to various reasons like high Transmission & Distribution (T&D) losses, low recovery, fuel cost, under-utilization of efficient power plants etc. (National Electric Power Regulatory Authority, 2020). The average tariff for electricity currently stands at PKR 16.69 (USD 0.095[39]) per unit after a recent tariff determination (Bhutta, 2021). For large residential consumers, Time of Use (ToU) billing is also available.

[39] 1 PKR = 0.0057 USD as on 27th October 2021, same exchange rate has been used to convert PKR to USD in this report

On the contrary, the minigrids developed by PPAF or other initiatives under donor grant have shown lower cost of electricity for domestic consumers, around PKR 6 (USD 0.034) per unit (found during consultations with PPAF). These tariffs are determined considering the cost of operation and maintenance of the systems as well as consumers' ability to pay. Communities are actively involved in setting electricity tariffs for domestic and commercial consumers. In minigrid projects developed under SRSP programme, a one-time connection cost from domestic and commercial users were collected and set aside in designated bank accounts for any unforeseen rehabilitation work. Adoption of this approach has led to ensuring sustainable operation of the units in the long run (Ashden, n.d.).

3.8.7 Financing for minigrids

Almost all minigrid projects in the country have been developed under grant/ loan component received from international donor agencies. These funding for minigrids mostly covers the upfront capital cost and sometimes the ongoing cost.

Pakistan Poverty Alleviation Fund has implemented several community micro-hydropower projects and solar minigrid projects using donor grant as well as microfinance schemes. The current HRE project is being implemented with grant funding from the KfW. The whole project has two phases, with total financial outlay amounting to EUR 22.5 million (USD 26 million[40]) (Pakistan Poverty Alleviation Fund , 2021).

State Bank of Pakistan has rolled out financing scheme for renewable energy in 2009, which was revised in 2016 to make it more attractive to both project developers and financing institutions. Private banks in Pakistan can use these funds to finance renewable energy projects ranging from 4 kW to 50 MW capacity (IRENA, 2018).

3.8.8 Opportunities for minigrids

There are many opportunities for development of minigrids in the country on account of following aspects.

Resource potential: Pakistan has abundant renewable energy sources, yet the share of renewable energy in the power mix is remarkably low: only 5.5% of installed capacity (National Electric Power Regulatory Authority , 2020). Hydropower is the most promising and cheapest sources of power generation in Pakistan. The economically and technically viable potential of hydro power in the country is estimated to be 60 GW for all scales and types. Pakistan has good solar energy potential as well. The annual global horizontal irradiance ranges from 1,500 kWh/m^2 - 2,300 kWh per m^2 per year, with the southern and southwestern parts recording greater irradiation levels than the north. The solar GHI map of Pakistan developed by the World Bank and IFC has been included in Annexure 2. The theoretical potential for wind power, without considering technical and economic constraints, is estimated to be 340 GW (IRENA, 2018). In this regard, the Government has set a target of installing at least 20% RE capacity by 2025 and 30% by 2030 in the national grid, prioritizing mini/microgrid solutions as key intervention to accomplish the targets.

Unmet energy demand: There are around 45 million people in the country without access to electricity and majority of those connected to grid face long hours of load shedding. RE minigrids can effectively

[40] 1 EUR = 1.16 USD as on 27th October 2021

plug the gap in electricity access in unserved areas by providing electricity at an affordable cost and also provide reliable electricity in underserved areas of the country.

Specific opportunities: Pakistan has very hard-to-reach geographic locations without access to electricity where grid-connected electricity will not reach soon. The demand for electricity in these rural regions is also low as compared to urban areas. Providing on-grid transmission to these villages for low loads will prove to be expensive. Noticeably, these communities are also geographically positioned in the highest solar insolation zones and/ or hydro resources. Decentralized generation such as solar/ solar hybrid minigrids near the load centres offer promising solutions for providing basic electrification and may also be scaled up to provide higher levels of services efficiently (Saleh, 2019).

3.8.9 Barriers to minigrids

One of the main challenges in the development of minigrids in the country is the lack of institutional support at the national level for rural electrification and distributed renewable energy projects. The focus of government is primarily on utility-scale projects in areas already served by the national grid and electrification of urban areas through national grid as there is increased demand for power. Comprehensive electrification planning consisting of national grid extension, minigrids and others have proved to be successful in electrifying remaining population rapidly.

There are also no policies and regulations covering issues like permit and licensing, tariff setting, financial incentives, and regulations for minigrid in the event of grid arrival. These regulations are necessary to build private sector interest and confidence.

The lack of access to finance also hinders the growth and deployment of minigrid systems in the country. Private-sector investment in rural areas is also constrained due to several challenges, such as: higher perceived commercial risks, high investment costs, lack of funding available and government support.

Lack of technical expertise is another limiting factor on the deployment of minigrids for rural electrification. Limited capacity to design, install, operate, and maintain energy services based on renewables and lack of standardisation, has resulted in the poor performance of these projects and lowered end-user confidence (IRENA, 2018).

3.9 Sri Lanka

3.9.1 Status of access to electricity and minigrids

The supply of primary sources of energy in Sri Lanka is dominated by coal, oil, and biomass. As of 2018, the International Energy Agency estimated that 5,010 KTOE (or Kilo Tonne of Oil Equivalent) of energy was supplied by liquid fuels, followed by biomass at 4,628 KTOE, coal at 1,459 KTOE and hydropower at 550 KTOE. The total contribution from all sources for the year was 11,647 KTOE (IEA, n.d.).

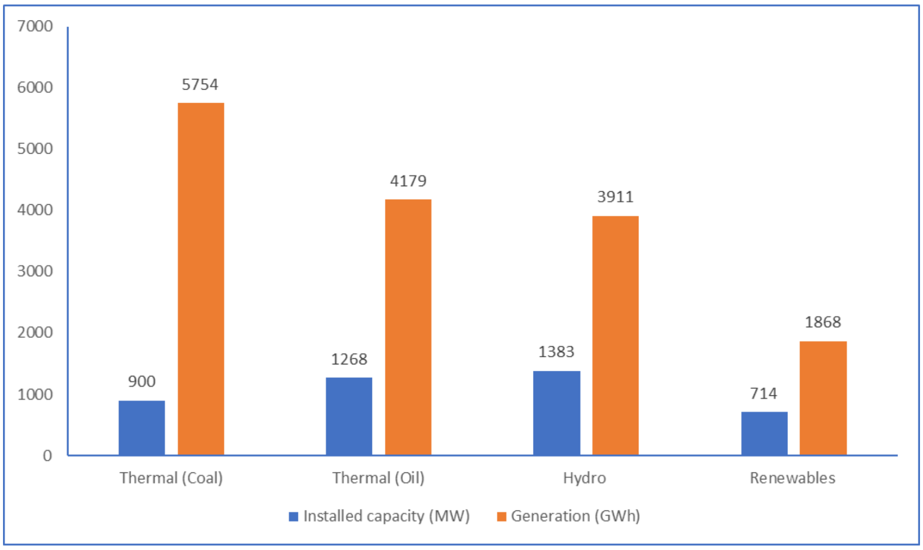


Figure 36: Installed Capacity and Energy Generation in 2020 in Sri Lanka from different sources[41]

Total installed generation capacity in Sri Lanka in 2020 was 4,265 MW, up from 4,217 MW in the previous year. The installed capacities and the corresponding energy generation data of different sources in Sri Lanka are provided in the **Error! Reference source not found.**Figure 36. As one can observe, bulk of the electricity supply in the country is met by thermal energy (coal and oil), followed by hydropower. Also, within the renewable energy sources, mini and micro hydro have a larger share in generation (Ceylon Electricity Board, 2021).

Reports indicate that Sri Lanka has managed to achieve near-complete electrification by 2017, and policy documents indicate that the country is fully electrified as of the present date (Ministry of Power, Energy and Business Development, 2019). The country has also committed, as part of its Intended Nationally Determined Contributions (INDCs), to reduce intensity of GHG emissions from energy sector by 20% till 2030 (Ministry of Mahaweli Development and Environment, 2016). This is a challenging task, due to Sri Lanka's dependence on fossil fuels (coal and oil) as shown above.

As far as the minigrid sector is concerned, there were over 250 community-level minigrids, primarily driven by micro hydropower, which were installed between 1997 and 2012. However, with changes in legal and regulatory provisions and the expansion of the national grid in isolated villages of Sri Lanka by the Ceylon Electricity Board, more than 100 of these minigrids went out of existence because households closer to the grid became customers of the CEB which was offering lower tariffs and more hours of supply. Only a handful of these minigrids were converted into small power producers that sell electricity to CEB (ESMAP, 2018).

The country has recently put up a plan to set up minigrids to power its outlying islands, about ten (10) of which are inhabited. Previously, these islands were supplied with electricity from the diesel generator sets owned by CEB and through a distribution network that covers only few consumers in each island (ADB, 2016). Sri Lanka's first hybrid minigrid was installed in Eluvathivu Island of Jaffna in 2016. The old diesel generator sets in the island were converted into solar-wind-diesel hybrid by the Ceylon Electricity Board with the help of financing received from ADB.

[41] (Ceylon Electricity Board, 2021)

Currently, Ceylon Electricity Board along with ADB is working to set up hybrid renewable energy-based power systems in three small, isolated islands, Analaitivu, Delft and Nainativu (part of the Jaffna Peninsula), under component 1 of 'Supporting Electricity Supply Reliability Improvement' project. The project will promote and strengthen energy-based livelihoods through access to electrical appliances and technologies, and Ministry of Power and Renewable Energy (MPRE) will be the executing agency. The three islands are presently served by CEB-owned diesel generating plants through a distribution network that covers parts of each island. The implementation work on these hybrid projects have not started yet, although the contractor has already been selected in February 2021. Additionally, under the same ADB project 'Supporting Electricity Supply Reliability Improvement', Lanka Electricity Company (Private) Limited (LECO), an electric utility in the region, has proposed to implement a microgrid as a pilot subproject within its franchised area.

More recently in the year 2021, the CEB, supported by ADB, has commissioned a utility scale, self-contained RE powered project in the island of Mannar. The project includes a 100 MW capacity of wind power system. This is the largest island-based wind powered RE grid in Sri Lanka (ADB, 2021).

3.9.2 National strategy for electricity sector

The roadmap for electricity sector in Sri Lanka is governed by the National Energy Policy and Strategies (NEPS), 2019 and the Long-Term Generation Expansion Plan (LTGEP), 2020 – 2039 produced by Ceylon Electricity Board. The NEPS 2019 identifies a vision of Sri Lanka to achieve carbon neutrality and "*complete transition of all the energy value chains"* by 2050, without explicitly stating whether generation would solely be RE based (Ministry of Power, Energy and Business Development, 2019). The LTGEP is a technical document that provides reference scenarios (based on business-as-usual) and a base case scenario (with RE investments) to show that generation from RE sources could assume a strong share of around 70% of all generating capacity as of 2039. In contrast, the reference scenario has a higher share of thermal power sources (coal, oil, and natural gas), amounting to over 70% of planned capacity additions (Transmission and Generation Planning Branch, 2019).

In summary, it appears that the strategy of Government of Sri Lanka (GoSL) is to replace current generation mix that is strongly in favour of liquid fuels and coal, to increased share of RE resources, such as wind, solar and hydropower, and augmented generation capacity of natural gas-based projects owing to their strong cost advantage.

3.9.3 Policy and regulations for minigrids

The energy policies for Sri Lanka are contained in the National Energy Policy and Strategies 2008, duly revised vide Sri Lanka Government Gazette Notification dated August 9, 2019; and the Energy Sector Development Plan for a Knowledge-based Economy 2015 – 2025.

The revised NEPS 2019, anchored by the Ministry of Power, Energy and Business Development, states that the overall objective of NEPS 2008, viz. to achieve complete electrification, has been attained. For NEPS 2019, the key objective is to 'ensure convenient and affordable energy services are available for equitable development of Sri Lanka using clean, safe, sustainable, reliable and economically feasible energy supply'.

The Sri Lanka Electricity Act was formulated in 2009 and amended in 2013. The Act granted rights for power generation, transmission, and distribution primarily to the national utility, CEB. There is a provision for private investments, in the form of IPPs, by obtaining a generation license, to generate electricity over and above the threshold of 25 MW. Such an entity either have to be a *local authority*, or a company where the government of Sri Lanka holds more than 50% of the shares or is a subsidiary of such a company (Article 9 (1)(c)). This clause is preceded by Article 7(1), which prohibits any individual / entity from generating and transmitting electricity, and allows distribution of electricity only under certain provisions, and further requiring that the entity possess a license.

In summary, the policy and strategy for development of RE resources in Sri Lanka is well contained in the NEPS 2019 and other relevant acts. However, with restrictions on entities who can generate, transmit or distribute electricity, the scope of development of minigrid projects has been restricted, unless there are revisions to the Electricity Act.

For the RE sector, the GoSL has created the Sri Lanka Sustainable Energy Authority, which acts as the nodal agency for renewable energy development in the country. The agency has developed Renewable Energy Resource Development Plan 2021 – 2026, a comprehensive document that outlines major RE resources to be developed in the country over the next five years (Sri Lanka Sustainable Energy Authority, 2020).

3.9.4 Technical aspects of minigrids

As mentioned in Section 3.9.1 above, there were roughly 250 minigrids developed with support from the World Bank (the flagship Renewable Energy for Rural Economic Development (RERED) project) and Government of Sri Lanka. These were mostly micro hydro powered minigrid projects, with the median size of 27 customers and an average installed capacity of 7.5 kW. At the centre of these minigrids was the Electricity Consumer Societies, which were created to set up, commission, operate and maintain these minigrids. Available literature on the subject indicates that the micro hydro based minigrids did not have access to quality plant and equipment, especially for distribution infrastructure. The distribution network, made of ordinary cables strung on bamboo poles, often needed repairs that added to maintenance costs and higher downtimes (ESMAP, 2018).

However, recent RE hybrid projects in outer islands as well as utility scale projects have used modern concepts and quality equipment in both generation and distribution systems. The system configuration of the hybrid system installed in Eluvathivu Island includes a 46kWp PV array, six 3.5kW wind turbines, twelve 8kW inverters and a 100kWh lithium-ion battery storage. Similarly, the proposed RE based hybrid systems for three small islands in Jaffna peninsula will utilize state of the art solar and wind technologies.

3.9.5 Business models for minigrids

As per the guidelines of the Electricity Act, the regulatory provisions do not support development of minigrid projects. As a result, there are no business models in operation in this sector.

Prior to introduction of the provisions, over a period of fifteen years (1997 – 2012), there were several minigrid projects in operation with programmatic support from GoSL and World Bank. The programme created Electricity Consumer Societies who were community level bodies that would own and operate the minigrids. The programme further incentivised private sector entities to identify strong sites, that would lead to the minigrids remaining operational for a certain period of time. The revenues to the private entities were tied to successful operation of the minigrid beyond that specified period. The programme had connected 10,000 rural households, who would make monthly payments to the ECS as tariffs. Proceeds from tariff revenues would be used to sustain operations of the minigrids.

3.9.6 Minigrid tariff

Information on tariffs for the micro hydro based minigrids installed under the RERED project is not available. Secondary literature also does not indicate tariffs to be a barrier for the minigrids' operations. This indicates that tariffs were possibly at par with the expectations of the consumers.

The tariff for grid-tied renewables for a year in that period – 2011 – indicates that average feed-in tariff for grid-tied RE projects varied between a very competitive LKR 6.64 (USD 0.033[42]) for waste heat recovery to power to LKR 22.02 (USD 0.11) for waste to energy projects. As of the present date, CEB's consumer tariff varies between LKR 5.9 (USD 0.029) and LKR 23.5 (USD 0.12), which is comparable (Ceylon Electricity Board, n.d.).

3.9.7 Financing for minigrids

The 250-odd minigrids implemented under the World Bank's RERED project were grant financed by RERED and GoSL. Subsequently, Electricity Consumer Societies were required to manage operational costs and keep the project operational.

As the minigrid sector is phased out, it is being replaced by a strong and emergent private sector developing Independent Power Projects (IPPs). As of 2020, the share of IPPs in installed capacity was almost 1,300 MW, covering RE generation (especially mini hydro, wind, and gradually emerging solar PV).

The financing model for replacing diesel minigrids by RE powered minigrids in the Sri Lankan islands is to offset higher operating costs of running diesel generator sets (diesel is imported) with high capital expenditure RE assets (such as wind and solar), which are procured with the help of low-cost sovereign debt and grants from ADB and other development partners.

3.9.8 Opportunities for minigrids

From a brief assessment of the minigrid sector in Sri Lanka that existed roughly between 1992 and 2012, one can conclude that there were significant opportunities for minigrid development in unserved and underserved areas of the country. As of the present day, however, there is full electrification in the country and therefore the focus has shifted from tail-end and distributed generation, and more towards engineering a transition to cleaner sources of energy.

Resource potential for minigrids: There are available solar PV, hydropower, and wind power resources in Sri Lanka for RE project development. Secondary reports estimate over 20,000 MW in wind power alone, while there is over 3,000 GW of potential solar power (ADB, 2017) The solar GHI map of Sri Lanka developed by the World Bank and IFC has been included in Annexure 2.

Unmet energy demand: There are small outlying islands in the country where population still rely on diesel powered grids which are only able to meet few of their energy needs. There is also high potential for rural enterprise development in Sri Lanka. However, the role and scope of minigrids is not expected to be significant.

[42] 1LKR = 0.005 USD as on 27th October 2021, same exchange rate has been used to convert LKR to USD in this report

3.9.9 Barriers to minigrids

Despite the presence of specific opportunities for minigrids in outer islands and availability of human resources and use of latest technologies both in hybrid projects and utility scale projects, the minigrid development in the country is mainly discouraged by the policy and regulations in power sector. As mentioned in section 3.9.3 above, the regulatory provisions in NEPS 2019 does not allow for any individual or entity to generate, transmit or distribute power. This prohibits setting up of minigrid projects. Further, the country has achieved full electrification by 2019, as per their national policy (NEPS 2019). As a result, there is no additional need or push from the government to set up minigrid projects.

4 CASE STUDIES

4.1 Introduction

Building upon the discussion on technologies, policies, barriers, drivers, and opportunities for minigrids in the SAARC Member States, this section deep dives into key aspects such as technological innovation, business models, and community involvement through various case studies to analyse the success factors and barriers for minigrid. Case studies have been chosen from the SAARC Member States as well as globally. Figure 37 below presents the location of each case study on a world map. The selected case studies have been discussed including technical features, financial aspects, business model, tariff mechanism, project outcomes and challenges. Table 1 below provides the key highlights of selected case studies.

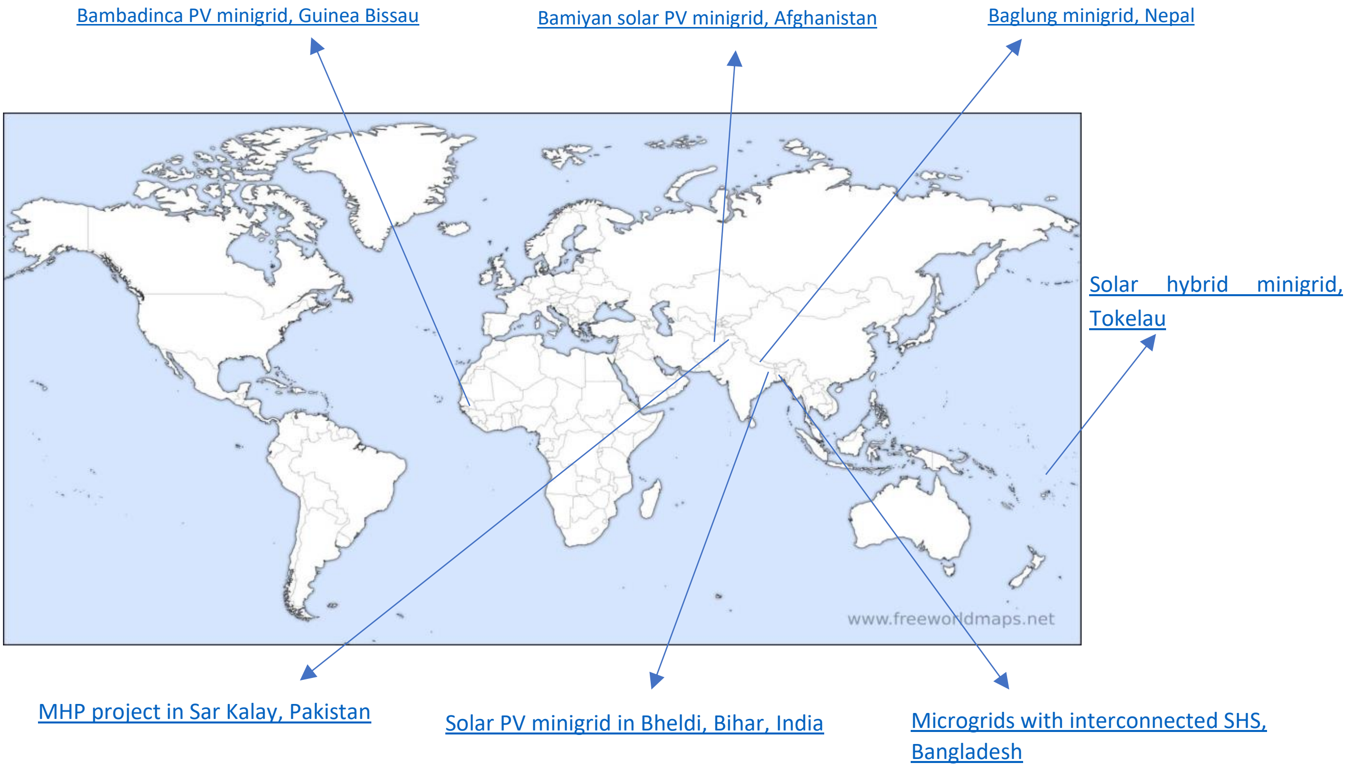


Figure 37: Location of Case Examples on World Map

Table 1: Key Rationale for Selection of Case Studies

S. No.	Case study title	Key highlights
1.	Bamiyan solar PV minigrid, Afghanistan	Innovative tariff structures –adding more customers across differentiated tariff segments improved revenue realisation, lowered tariff in long run and helped achieve viability
2.	Microgrids with interconnected SHS, Bangladesh	Role of innovative technologies in connecting solar PV rooftop users in a cluster (such as a village)
3.	Solar PV minigrid in Bheldi, India	Smart design and management allowing for a project to operate at optimal levels
4.	Baglung minigrid, Nepal	Aggregation of small micro hydro power (MHP) units to form a reliable minigrid that can be later connected to national grid

S. No.	Case study title	Key highlights
5.	Solar hybrid minigrid, Tokelau	Leveraging diesel use in baseline to create a lower-cost model for green electricity access
6.	Bambadinca PV minigrid, Guinea Bissau	Poor energy access supports minigrids due to high demand for electricity
7.	MHP project in Sar Kalay, Pakistan	Active involvement of community supports development of minigrid by overcoming challenges related to installation, consumer adoption, tariff setting

4.2 Bamiyan solar PV minigrid, Afghanistan

Innovative, first-of-its-kind MW scale minigrid in Afghanistan

4.2.1 Introduction

Bamiyan province is located in the Central Highlands Region of Afghanistan, and its capital is Bamiyan town. The people of Bamiyan town depended upon kerosene lamps, candles, diesel generators and a few had small solar panels on rooftop (mainly for lighting) to deliver their energy needs. A diesel generator, operated by DABS, was in place to supply power to the market area in Bamiyan town. Previous efforts by Ministry of Rural Rehabilitation and Development, Government of Afghanistan to set up a diesel-powered minigrid in the town area did not sustain, apparently due to lack of on-site repair and maintenance of the power plant. In 2013, the New Zealand Ministry of Foreign Affairs and Trade (NZMFAT) supported the installation of a 1 MW solar PV-diesel hybrid project in Bamiyan under the Bamiyan Renewable Energy Programme. After completion of the project in October 2013, it was handed over to DABS for operation and maintenance. The specific details on following sections of the case study have been extracted from several references[43].

4.2.2 Technical features

The solar PV system was installed at four different sites in Bamiyan, and the total capacity comprises of 1,050 kW. The individual capacities of each site included 400 kW at Bamiyan New City, 300 kW at Hyderabad, 300 kW at Mullah-Gholam and 50 kW at Folaadi valley. Figure 38depicts the solar PV systems installed at Mullah-Gollam. Each unit has a solar power plant and a back-up diesel power plant. The solar PV and diesel generator feeds into battery banks, from which 24x7 power is supplied. Each of the three larger sites are each equipped with a 275 KVA diesel generator set. The batteries used in the project are flooded lead acid batteries of a total cumulative capacity of 3,750 ampere-hours.

Interestingly, the four sites are independent and there is no interconnection. The three larger sites connect to a 20 kV transmission and a 0.4 kV distribution line, while the smaller Folaadi valley site connects directly to a 0.4 kV distribution line. A series of step-down transformers extend power to the households, and each user connection is fitted with a digital prepaid meter. The project was designed

[43] (USAID, n.d.);(Foster, Woods, & Hoffbeck, 2015); (IRENA, Renewable Power Generation Costs in 2019, 2020); (Chris Greacen, 2019); (100% Renewable Energy Atlas , 2019)

to generate high quality, assured AC power (230V, 50 Hz) supply. At the time of construction, the project was the largest off-grid solar PV installation in Afghanistan.

A study was undertaken by the lead contractor in the project, Sustainable Energy Systems International (SESI), to ascertain average demand from households and other users, i.e., market, public offices, and others. An assessment of factors influencing operations and management was also conducted.

Figure 38: BREP, Mullah Ghulam Site, Bamiyan[44]

Based on the findings collected from the study, an average load of 200 watts was earmarked for each household, with an average daily allocation of 1.5 kWh. This was estimated keeping in mind future demand growth amongst households, as reliable power was made available. An assessment of factors influencing operations and management was also conducted.

4.2.3 Financial aspects

The total cost of 1 MW Bamiyan project installed in 2013, including T&D infrastructure, was USD 14.1 million. The project cost appears higher compared to the World Bank cost trends for 2013 which shows the average cost of 1 MW minigrid project in 2013 to be around USD 6.2 million per MW[45].

The above cost of the Bamiyan project is higher, partly due to overall approach of project planners to install state-of-the-art plant and equipment, to avoid higher operation and maintenance costs and possible disruptions in service. Other major reason for higher costs is due to higher costs of importing and transporting personnel and materials to the site in Bamiyan. Finally, there was investment in batteries and diesel generator sets, which again translated to higher outlay on generation assets. This led the design team to opt for solar and AC bus equipment from SMA Solar Technology AG, (Germany),

[44] (Foster, Woods, & Hoffbeck, 2015)

[45] As per World Bank Cost trends, average median cost for mini grid project in 2013 was USD 6,200 per kW. Although there could be variance between per kW and per MW costs, the per kW costs can be considered as a rough approximation. As per IRENA, the global average cost of mini grid project is around USD 1 million per MW in 2019 (IRENA, Renewable Power Generation Costs in 2019, 2020).

while the batteries were supplied by Crown Batteries, UK, who are specialists in providing storage support to RE projects.

The entire financing was provided by NZMFAT. The approach for financing was to grant the capital expenditure, while the operating expenditure was expected to be met from tariff revenues. The overall business strategy to sustain the project is discussed in the following section on business model.

4.2.4 Business model

As mentioned above, the project capital cost was funded by the NZMFAT. The project is being maintained and operated by DABS, Afghanistan's national electricity authority. In addition, the following two key entities were involved in the overall project design, development, and commissioning processes:

i. Sustainable Energy Services International: a New Zealand based energy solutions company with operations in Afghanistan, anchored the project development process including community level surveys, feasibility, design, and turnkey installation of the generation assets.
ii. NetCon: a New Zealand based electrical distribution network installation company, was responsible for erecting the distribution network for the BREP.

The consortium installed the project and operated the project for one year. The overall approach to ensuring project viability was built on the following premises:

- State of the art plant and equipment was installed to minimize post-installation O&M concerns
- For the operating expenditure, a cost-plus tariff structure was put in place, which would reduce over time as more and more users were added to the network
- In addition, the strategy adopted in the BREP was to ensure delivery of quality power 24x7, which gave faith and confidence to the users, who in turn were willing to pay more; and finally
- An innovative pre-paid metering system was attempted for the first time in BREP, which assured revenues from all users.
- Finally, SESI-NetCon remained at the site for one year, providing hands-on support and capacity development to DABS team for seamless transition and trouble-free O&M.

4.2.5 Tariff Mechanism

The project engaged a variable, cost-plus tariff that would cover O&M expenses. As a result, the tariff was very high in the initial stages, because of which there was resistance, especially from non-commercial users. This was because of two main reasons:

- Prior to BREP, there was no electricity meter in Bamiyan. As a result, users paid a daily charge (like AFN 5 per light per day, about USD 0.055[46]) or a periodic charge based on their appliances etc. As a result, users were not aware of how a daily rate would reflect in a per-kWh tariff.
- The per kWh rate at the start was close to AFN 50-100 (USD 0.55 – 1.10) per kWh. These rates were high for non-commercial users, and even for some commercial users who complained about prices being same as diesel.

However, as the project expanded user base between 2014 and 2016, the tariff reduced to around AFN 16 (USD 0.18) per kWh in 2017 for households, which was more competitive. For commercial

[46] 1 AFN = 0.011 USD as on 27th October 2021, same rate has been used to convert AFN to USD

users, the tariff was around AFN 45 (USD 0.5) per kWh. This could also be the result of DABS charging a lower tariff to improve user acceptance and raise capacity utilisation. By 2016/17, the plant was operating at optimal PV capacity.

It is notable to bear in mind that for the first time in this project, prepaid meters were introduced in Afghanistan. These meters required users to deposit cash, as per their planned electricity demand, into the local bank account of the utility, DABS. Once the cash was credited, the user's entitlement increases automatically.

4.2.6 Project outcomes

BREP was the first and most successful minigrid set up and operated in Afghanistan. It also was the largest minigrid in the country at that time. In addition, the project gave access to stable and reliable power, with quality systems that required minimum after-sales maintenance. This is vital in a country like Afghanistan, where internal security situation remains volatile. This is also a key lesson learnt for future systems, especially minigrids, to be installed in the country.

One of the key contributions of the project was the introduction of prepaid, digital meters. Not only the project was a first-of-its-kind in Afghanistan, but also a significant measure to reduce operating expenses, as well as human interface in billing, metering, and collection operations.

Further, the entire network is web-accessible and can be monitored remotely for error codes, power output, voltage, amperage, battery conditions and others. This acts as a basis for acting on snags, troubleshooting and other O&M requirements.

4.2.7 Challenges

The biggest challenge in the project was to overcome the initial reluctance of the community to pay what appeared to them as high tariff. As a result, capacity utilisation of the BREP was low in the first year of operation.

Another key challenge is to successfully maintain the project over time, including but not limited to recovering periodic costs of operation and maintenance of the asset, including recurrent expenses on diesel and the distribution network. As mentioned below in this section, security constraints also restrict movement of people and resources, which acts as a key constraint.

The project could only be completed by airlifting critical pieces of equipment, after facing delays in import and transit through Wardak province, which was dangerous due to high insurgency in the region. Due to relative inaccessibility of Bamiyan (the province is in the highlands and navigation during winter is not possible due to snowfall), operation and maintenance was and remains a key challenge. Finally, even though Bamiyan is politically amongst the most secure and peaceful provinces in the country, political instability was and remains a threat to the long-term sustainability of the system.

4.2.8 Key highlights

The biggest contribution of the project was to demonstrate that in a country with a delicate security situation, it is possible to set up a state-of-the-art, RE powered minigrid of 1 MW capacity, which can be serviced and maintained over time. The project acted as a strong impetus and can be termed as a worthy predecessor to other minigrid initiatives such as the Afghanistan Sustainable Energy for Rural Development by MRRD.

Another key highlight of the project is the fact that households and enterprises in the catchment were satisfied with the power quality and reliability, which indicates that communities are willing to pay more for quality service delivery. It may be mentioned that businesses and enterprises were keen to adopt the power from BREP, while households joined subsequently.

4.3 Microgrids with interconnected solar home systems, Bangladesh

Uber of the off-grid world!
Share electricity and create opportunities

4.3.1 Introduction

Solar home systems are becoming popular day by day in Bangladesh. Bangladesh has already installed more than 6 million (6,023,632) SHS of total capacity 262.753 MWp till date and about 13 million beneficiaries are getting solar electricity (Sustainable and Renewable Energy Development Authority, 2021). Under IDCOL program to ensure access to clean electricity for the energy starved off grid rural areas of Bangladesh, more than 65,000 SHSs are now being installed every month with average year to year installation growth of 58%. This program is one of the largest and fastest growing off grid renewable energy program in the world (Sustainable and Renewable Energy Development Authority, 2021).

Approximately one-third of the electricity generated by the SHS goes to waste in Bangladesh totalling to 1 billion USD, as people's usage pattern varies day to day and season to season. SOLshare[47] has created a revolutionary new approach to interconnect SHS into smart peer to peer microgrids, monetizing excess solar energy with mobile money in real time and empowering SHS owners to earn a direct income from the sun. The schematic of microgrid developed by SOLshare is depicted in Figure 39. The specific details on following sections of the case study have been extracted from several references[48].

[47] SOLshare, founded in 2014, is an international social enterprise with operations in Bangladesh and India. It has created a revolutionary new approach to bring affordable solar electricity to everyone in Bangladesh and beyond. It has built the world's first ICT enabled solar P2P electricity trading network for some of the most demanding and dynamic markets in the world.

[48] (SOLshare, n.d.); (Efficiency for Access Coalition, 2021); (SOLshare, n.d.); (The Business Standard, 2021); (Burger & Weinmann, 2020); (Ashden, 2020); (Nelis Global, 2020)

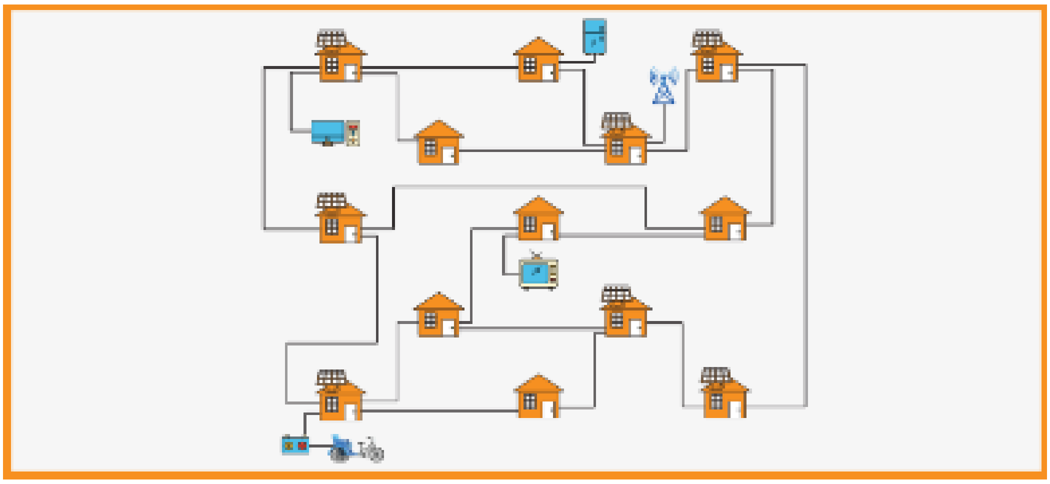


Figure 39: Typical SOLshare Microgrid[49]

4.3.2 Technical features

To bring affordable solar electricity in remote areas of Bangladesh, SOLshare installed the world's first smart peer to peer solar sharing grid. Households (those with the SHS and those without SHS) and other entities are connected to each other to form a microgrid and beneficiaries can be producers, consumers, and prosumers. SHS is the electricity generator for the interconnected households and battery stores excess electricity that can be sold to other consumers.

SOLshare has developed an IoT driven energy trading platform called SOLbazaar. SHS users sell their excess energy to non SHS user in SOLbazaar. SOLbazaar consists of three components: the SOLbox, the SOLapp and the SOLweb.

SOLbox is a bi-directional smart DC electricity meter that enables the creation of DC smart grid integrating SHSs or battery. It is a low voltage DC box. SOLbox enables peer to peer electricity trading, smart grid management, remote monitoring, mobile money payment and data analytics. The minimum of 10 households or businesses which have SOLboxes are interconnected to each other to form a microgrid. SOLboxes communicate with the Wi-Fi towers installed in the villages and electricity generation, consumption and trade can be monitored easily. The SOLapp takes user information and payment details and manages customer portfolios. The information from SOLbox and SOLapp are then passed onto the SOLweb, where all the information is gathered and analyzed to understand system patterns and irregularities.

SOLshare microgrid can be connected with the national grid as the SOLshare network grows. It can operate in island mode when the grid is unavailable and microgrid can draw power from the grid when it is available. As of today, the total PV capacity of 48 kWp has been connected to the SOLshare network. SOLshare was operating 40 microgrids in Bangladesh by the end of 2020. The company is expecting to operate 110 microgrids in the country by the end of 2021.

4.3.3 Financial aspects

The first microgrid was built by SOLshare in Shariatpur, Bangladesh in 2015 with the help of grant money received from GIZ office in Bangladesh. The total capital expenditure for the SOLshare project

[49] (SOLshare, n.d.)

is limited to cost of the cables required to form a microgrid and the installation of the SOLbox. SOLshare has a hybrid form of financing. The microgrid projects are basically financed by Venture Capital Funding and Social impact investors. SOLshare has been financing its projects through monetary award prizes, grants and equity and has been receiving financing from international organizations such as United Nations Department of Economic and Social Affairs (UNDESA) together with Grameen Shakti, United Nations High Commissioner for Refugees (UNHCR) in the Rohingya camps, SBK Foundation, the ADB and the KfW/DEG among many others.

4.3.4 Business model and tariff mechanism

SOLshare is well known as the 'Uber' of the off-grid world. The business model includes both Business to Business as well as Business to Consumers (B2C) elements.

Energy for Access (EFA) in its report "Business Model Innovations" identifies the SOLshare's business model as Circular use business model. In this business model, SOLshare allows households with solar panels to sell excess energy, which would otherwise be wasted for those who have deficit of energy needs. This model optimizes already existing infrastructures and creates new customer, producer, and prosumers. The microgrid electricity can be utilized to run appliances such as large TV for village cinemas, hair trimmers for barbers, printers, photocopy machines and internet access for computer shops, fridge for pharmacies, motors for sewing machines The operational risks associated with circular use business model are difficult to assess.

SOLshare's direct customers are the microfinance institutions or NGOs that provide loans and distribute the solar systems; including Grameen Shakti (1.8 million solar systems distributed). SOLshare establishes B2B partnerships with partner organisations who have experience with financing and distributing SHS. They also provide technical training and after sales service to its customers. SOLshare uses the existing infrastructure of POs and installs SOLbox as an additional component to the conventional solar home systems. SOLshare collects its revenue in three forms: sale of the SOLbox, fee for every transaction and fee for managing the grid. POs decide about the charge for managing the grid which they will collect from the customers.

To consider the excess energy generated that cannot wholly be consumed within the community, buffer systems like micro utility is established in the villages. Water pump, corn shellers, rice cutters, solar rickshaw charging stations are then connected to the buffer system.

Payment is automated in the mobile phone through a mobile application. Whenever a household is a net consumer, balance decrease and whenever HH is a net producer, the balance increases. The balance in the mobile is in the form of money not in kilowatt hours, so it can be used for payments of all sorts, not just energy.

4.3.5 Project outcomes

- Almost 84% of end users connected to microgrid live on less than USD 5 per day and around 40% of customers are using electricity for the first time.
- United Nations Framework Convention on Climate Change (UNFCCC) estimates that SOLshare systems enable communities to reduce their annual cost of energy by 25%. By the end of 2020, SOLshare microgrid prevented use of 1,756 liters of diesel and abated the emissions of 4,970 kg of CO_2 on an annual basis.

- The household with SHS that sells 50% of its generated energy earns approximately USD 10 per month. A producer (installs SHS just to sell energy) breaks even within two years, with a simple return on investment of 173% after three years.
- With SOLshare, rural communities go from being solar power users to smart entrepreneurs, who can sell surplus solar power in return for money. The existence of trading network acts as a driver against pollution since communities are now more than willing to turn towards solar energy generation.
- Currently, 4 million households are powered by SOLshare and an additional 1 million are expected to be powered by the year 2030, including interconnecting them to the national grid through a single point of common coupling.
- SOLgrids impact on ecosystem is lower as PV systems are constructed on rooftops of already existing buildings, thereby avoiding potential land use change.
- 40% of the end users are women and children. Many women have started their own home-grown businesses through access to energy, which has increased safety and allows women to work and children to study after dark.

4.3.6 Challenges

Access to finance has been a major challenge for the SOLshare's microgrid projects because of various risk perceptions related to the company being a start-up with presence only in Bangladesh and India, new technological concept, acceptance among consumers, financial viability, etc. Another challenge was the geography of the project area. Most of the microgrids are in very remote areas and reaching those communities is a humongous task.

Other major challenge for the expansion of SOLshare projects is the aggressive approach of Bangladesh towards grid extension. SOLshare has built a grid box technology, which can connect the microgrid to the national grid (when it arrives to that area) through the interconnection point. The technology can control the entire network connected to it. However, this technology is currently in research and development stage.

4.3.7 Key highlights

SOLshare turns the purchase of a solar home system into an investment with return. The cost of electricity from SOLshare grid is 25% lower than that of an SHS system of capacity 20Wp. The SOLshare microgrids are dynamic; new households can be added to the grid and microgrids can also be interconnected among themselves, growing in the bottom-up manner such as the national grid.

SOLshare microgrid model provides reliable electricity and are replicable where unreliability of grid electricity is an issue, not only in Bangladesh but also in other countries like Bhutan. Many countries such as Bhutan and Nepal have difficult terrain and have adopted solar home systems for electricity access. So those SHS can be interconnected to form a microgrid with SOLshare model. In a study conducted by SOLshare, they found the dissatisfaction of the national grid customers due to the unreliable electricity supply in Bangladesh. During 6 pm to 10 pm, the national grid often suffered from load shedding in the rural areas. So, even national grid customers, with their experiences, know that they need a backup or even a complementary system, which can be provided via microgrids of SOLshare.

4.4 Solar PV minigrid in Bheldi, Saran District, Bihar, India

Smart planning, design, and management of minigrid systems

4.4.1 Introduction

The Bheldi minigrid[50], set up in 2014-15, operates under the aegis of Smart Power India, which supports decentralised, renewable energy powered minigrids in India. SPI has engaged with Tata Power, one of the largest private sector players in the power sector in India, to realise a vision to energise 10,000 minigrid projects in India. These projects will empower productive applications, as well as support social infrastructure (e.g., health and education). The Bheldi project was initially supported under Rockefeller Foundation's Smart Power for Environmentally sound Economic Development project. Rockefeller Foundation remains a supporter of the SPI-Tata Power programme of activities. The site is located in Saran district (Parsa Block) of the state of Bihar in Eastern India.

Prior to the minigrid project, the site had no grid electricity connection. There were a handful of diesel generator operators, who provided electricity to the Bheldi market, and to a few households in the evening, by operating ~5 kVA diesel generator sets. The bill payment was calculated as a daily charge. Some households who could afford had their captive DG sets.

In 2014, the project team conducted an initial survey of the project site in Bheldi and identified the potential for a 40-kW solar PV unit to energise the Bheldi market, agricultural pumps, and other residential and commercial loads. The team also carried out community level consultations to ascertain the following:

- Operations of commercial and enterprise loads in the site, potential for adding new enterprises
- Community-level interest to adopt to solar power from their existing energy use practices
- Availability of land to set up the power station
- Willingness to pay for all consumer groups

As the SPEED programme advocated a market-based approach, attaining viability for a project was a key consideration. As such, time and effort were devoted in ascertaining the 24-hour demand profile at the site, which would determine sizing not only of the solar PV plant, but also of the battery bank. Moreover, the viability of post commissioning operation and maintenance was assessed in detail[51].

4.4.2 Technical features

The minigrid was powered by a 30-kW solar PV unit with a battery bank, a Maximum Power Point Tracking (MPPT) Charge Controller and inverter for conversion to 230 V (AC) supply. Figure 40 shows the minigrid site at Bheldi.

The system had total of 120 solar PV panels of 250 W each. The battery bank capacity was 1,200 Ah, 48V advanced lead acid batteries (Absorbed glass mat or AGM), having superior performance in the event of frequent start-stop applications. The power output was coupled to three (3) inverters in series, each with capacity of 6.5 kW, while the MPPT charge controllers had a cumulative capacity of

[50] Specific details on this case study, mentioned here, are based on the information available with one of the authors

[51] Developed under the aegis of Rockefeller Foundation's SPEED project, not much information is publicly available. The article throws some light on the project and its social impacts: https://www.rockefellerfoundation.org/wp-content/uploads/SmartPower-Connect-May-2017.pdf

28 kW. Configuration of the inverters was done such to synchronise with the varying load profile of the site. The distribution network was set up using reinforced wooden poles, which carried 4-core and 3.5-core cables of varying dimensions. Households were connected via single phase. Each household was fitted with *load limiters*, an innovative element to manage power consumption of households.

Figure 40: Plant Site in Bheldi[52]

The solar PV capacity was augmented to 40 kW as demand from the community increased and so were the inverter and charge controller capacities to enhance the delivery capacity. Subsequently, smart prepaid meters were also installed in the consumer premises.

4.4.3 Financial aspects

The total *indicative* capital cost of the project, including transmission & distribution infrastructure, was INR 7 million (USD 93,292[53]). These costs do not include *a priori* site development and community engagement costs that were incurred. The broad components of the project costs are indicated as follows:

#	Cost component	Value (INR lakhs)	Value (USD)*
1	Solar PV panels, inverter, and battery bank	52	USD 69,302
2	Power distribution including smart meters	12	USD 15,993
3	Civil work and other peripherals	6	USD 7,996
**: numbers might not add up due to rounding off*			

The project cost appears higher, due to higher component costs, especially solar PV, as this project was designed and executed in FY 2014-15. The financing of the project was made by a Special Purpose Vehicle called TARA Urja, which acted as a Renewable Energy Service Company and invested in the decentralised minigrid project, and then recovered the investment over time.

[52] Source: SmartPower Connect
[53] 1 INR = 0.013 USD as on 27th October 2021, same exchange rate has been used to convert INR to USD in this report

4.4.4 Business model

As indicated above, the project is supported by Rockefeller Foundation through the RESCO named TARA Urja. The salient features of the business model are:

- To better mirror the minigrid business, TARA Urja created a (wholly owned) subsidiary, TARA Micro Utility Business (TARA MUB). TARA Urja, as the owner of the generation asset, sold bulk power generated from the minigrid at a fixed rate to TARA MUB. This ensured that the generation unit had a fixed revenue that was partially de-risked, due to TARA MUB making a payment on a per kWh basis at the site
- For TARA MUB, its role was that of a distribution utility, with the focus to generate revenues from each type of consumer over and above the amount that it had to pay to TARA Urja (the generation utility). The difference between what TARA MUB would receive from consumers, and in turn pay to TARA Urja, would cover for TARA MUB's own expenses of operation and maintenance of the distribution network, salary of staffs at the site and other overhead expenses, and ensure that it could earn a profit on the investment as well
- As a result, TARA MUB introduced several innovations and modernizations in the distribution architecture. One of the key aspects was the *load limiter*, a device that would let the consumer use only as much current (amperes) as his entitlement. The load limiters were calibrated to allow a fixed quantum of current (amperes) per period (say a week), which was determined according to the bundle of the consumer. Upon expiry of the time, or of the consumer's quota, the consumer is required to make a prepayment (as per his bundle) to the site office, against which he would receive a message on his registered mobile, as well as an enhancement of his entitlement. This reduced the costs of revenue collection, and the officer in the site office operated a cloud-based application whereby the entitlements of each consumer was automatically tracked and updated on a real time basis. This further streamlined the revenue collection process.

4.4.5 Tariff mechanism

The project proposed a differential tariff based on the category of consumer. For instance, residential users with fans were charged a bundled tariff, which covered a fixed quantity of power that they could consume over a period, say seven (7) days.

Commercial consumers with only single-phase loads were also charged a bundled tariff like residential consumers. Consumers who operated enterprises, and other bulk consumers such as telecom towers and irrigation pumps, were charged a per kWh tariff with a standard meter. One of the key innovations in the project was that payment of the tariff, for all consumer types, was on a prepaid basis. Over time, as demand expanded, the capacity of the site was expanded, and the *load limiters* were replaced with smart meters that were connected to internet and provided the same functionality with added features. As one of the first examples of a fully automated minigrid operational in FY 2014 - 15, the Bheldi minigrid project set up a precedent of a low-overhead, low-maintenance decentralised minigrid that would deliver reliable and cost-effective power to a cross section of consumers.

4.4.6 Project outcomes

The project is among several DRE minigrids implemented under the SPI programme in the Indian states of Uttar Pradesh and Bihar where quality power was delivered to a range of consumers, with a focused approach towards energising enterprises. This project led to strong economic impact in the village, where several new enterprises and commercial activities were introduced. These enterprises included tailoring shops, welding shops, a general market complex and sweet shops (which were used to be powered by diesel generators before the project), among others. At the same time, social aspects such as health and education have also benefited significantly from electricity access.

Moreover, the project had a focused approach towards cost recovery. As a result, several of the plants are maintained, and are in working condition even as of the present date, although they have needed renovation and modernisation as technologies have advanced. Finally, the quality of power supplied has withstood competition from the national grid, which is present in Bheldi as of the present day. However, users have still retained the project connections, especially for enterprise demand.

4.4.7 Challenges

Initial adoption of consumers was slow, due to the use of *bundled tariff* and *tariff packages*, which was not familiar to the community and, despite community consultations that were done, prospective users were not ready to adopt.

One of the key operational challenges was for the micro-utility business to remain viable. A minimum level of capacity utilisation together with timely payments was required for the distribution utility to generate enough revenue, to cover all maintenance expenses and make payment back to the generation utility. This was a recurrent challenge in the initial months of project operation. The other challenge in the project was to manage expectations of the consumers. As power was provided to them, users' demand tended to rise, beyond their rated demand. Demand for new gadgets and appliances also grew in the site.

4.4.8 Key highlights

The project had introduced technological innovation through use of load limiters. For the specific application, load limiters were tied to the current flow (amperes) rather than power (kilowatts). This made the load limiters tamper proof at the same allowed the consumer to consume the power as entitled to them. Moreover, prepayment of entitlement, and acknowledgement through a cloud-based system were new to the Bheldi community, though the adoption was slow in the beginning. However, over the long run it gave more freedom to the user, and reduced conflict over non-payment.

The second highlight of the project was the structuring of the business model, which de-risked project proponents by separating the generation utility from the distribution utility. With fixed monthly tariff payments, the generator was assured of its return on investment, subject to proper maintenance of the asset. At the same time, the distribution utility used load limiters, prepayment, and other means to create a system of revenue assurance and thereby partially de-risked itself.

4.5 Baglung minigrid, Nepal

Interconnecting MHPs to form minigrid for reliable electricity

4.5.1 Introduction

In Nepal, there are many micro hydro plants providing access to electricity in off grid areas, but it has been observed that, with the arrival of national grid to those areas, the MHPs are being abandoned in many cases. Baglung minigrid was thus developed to avoid this kind of situation in the future. The concept of this project was to aggregate the power output of small sized MHPs so that sizeable power output may be available in the locally formed minigrid. Also, with the new aggregated capacity, there is a strong possibility that the national utility might agree to connect this minigrid to the national grid network once it reaches there. The specific details on following sections of the case study have been extracted from several references[54].

4.5.2 Technical features

In 2012, six MHPs ranging from capacity of 9 kW to 26 kW, previously running in isolation mode were interconnected to each other and 107 kW capacity minigrid was formed. The 6 micro hydro plants include Upper Kalung Khola (12 kW), Kalung Khola (22 kW), Urja Khola I (26 kW), Urja Khola II (9kW), Urjakhola IV (14 kW) and Theulakhola MHP (24 kW). All these MHPs are producing power from the same source of stream, Kalung Khola. Figure 41 shows locations of the six MHPs on the map of Nepal. The minigrid system serves 1178 households through an 8 km long 11 kV transmission line and associated distribution lines. The core technology used in this pilot project was microprocessor-based grid synchronize electronic load controller to regulate frequency of the system.

Each of the MHP units generates power at distribution voltage of 400 V. Power stations constitutes turbine generator sets, frequency controlling unit, voltage regulating unit, synchronizing unit, measurement unit, switchgear and protection unit, bus bar arrangement & 11 kV line connecting 0.4/11 kV transformer unit. The interconnection of MHP with other generator is facilitated by synchronizing unit in both automatic and manual mode. Three phase 11 kV single circuit transmission line was constructed such that the total length of the line can be broken into three different sections by means of two sets of series drop out fuses to make the fault-finding process easy, minimize the fault clearance time and to operate the minigrid in partial breakdown mode in case of longer duration problems.

[54] (Bhupendra Shakya, 2012); (Engineering Consultancy for Constructive Development Efforts, 2013); (Priti Kumar, 2015)

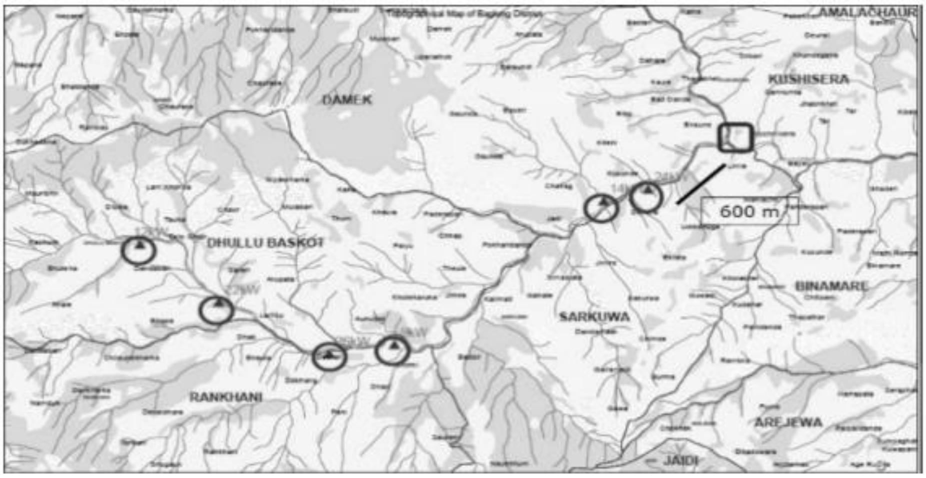


Figure 41: 6 MHPs (circles) in Baglung connected to form minigrid (rectangle)[55]

4.5.3 Financial aspects

The Baglung Minigrid Project was developed through the support of UNDP/AEPC and the active involvement of the community. 90% of the cost of the project was funded by UNDP/AEPC and remaining was contributed by the village community. The total project cost was around 176,000 USD. 86% of the total project cost was of electromechanical equipment. The project used the already operating MHPs as the generating plants. Thus, cost of generating plants in the Baglung minigrid did not have to be considered.

4.5.4 Business model and tariff mechanism

The Baglung minigrid was developed as Community based IPP cooperative model. Minigrid is operated and managed by local community named *Urja Upatyaka* Minigrid Cooperative. The cooperative was formed constituting the representatives of each micro hydro connected to the minigrid. The cooperative is responsible for operating and maintaining the minigrid, distribution of electricity and providing consumer services such as tariff collection. Individual MHP group is responsible solely for power generation. The cooperative has the decisive power related to operation, maintenance, expansion of transmission and distribution lines, fixing power purchase agreement rate, tariff structure, office management, hiring the staffs and all other related issues. The cooperative buys electricity from respective MHPs at a fixed PPA rate and sells it to consumers that were previously supplied by individual MHP. New consumers were also added by expanding distribution system.

The buying rate of electricity from individual MHPs was set at NPR 4.5 per unit (USD 0.037[56] per unit). Tariff of electricity provided by the minigrid was fixed after discussion with the consumers and each MHP group. Each consumer has installed energy meter and tariff is paid based on the energy consumption. The monthly tariff rate was set at NPR 75 (USD 0.62) up to 12 units and NPR 7 (USD 0.058) for each additional unit. The profit from the tariff collection is used to operate the *Urja Upatyaka* Cooperative. Consumers failing to pay on time are fined at a certain rate. For three phase consumers, tariff is set on monthly basis, which is different for each consumer.

[55] (N.P. Chaudhary, S. Baral, & B. Adhikary, 2020)

[56] 1 NPR = 0.0083 USD as on 27^{th} October 2021

4.5.5 Project outcomes

- After the connection of 6 MHPs to form a minigrid, the consumers have observed improvement in quality, reliability, and availability of electricity.
- Community is involved in power generation, transmission as well as distribution and their outlook towards mini hydro has changed in a positive manner.
- There has been an increase in income generated by these MHPs through sale of energy. 3 MHPs of capacity greater than 15 kW have seen an increase of around NPR 50,000 - 70,000 (USD 417 – 583[57]) in their annual income while the increase in income of remaining 3 MHP of capacity less than 15 kW is around NPR 15,000 - 30,000 (USD 125 – 250) per annum.
- The income of entrepreneurs has increased from 5% to 40% after the electricity access through minigrid. The minigrid created more than 55 job opportunities for local people through the establishment of agro processing mills, poultry farming, computer institute, photo studio, electronic shop, etc.
- Nepal Electricity Authority, as a general practice, is connecting power plants of capacity more than 100 kW whenever the national grid reaches that area. So, the Baglung minigrid network can also be connected to the national grid after arrival of the national grid.

4.5.6 Challenges

The development cost of minigrid with interconnection of MHPs was relatively high and analysis shows that even for an optimistic scenario of Plant Load Factor (PLF) doubling after the formation of the minigrid, minigrids are not financially viable. Furthermore, the capital expenditure of a minigrid is entirely site specific. So, minigrids should be assessed on a site-by-site basis for economic viability. After the installation of minigrid, management of the grid with multiple MHPs connected was a complex task. This required continuous support in technical and managerial aspect for an extended period. The centralized load management system is not available in Baglung minigrid, and the load management is being done with mutual understanding among the MHPs.

The MHPs are run of river projects, therefore, during dry season it was difficult to meet the increased electricity demand. During wet season, because of no storage available, 70% of energy generated was wasted. In the Baglung minigrid system, Feed in Tariffs are set at the same level for all MHPs in a minigrid and do not consider the fact that operational cost for each MHP differs according to its size. Thus, minigrid should ensure that operational cost of MHPs is met before setting tariff for the purchase of power.

4.5.7 Key highlights

The experience from the Baglung minigrid demonstrates that minigrids are technically viable and supply reliable electricity to consumers. When few MHPs have power deficit and others with surplus power, minigrid can serve the demand better than single standalone MHP.

Baglung minigrid has energy-based tariff structure, unlike the earlier power-based tariff structure. Consumers now are self-motivated to save electricity after knowing the per unit price of electricity. Baglung minigrid has become a topic of research and has built confidence to replicate minigrid projects in other parts of the country.

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[57] 1 NPR = 0.0083 USD as on 27th October 2021

4.6 Solar hybrid minigrid, Tokelau

Reducing diesel cost with 90+% contribution from solar minigrids

4.6.1 Introduction

Tokelau, an island nation in the South Pacific, is made up of three small atolls, Atafu, Nukunonu and Fakaofo, and is populated by 1,411 citizens. All three atolls were provided with diesel generator sets for their power needs. The dependency on imported fuel presented huge financial and logistical challenges to the island nation.

In 2012, as part of the Tokelau Renewable Energy Project (TREP), three hybrid solar PV systems were commissioned in three atolls of Tokelau - Nukunonu, Fakaofo and Atafu - to provide at least 90% of the islands' electricity needs over the course of a year from solar power.

The specific details on following sections of the case study have been extracted from several references[58].

4.6.2 Technical features

To ensure reliable and sustainable design of the systems, the hybrid solar PV systems were designed in line with New Zealand Ministry of Foreign Affairs and Trade (NZMFAT) Renewable Energy Minigrid Common Design Principles which has developed based on decades of in-field experience with off-grid PV systems in remote communities. The hybrid system consisted of 240 - 400kW capacity of solar PV in each atoll (combined capacity of 1 MW) and 1.4-1.9 MWh of lead acid battery storage. Figure 42depicts the installed solar PV system in Tokelau. The system was composed of identical clusters, which made it easier for the operators/ technicians to troubleshoot problems, as the same solution can be applied across all systems as well order and stock spare parts.

The batteries were sized to provide storage up to 1.5 – 2 days in case of no solar output and before the backup generator is turned on. The diesel generators which were the only source of electricity earlier, are now used as back-up for the solar PV-battery system. The generator only ran at its optimum load factor, or did not run at all. This improved the fuel efficiency of the generator and reduces maintenance costs. The system is remotely monitored using the SMA Sunny Portal to ensure system performance is maintained and to help with any fault diagnosis.

[58] (Power Technology, 2013); (Collaboration on Energy and Environmental Markets, n.d.); (New Zealand Ministry of Foreign Affairs and Trade , 2013); (ITP Australia, n.d.); (EU-GIZ ACSE , 2016); (ITP Australia, 2013)

Figure 42: Installed solar PV system in Tokelau[59]

4.6.3 Financial aspects

The cost of the entire PV – battery system, including the civil works required for PV array & the battery building, and local labour, was NZD 8.45 million (USD 6.04 million[60]). These costs are based on quotes provided in 2011 and if the systems were to be built today (2021), the cost would be 25-30% lower because of lower prices of solar PV modules and batteries. The capital cost of the project was entirely funded by the Government of New Zealand, as a four-year advance in the aid money given to Tokelau. Installation work and operation & maintenance are funded by the Government of Tokelau.

Before the hybrid PV systems were installed, the diesel cost for providing electricity was around NZD 1 million per year (USD 0.72 million per year). After the installation of solar PV, it was estimated that the total cost savings from avoided diesel use would be approximately NZD 900,000 per year (USD 643,563 per year), which is 90% of the fuel cost before installation of PV systems. The total cost savings is expected to increase with increasing diesel fuel prices. Considering a 3% increase in fuel prices per year for the 25-year period, the annual savings would have been NZD 2 million (USD 1.43 million).

4.6.4 Business model and tariff mechanism

The solar PV systems were designed, procured, and installed by Powersmart Solar NZ Ltd, with support from IT Power (Australia) Pvt Ltd. The solar PV systems were handed over to the Government of Tokelau after commissioning and are being operated by local technicians and operators. These technicians were trained on regular operation and maintenance of the PV system components, and on troubleshooting procedures. The electricity tariff of the consumers was set at NZD 0.50 (USD 0.36[61]) per kWh.

Electricity is sold using pre-pay meters that are installed and maintained by the Tokelau Energy Department. The typical equipment being used on the island include refrigerators, freezers, fluorescent lighting, fans, microwaves and washing machines. Equipment such as electric ovens, water heaters and air-conditioners are banned on the atolls The village councils collect the electricity bills

[59] (ITP Australia, n.d.)
[60] 1 NZD = 0.72 USD as on 27th October 2021, same exchange rate has been used to convert NZD to USD in this report
[61] 1 NZD = 0.72 USD as on 27th October 2021

from consumers, which is used for purchasing the diesel fuel and salary payment of technicians and operators.

4.6.5 Project outcomes

- The expenditure on diesel fuel has reduced considerably, by 84% from the pre-solar days. It has been found that if there are seven hours of bright sunlight, then the solar PV-battery system is capable to provide the electricity needs and there is no need for back-up generation.
- The overall quality of life has improved in the atolls because of 24/7 availability of electricity and has also allowed the use of most modern services.
- Awareness campaigns were organized to educate consumers on how to save electricity and to encourage them to purchase energy efficient lighting and equipment. These programmes have brought about reduction in energy consumption.

4.6.6 Challenges

Since the solar PV systems were to be installed in an island set up with high temperatures and humidity, it posed a challenge on both the design and installation of the system. The solar cables were routed in an aluminium channel and UV stabilised conduit, and each equipment was manufactured from either 316 stainless steel or anodised aluminium to avoid corrosion. Additionally, care was taken to ensure that the battery and inverter rooms were well ventilated with passive heat controls.

During the project technical and financial review undertaken by ITP Australia in 2013, it was found that the current tariff of NZD 0.50 (USD 0.36) per kWh is not sufficient to generate the revenue required to fully finance the O&M including replacement of equipment. The study recommended that a tariff of around NZD 0.77 (USD 0.55) per kWh is required for the same. However, during discussions with stakeholders, it was discovered that the current tariff is already a burden on the consumers who expected a lower tariff from the solar power system. Also, share of the household income spent on electricity needs is higher than for the average New Zealand household, whereas the actual consumption in Tokelau is significantly lower.

In the recent years, electricity demand from the community has increased, which has led to increased diesel fuel consumption. In this regard, the Government of Tokelau has added 30kW of PV on each island in 2016 and will be installing a further 210 kW of PV and almost 2 MWh of battery capacity to meet the rising demand and restore the contribution of renewable energy to 90+%.

4.6.7 Key highlights

Actual performance of the solar hybrid systems has exceeded the designed parameters and Tokelau is the first country to have almost all its electricity needs met by solar power systems. The solar fraction for Atafu, Nukunonu and Fakaofo atolls were designed to be 89%, 91% and 86% respectively. During the technical review by ITP Australia in 2013, the solar fractions were found to be more than 90% on Atafu and Nukunonu and around 89% on Fakaofo, more than the designed parameters.

The project is a good example for other small island nations and/ or communities which are aiming to reduce expenditure on diesel fuel required for electricity production and thus enhance their energy security and environment by implementing renewable energy minigrid projects. The project has been a major success and has received major recognition from reputed institutions. The island nation of Tokelau received the 2014 Energy Efficiency and Conservation Authority (EECA) Renewable Energy

Award for switching from diesel-generated electricity to clean, renewable solar energy and providing almost 90% of Tokelau's electricity needs. The project developers have received two awards - Sustainable Electricity Association New Zealand (SEANZ) 'Best Solar PV Implementation Off-Shore' award and New Zealand Innovators Award for the Tokelau Renewable Energy Project in the year 2012.

4.7 Bambadinca PV minigrid, Guinea Bissau

Public - Community model to increase access to electricity

4.7.1 Introduction

Bambadinca, one of the rural communities in Guinea Bissau with over 1,000 households in 2011, had 96% of the households depended on candles and batteries and only 60 households with access to electricity through a diesel generator working 5 hours/day and charging 10 EUR (USD 11.6[62])/month/per light bulb. The main economic activities in Bambadinca included agriculture and trade. There are around 70% of the population lying below the poverty line (< USD 2/ day). Households spent almost 24% of monthly income on traditional energy solutions. To improve access to electricity and poverty in Bambadinca, a hybrid PV minigrid project was implemented based on public-community model. The specific details on following sections of the case study have been extracted from several references[63].

4.7.2 Technical features

The minigrid project development in Bambadinca started in 2012 and was commissioned in 2015. The technical features included a hybrid Solar PV - Diesel – Battery system. The hybrid system consisted of 312kWp solar PV array, 135kVA inverter with a 1.1MWh battery bank and 240kVA diesel genset. Figure 43 shows the minigrid system installed in Bambadinca. The system was sized to meet the energy demands during non-daylight hours or cloudy days as well to guarantee electrical demands over the day. The distribution line distance is of 13.3 km and supplies a total of 1,421 customers. The consumption during the night period is met by batteries and generators (if necessary). The system ensures 24/7 electricity supply in to Bambadinca, achieving a low use of diesel generators.

[62] 1 EUR = 1.16 USD as on 27th October 2021, same exchange rate has been used to convert EUR to USD in this report

[63] (Wame, 2014); (Xenakis, n.d.); (ARE & UNIDO ITPO, 2021); (ESMAP, 2017); (Xenakis, 2017); (UNIDO, 2017); (Ecowas Centre for Renewable Energy and Energy Efficiency, 2020)

Figure 43: Bambadinca PV Minigrid[64]

4.7.3 Financial aspects

The total capital expenditure of the project was USD 3,262,754. The financing was provided by the European Union, Global Environment Facility (GEF), United Nations Industrial Development Organization (UNIDO), ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) and Portuguese Cooperation. The project was implemented by TESE - Development Association in association with Community Association for the Development of Bambadinca (ACDB). The Guinean Association for the Study and Release of Appropriate Technologies supported the project through micro-credits for households to finance the connection costs and for supporting 300 households to develop income generating activities.

4.7.4 Business model

The selected management model was a tripartite Public-Community Partnership among Community Association for the Development of Bambadinca (ACDB)/ Community Energy Service of Bambadinca (SCEB) as one party, General Directorate of Energy (DGE) / Regional Energy Office of Bafatá (DREB) as the national/ regional authority (second party) and the local community leaders as the third party. The management model was chosen to ensure economic and social sustainability of the project.

The minigrid is being operated by SCEB with support from ACDB. The community leaders provide support in awareness activities, conflict resolution ad monitoring illegal connections. The local community has been involved in the project since the beginning, both for the development of the management model and for the definition of the tariffs and invoicing models.

4.7.5 Tariff mechanism

A tariff determination study was undertaken before the project implementation considering recovery of all the operation and maintenance costs over the project lifetime of 20 years. To have a balance between the ability to pay and the long-term financial sustainability of the project, the project proposed a prepayment, cost-reflective tariff model, which included time-of-use with a power limitation and cross subsidies to favour lower income customers. The main objective was to have tariffs that guarantee a full recovery of costs within a 20-year period.

[64] (Xenakis, n.d.)

The tariffs were presented, published, and later adopted by the DGE in December 2014. The lowest tariffs of 250 XOF/ kWh (0.44 USD[65]/ kWh) apply between 9 am and 6 pm, medium tariffs during the evening hours (6 pm and 11:59 pm) at 320 XOF/kWh (0.57 USD/kWh) and highest during the night between 12 am and 9 am, at 500 XOF/kWh (0.88 USD/kWh). To ensure the sustainability of the project, awareness campaigns were organized on energy efficiency, electricity safety and importance of tariff payments.

4.7.6 Project outcomes

- The main outcome of project implementation was the increase in access to electricity from 5% to over 85%, to number of households, enterprises, and institutions.
- Project has provided electricity to 8,000 households, 5 schools, 9 religious' institutions, Local Health Centre, Local municipality, ACDB, DGE, 110 small enterprises, 333 micro credit beneficiaries.
- Project created 12 permanent jobs for operation and management of the minigrid. The responsibilities included financial & commercial management, system O&M, monitoring & security, and prevention & conflict resolution.
- Greenhouse gas emissions reduction from the project were estimated to be 409 tonnes CO_2 equivalent per year and 8,180 tonnes CO_2 equivalent over its 20 years lifetime.
- Capacity building of SCEB on operation & maintenance of solar PV, installation practices and O&M of low and medium voltage grids.
- Awareness raising campaign for the community to understand, support and accept the solar minigrid project.
- The monthly expenditure on energy was reduced from 24% of the consumer income to only 10%.

4.7.7 Challenges

- Tariff determination process was challenging since there was high local expectations, subsidies were absent and there was price variety between the urban and rural.
- Limited financial management capacity led to payment problems for the replacement of spare parts
- Political instability (coup of 2012) impacted the suppliers risk perception and hence the project´s timeline
- Due to capacity limitations of the hybrid system, parts of the population have been left out.

4.7.8 Key highlights

Key success factor of this project was the participatory approach in the project implementation, which involved the community from the inception. The community was involved in identifying the technology to be used, willingness to pay/ ability to pay of consumers, tariff setting, environmental conditions, etc. This resulted in fast adoption of electricity from the project, connecting over 250 customers within 6 months of which 80% were households.

Community is also involved in collection of payments, which has led to high rate of payment from the beneficiaries. Local training and awareness campaigns further endorsed the acceptability and support

[65] 1 XOF = 0.0018 USD as on 27th October 2021, same exchange rate has been used to convert XOF to USD in this report

for the project. The project also demonstrated a replicable model that can be implemented in areas of Guinea-Bissau, where national grid will not reach in the near future. One such replication project was Bissora minigrid, which is operating since 2015 and has an installed electric capacity of 312 kWp.

4.8 MHP project in Sar Kalay village, Khyber Pakhtunkhwa Province, Pakistan

Sustainable electricity access for remote and inaccessible village in Pakistan

4.8.1 Introduction

The Sar Kalay village, a remote and off-grid area, is located in the district of Buner of Khyber Pakhtunkhwa province of Pakistan. PPAF with the support of KfW has financed the implementation of a micro hydropower plant in the village. The project[66] site is about 200 km from the national capital, Islamabad and located close to the Swat valley. The project implementation was initiated in the year 2014 and finally commissioned in 2017.

Prior to the project, the site had no grid electricity connection. There are around 60 households in the village making up for a population of around 600 inhabitants. The village is endowed with natural resources but was deprived of basic access to electricity, one of the key requisites for quality life. Sources of lighting were limited to kerosene oil lanterns or firewood. Majority of inhabitants of village are poor so they could not afford to buy solar lights or home systems and had to rely on kerosene lamps and firewood as only options. Without electricity, there was no access to motive energy (such as motor drives, pumps and so on), and agriculture was largely dependent on the rains.

4.8.2 Technical features

The total capacity of the MHP unit is 36 kW and the unit is powered by a single turbine/ generator of the same size. The site has an average flow rate of 0.21 m^3/s, and the total head available is 27.57 metres for the site, which is located in the mountains as shown in Figure 44.

The power distribution network includes a 6-km long reticulation system consisting of ABC cables with accessories such as conductors. The lines are supported using tubular poles, while connections are in the form of single-phase energy meters connected to individual households and other loads such as schools and shops, together with meter boxes. The total feasible annual generation from the site is around 315,000 kWh (assuming 100% generation), but the effective generation is expected around 200,000 kWh per annum, which yields a capacity utilisation factor of close to 70% from the site.

[66] Specific details on this case study are based on the information provided by PPAF team

Figure 44: Water channel at MHP plant site, Sar Kalay, Buner district

4.8.3 Financial aspects

The total capital cost of the project was PKR 30 million (USD 171,000[67]). The break-down of this cost is provided as below:

Item	**Cost (PKR)**	**Cost (USD)**
Civil works	19 million	108,300
Distribution network	8.5 million	48,450
Plant & Machinery	2.5 million	14,250
Totals	**30 million**	**171,000**

From above, it can be seen that the civil works were a significant cost component due to the mountainous terrain. Financing of the project was primarily done through grants provided by the KfW Development Bank. The community has also contributed towards the cost of project amounting to PKR 2.5 million (USD 14,250) in addition to provision of land for the project, which was not priced.

The annual operation and maintenance cost for the project is estimated to be around PKR 200,000 (USD 1,140[68]). This amount primarily includes salaries and emoluments of operators at the site. MHP does not have high operating expenses. While determining the sizing of the MHP unit, viability of the project was assessed covering post commissioning operation and maintenance and found to be viable.

4.8.4 Business model and tariff mechanism

National Rural Support Programme (NRSP)[69], a leading partner organization of PPAF, has implemented the project with active participation of the community. To effectively manage the day-to-day operations and maintain long term sustainability of the project, the community formed an Operation and Maintenance committee comprising of active members from the community. The O&M committee has taken over the complete responsibility of plant operation and hired services of trained

[67] 1 PKR = 0.0057 USD as on 27th October 2021
[68] 1 PKR = 0.0057 USD as on 27th October 2021
[69] https://nrsp.org.pk

operators to run the plant. These operators were provided with hands-on training during installation of systems as part of the project.

Apart from this, the O&M committee, in consultation with the beneficiary community, has set up a tariff collection mechanism. Each household has an energy meter installed and based on their actual consumption, electricity bill is collected and deposited in community bank account. The salaries of plant operators and other operational expenses are paid out of this amount. The O&M expenses are afforded by the users, who used to spend as much as PKR 5,000 (USD 28.5) per month on kerosene, which is replaced by electricity from MHP whose monthly bill comes to around PKR 1,200 (USD 6.84) per month.

The business model for the project hinges on *user pays* principle. The tariff is set at PKR 15 (USD 0.086) per kWh for domestic and commercial users alike to recover all operating expenses. In addition, users pay PKR 200 (about USD 1.14) as fixed charges for the electricity connection. Thus, the monthly bills carry a fixed line charge and a variable charge per kWh of consumption.

4.8.5 Project outcomes

The project was among a number of DRE minigrids implemented by the PPAF, in collaboration with NRSP across several sites in Pakistan, where quality power was delivered to a range of consumers, with a focused approach towards empowering communities with electricity access. As discussed above, the project has led to reduced monthly expenditure on energy use.

The project has also led to strong socio-economic impact in the village, where a number of new enterprises and commercial activities were introduced. Prominently, this included tailoring, embroidery and use of tooling equipment such as *lathe machines* that run on electricity. Submersible pumps at homestead and/or agricultural fields have also mechanised agriculture on one hand, while lending access to groundwater for household consumption on the other. At the same time, social aspects such as health and education has also benefited significantly from electricity access.

4.8.6 Challenges

The construction of MHP was a very challenging task for local community as well as NRSP team. The site of powerhouse and water channel is located in a deep trench surrounded by high mountains, where transportation of machinery and construction material was only possible through donkeys or on human shoulders. In this regard, the role of the community proved to be a key success factor. The community was keen and proactive and collaborated with the PPAF /NRSP team throughout the project development cycle.

The price of MHP electricity is kept at PKR 15 (USD 0.086[70]) per kWh, which was higher than the average tariff charged by utilities under guidance from NEPRA during 2017 in Pakistan. This was a challenge to overcome due to higher-than-normal electricity prices.

4.8.7 Key highlights

The project has been instrumental in providing sustainable and affordable energy access to a previously disconnected and remote location. The strong economics of the project and active involvement of community from the start of project implementation has ensured sustainability of the

[70] 1 PKR = 0.0057 USD as on 27th October 2021

plant. The project has laid strong emphasis on empowerment of women, both in terms of quality of life and for enterprise development. Other key highlights which were reported through consumers of MHP are:

- The availability of electricity provided more free time to women, which they now utilize for stitching of cloths and doing embroidery work, using tools and/or machines run on electricity. Thus, supporting economic empowerment of women in Sar Kalay village
- Shops are now open till late in the evening (even up to 11 PM), and as a result of this daily income has increased by 20% because people could buy grocery items from shop after sunset.
- Construction of MHP has also produced new opportunities for employment in the village. The MHP plant operator is earning equal to that of a teacher. The project has provided a gateway for other developmental activities in the village through Government and non-government organizations.

4.9 Key lessons

The lessons from the above case studies have been discussed in this section with respect to two parameters –factors supporting minigrid development and barriers for minigrid. Same has been presented in the Figure 45.

Key factors supporting minigrid development in SAARC region

- Access to and demand for electricity is the prime driver across minigrids in the SMS or globally. As the case studies from Sar Kalay (Pakistan), Bambadinca (Guinea Bissau) demonstrate, consumers are even willing to pay higher tariff for reliable electricity access
- Role of enterprises as *productive* loads evolves as one of the key factors supporting minigrid development. Examples from Bamiyan (Afghanistan), Bheldi (India) and Sar Kalay (Pakistan) show that enterprises enable a minigrid to charge full tariffs from industrial, commercial consumers, while using these proceeds to subsidize domestic users (especially seen in Bamiyan). This enables the minigrid to support its operations over time, covering key O&M expenses such as battery replacement.
- Innovations in technical design and business models have proven to be instrumental in lowering costs, overcoming operational barriers, and streamlining operations. Among the case studies, SOLshare (Bangladesh), Bheldi (India), Bamiyan (Afghanistan) and Baglung (Nepal) are clear examples where innovative design aspects were used to make projects more sustainable and viable.
- Community engagement and involvement is a critical step, not only in early adoption of customers for a minigrid project but also to ensure that communities (consumers) are able to upgrade to operate smarter and lower-cost enterprises. As shown in the Tokelau as well as in Bamiyan (Afghanistan), consumers replacing diesel with solar PV power benefitted in the long run from better delivery. As in the case of Bambadinca (Guinea Bissau), the active involvement of community from the start for the tariff setting and later, for the management and operation of minigrid ensured success and sustainability.

Key barriers for minigrids

- It can be observed from the case studies that the cost of capital and O&M expenses for the project are not fully offset by revenues from tariffs. One of the reasons could be that the unelectrified areas are usually rural and the consumers not economically affluent, as a result their ability to pay is also limited. One relevant example is the SOLshare model: even in presence of an innovative financing mechanism and requiring minimal capital cost support, the project needed financial inputs to sustain itself. While the site in Bamiyan, Afghanistan has demonstrated a way out through higher tariffs from commercial and enterprise loads to cover for higher O&M outgo, the site has faced constraints by way of limited ability to pay from consumers in the absence of commercial and enterprise loads.
- The case studies have highlighted the barrier related to absence of advance project management and technical skills among the operators of minigrid. These skills are essential for efficient operation of minigrids using complex designs. For example, in SOLshare model (Bangladesh) and Baglung minigrid (Nepal), advance technical skills and project management skills for managing several sites at a time is an essential requirement for efficient operation.
- Introduction of any new technical concept or technologies in minigrid often trigger risk perceptions related to its viability, consumer acceptance, among others and thus they require additional financial support and risk coverage for financial viability. As in the case of SOLshare model, the access to finance was an issue due to risk perception related to new technological concept.
- Adoption of minigrid by consumers in remote areas usually builds up over a time and therefore the capacity utilization factor of the minigrid project is lower at the beginning. In case of Bamiyan case study, the adoption of consumers was very low at the start because prospective consumers were not ready to adapt.

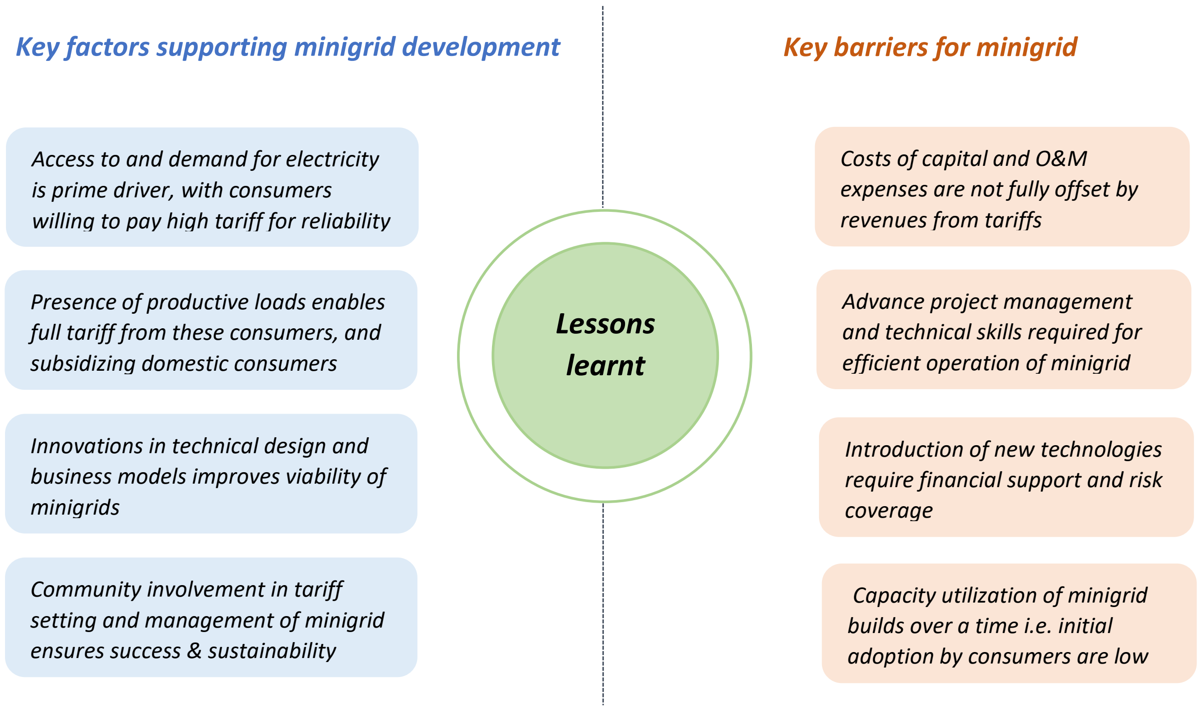


Figure 45: Lessons Learnt from Case Studies

5 CONCLUSION AND RECOMMENDATIONS

5.1 Country wise summary and recommendations

The access to electricity in the SAARC Member States has improved considerably over the last few years. Countries such as Maldives, Sri Lanka, Bangladesh, Bhutan, and India have either achieved or are close to achieving 100% electrification of their population. Nepal and Pakistan still have a set of large population without access to electricity whereas, Afghanistan has almost two third of its population not connected to the main electric grid. While enhancing electricity access and achieving 100% electrification are the key drivers for promoting minigrids, the study shows that the drivers for minigrids in the SAARC Member States also include increasing the renewable energy share in the national energy mix; reducing diesel fuel consumption; adhering to environment related commitments such as mandatory level of forest cover and net- zero transition; and increasing the export of surplus electricity to neighbours.

The key prospects and drivers, barriers, and recommendations for minigrid sector in each of the SAARC Member States have been discussed below in detail. The Table 2 provides the summarized version for each country.

5.1.1 Afghanistan

i. Prospects and drivers

a. Only one-third of the country's population has access to electricity through national grid. There are several provinces in the country that are yet to be connected. In other provinces, electricity access is limited to the capital and major towns. This leaves ample opportunity for renewable energy based decentralised minigrids. Currently this market is occupied by captive diesel generators, standalone solar PV based home systems and lanterns, as well as diesel powered minigrids.
b. The renewable energy policy of Afghanistan has entrusted Ministry of Rural Rehabilitation and Development for development of minigrid projects, up to the capacity of 1 MW. This gives a clear mandate for development of RE powered decentralised minigrids. Under MRRD's guidance, there are ongoing efforts to set up 25 minigrids in an integrated manner across provinces in Afghanistan.
c. There is considerable traction in the field of minigrid development, with Green Climate Fund supporting the development of minigrids in the country through Afghanistan Renewable Energy Market Transformation Initiative project. The project will implement three solar minigrids and develop construction designs for other 5 minigrids as well as develop minigrid handbook, regulations, and conduct capacity building and trainings.
d. There is a strong enterprise demand in several provinces, creating sustained demand for electricity. Moreover, due to use of diesel and kerosene for meeting energy needs in the present situation, there is likelihood of RE projects being viable due to high avoided expenses on fossil fuels.
e. The presence of a strong renewable energy industry union ensures the interest of local enterprises for expanding this sector. The mandate is to act as a lobbying union to establish renewable energy as a permanent pillar of Afghanistan's national energy industry. There are over 100 companies representing project developers, energy service

providers, equipment manufacturers and suppliers, among others that are members of the union.

ii. Barriers

a. There is no specific minigrid policy in Afghanistan, which will stimulate this market. While the institutional framework is clear, with MRRD designated for all project development under 1 MW, there is a need for more clarity on technical and operational aspects of minigrids.
b. Although the private sector is actively participating in renewable energy projects, the enabling environment for private sector growth and development is weak. Ancillary services such as insurance, access to working capital and enforcement of contracts are not well developed.
c. Further, governance and security situation also act as deterrents to private sector development. Especially, there are safety and security concerns associated with movement of goods and services across provinces in Afghanistan. Further, several provinces are not recommended for investment, whether by private sector or through PPP modes on account of security related concerns. As a result, the overall outlook for private sector remains weak, especially with reference to the RE sector.
d. There is a dearth of technical expertise/ support for operation and maintenance of minigrids. This includes lack of availability of spares, as well as non-availability of human capital for carrying out O&M of a minigrid project and thus raising the operating costs of a project.

iii. Recommendations

a. Although there is no specific policy and/or regulatory guidelines for minigrid deployment, under the AREMTI, MRRD is intending to commission studies to develop best practices handbook and other knowledge products. These are expected to form the mainstay for future minigrid projects in Afghanistan. It is recommended that such products be mainstreamed and widely disseminated as support documents for entrepreneurs and other stakeholders in the sector. Such developments (as mentioned above) shall also provide confidence to the private sector and other stakeholders for setting up, operation and maintenance of minigrid projects.
   Importantly, MRRD has a clear mandate to develop minigrid projects up to capacity of 1 MW per site.

   In view of this, it is recommended that the national electricity utility DABS, and MRRD may jointly develop and introduce a least cost electrification Master Plan for Afghanistan, ensuring minigrids and grid extension initiatives complement each other in achieving universal electricity access.
b. Capacities to be enhanced across key institutions and personnel for design, development, and O&M of minigrids; especially on technical support that should be extended to minigrid projects on the ground.
c. A mechanism for Business-to-Business network could be created to facilitate AREU members in exploring collaborations and accessing technical know-how from other countries in the region.

5.1.2 Bangladesh

i. Prospects and drivers

a. Bangladesh has achieved almost 99% electrification as of 2021 and has targeted for universal access by the end of this year. The current focus of the Government of Bangladesh is to reach 100% electrification of urban as well as rural areas via national grid only and hence, there is not much focus on minigrids except for a few remote island locations.
b. There are remote islands/ areas in Bangladesh, which are off-grid and population concentrations are dispersed and national grid might not be feasible or possible to reach even through submarine cables. In such cases, renewable energy based minigrid might be the best option for providing reliable and quality access to electricity which will also serve the commercial needs of the rural markets and small enterprises.
c. ME SOLshare Limited which has installed smart peer to peer solar microgrids in Bangladesh by connecting solar home systems, is targeting to provide power to an additional 1 million households through microgrids by the year 2030, including interconnection with the national grid.
d. Through Nationally Determined Contributions, Bangladesh has made commitments to reduce unconditional 5% of GHG emissions by 2030 in the power, transport, and industry sectors and a conditional 15% reduction in GHG emissions by 2030. The government has also set a target to generate 10% of electricity from renewable sources. The current installed capacity of renewable energy is only 3% of the total power generation capacity. While these targets are expected to be largely met by MW scale solar parks and roof-top solar projects, distributed projects such as solar pumps and minigrids will also contribute, albeit in a limited manner.

ii. Barriers

a. There is no specific policy or strategy of the Government to develop minigrid projects in Bangladesh. As such, project developers are not interested to develop and finance minigrid projects even though there is an opportunity for minigrid development in some off grid areas and remote islands. Private sector companies find this challenging because of high perceived commercial risks pertaining to grid arrival and lack of financing and government support.
b. The tariff for solar minigrids is much higher than the subsidized tariff paid by the national grid consumers. This discourages consumers from using more electricity than that required to meet basic needs and thus create resentment among the consumers. However, the Government has made a policy decision to purchase the minigrid electricity at higher tariffs from their operators and sell it to the consumers at subsidized tariff, which is same as the grid tariff.
c. Several solar home systems and solar minigrids have been made redundant after the expansion of the national electricity grid to these areas as people prefer to use grid electricity at lower prices. Thus, highlighting the uncertainty in the operation of minigrids and risks related to arrival of national grid.

d. Bangladesh is densely populated country with little land availability and has restrictions on use of agricultural land. Thus, identification of land area for minigrid project development is challenging.

iii. Recommendations

a. There are off-grid areas in remote islands of Bangladesh where population concentrations are dispersed. Distribution utilities are responsible to provide electricity to those areas, however, connecting them to national grid would be costly and time consuming. Renewable energy based minigrid would be the least-cost option for providing reliable access to electricity. MPEMR with the support of IDCOL or SREDA may formulate and introduce a special policy for development of minigrids in remote areas covering tariff regulations, financial support, grid arrival rules, among others.
b. Government is planning to connect the existing minigrids in Bangladesh to the national grid within months. Existing minigrids need to be upgraded to match the requirements of national grid and connect them to the national grid. MPEMR would need to formulate the guidelines for the grid interconnection of minigrid infrastructure. In the meanwhile, distribution utilities should continue to purchase the electricity from the minigrids that are being connected to national grid at minigrid tariff and sell it to the consumers at subsidized tariff.
c. SREDA may prioritize minigrid projects in the roadmap for providing electricity access to remote areas where national grid would take longer time to reach and would not be cost effective.

5.1.3 Bhutan

i. Prospects and drivers

a. Bhutan has achieved almost 100% access to electricity; however, reliability of electricity supply remains an issue. Around 58% of households had faced one or more electric power failures/interruptions lasting at least one hour and the proportion of households that faced more frequent power interruptions is higher in rural areas (64.3%) than in urban areas (46.6%) (IRENA, 2019). Minigrids could enhance the electricity supply if installed in grid connected mode.
b. Local population in rural areas are showing interest in running enterprises. They are keen to stay in their own locality if they are provided with reliable electricity via minigrids. This creates an opportunity to develop local solutions such as minigrids to provide reliable electricity for running enterprises.
c. There is a strong interest of the Royal Government of Bhutan to develop minigrids in areas where transmission lines extension is uneconomical or has to pass through protected areas & national parks or lead to deforestation. Bhutan has a mandate to maintain 60% of the country's land under forest covers to preserve its environment. If minigrids are proved to be more technically and economically viable, then the construction of new T&D lines could be avoided as well as those underutilized transmission lines could even be decommissioned.

d. The country sells surplus electricity generated to the neighboring countries for generating revenue for the country. There is an interest from the Government to produce RE electricity locally to increase foreign revenue generation.

ii. Barriers

a. There is no dedicated policy and regulations regarding minigrid development in Bhutan. There are no clear guidelines regarding arrival of national grid at the minigrid site, whether the minigrid will be connected to the grid or how developers will be compensated. The country has set no specific targets for electricity generation via minigrids.
b. The electricity tariffs in Bhutan are subsidized and public utilities like DGPC and BPC claim that they do not obtain a fair return on their assets. In this scenario, private sector participants may be unwilling to make investments in the absence of clear indication of returns to investors.
c. Bhutan has piloted solar and wind minigrid projects only after 2014. The government as well as the private sector lacks necessary technical and financial expertise to develop and operate minigrid in the country.

iii. Recommendations

a. Department of renewable energy may formulate a national minigrid policy or regulation to facilitate development of minigrid sector in the country. The policy/ regulation should clearly mention the rules related to future of minigrid in the event of arrival of national grid. It should also include measures for de-risking minigrid business models in the form of financing schemes, tariff regulations, payment guarantees, etc.
b. Royal Government of Bhutan could set up national target for minigrid projects in the country in terms of capacity or numbers and identify target community for project development. This will show intent of the Government for development of minigrids in the country and thus create private sector interest in the sector.
c. Bhutan Electricity Authority may formulate tariff regulation for minigrid sector and ensure fair return on investment so that private sector participation in the sector will increase. Private sector participation enhances development of the minigrid sector and helps to meet customers' demand of reliable electricity.
d. Capacity building trainings and vocational programs on renewable energy minigrid design and operation should be developed engaging with development partners and local educational institutions to ensure enough properly trained professionals are available in the country to support private sector investment.
e. The geography of Bhutan is similar to that of Nepal. The study recommends that Bhutan should replicate the lessons learnt from case studies in Nepal (discussed in section 4.4) where MHPs operating in the country could be interconnected to form a minigrid for reliable supply of electricity to the consumers.

5.1.4 India

i. Prospects and drivers

a. There are still 5.5 million people in India that lack access to electricity despite achieving 100% electrification of households due to non-availability of last mile connectivity in remote areas. Also, there are issues related to reliability (hours of supply) and quality of electricity in rural areas connected to the national grid. Minigrids can fill this gap in supply of electricity.

b. Minigrid policies (in two states of India - Uttar Pradesh and Bihar) have been driving private sector interest in these states to develop minigrid projects for providing last mile electrification, reliable & quality power and push socio-economic development. Central ministry on new and renewable energy has issued a draft 'National Policy for Renewable Energy based Micro and Minigrids' in June 2016, which is yet to be approved.

c. Private sector is at the fore front of expanding minigrid market in India for providing electricity services for a multitude of applications. Smart Power India (an initiative of Rockefeller Foundation) together with Tata Power Limited (One of India's leading power companies) has set a target to install 10,000 minigrids in India in the next few years. Also, ESMAP study on 'Mini-Grids for Half a Billion People' has reported around 1,905 minigrids that are planned to be installed in India in coming years.

d. Minigrids are also being promoted to provide electricity for public institutions in health care and education sector and for enterprise development in rural areas following the PPP (Public-Private-Partnership) approach where the CSR funds/ government grants/ local area development schemes are being matched with private sector equity and community contribution to install and operate minigrids. Hamara Grid Private Limited, is working with District Administration and Village Development Board in Northeast India to electrify 1000 villages spread over ten districts. Mlinda has a target to install minigrids in 50 villages.

e. Operational diesel based minigrids are being converted/ hybridised into solar/ wind/ diesel minigrids in large and densely populated islands (such as Sagar island in Sunderbans where state government is developing 500 kW solar-wind hybrid; Andaman & Nicobar and Lakshadweep islands where majority of the power generation comes from diesel based units) and hilly/ remote regions (such as Zanskar valley in UT of Ladakh where CESL- a newly established subsidiary of EESL- state-owned Super ESCO is exploring international carbon finance market to monetize GHG reductions from such projects).

ii. Barriers

a. Lack of clarity in policies regarding future grid arrival at the place of minigrid site has restricted developers in pursuing minigrids in remote areas. Health centres, schools, streetlights, and other public good infrastructure have remained uncovered in the state minigrid policies.

b. Grid arrival is a reality as almost all villages are connected to the national grid. However, the quality of supply from the grid is often not reliable. There is a need to design and implement innovative business models to promote minigrid in these areas.

c. Minigrid power is expensive compared to power from the grid because developers try to recover their investment within only a first few years as well as due to presence of low demand for electricity in remote areas.

d. Constraints in availability of funds to minigrid developers to finance the operational expenses including replacement of equipment, arising because of untimely payment by consumers, improper billing, and payment mechanism, etc. There is also lack of patient capital[71] available to finance minigrids. Minigrids usually take 12 to 18 months to build power demand and attain a good capacity utilization. The financing mechanisms should thus structure the investments accordingly.

iii. Recommendations

a. The draft national minigrid policy which has specified the guidelines for future arrival of grid at minigrid site, financial incentives, tariff setting, etc. should be approved by the MNRE. Considering the success of minigrid policies of two states (UP and Bihar) of India, the study recommends other states to also develop specific minigrid policies to drive private sector interest and scale up minigrid development.

b. Business models for minigrids need to be built around unreliable, poor-quality supply and inability to operate livelihoods-based machinery on the national grid. Grid interactive minigrid projects should be promoted to provide the last-mile-connectivity and support the growth of local economies and livelihoods. Grid interactive minigrid can integrate with grid where or when it is available. It will allow the system to export surplus power generated and import when needed.

c. Project developers in India have started to engage with the community from the beginning during the minigrid development which has helped them to increase the uptake of productive appliances and thus improve the demand in these areas. This practice should be adopted in future projects to increase the productive demand and thus reduce the cost of electricity. Also, efforts to effect behavioral change at consumer end should also be made a part of the minigrid establishment process. This will result in demand side management through increased user awareness about the pattern of energy usage.

d. Design and implementation of innovative payment collection mechanism such as taking 3-6 months of payment as advance security deposit from rural customers to ensure revenue visibility, combination of pre-paid metering and institutional Power Purchase Agreements with an anchor client will improve the fund availability. A clarity in policy will also give confidence to financiers and investors on returns from minigrid projects.

5.1.5 Maldives

i. Prospects and drivers

a. Maldives has achieved 100% electrification in each of its islands, providing 24/7 supply mainly through diesel based minigrids. However, the Government is facing challenges to reduce the cost of electricity since diesel fuel is imported and transported to the dispersed generating locations, which adds to the cost of generation. Government is thus providing subsidies to domestic consumers, which was around USD 65 million in 2019.

b. Government is promoting hybridization of diesel minigrids with renewable energy to reduce dependency on diesel fuel and reduce overall electricity cost as the cost of solar PV electricity is falling.

[71] Patient capital is an investment that does not seek to maximize financial returns to investors, but seeks to maximize social impact and to catalyze the creation of markets to combat poverty

c. Government of Maldives has also set a target to reach net-zero global GHG emissions by 2030 with international assistance and private investments. The key priority of the government, in this regard, is to reduce its dependence on imported diesel fuel and invest in renewable energy projects.
d. Under World Bank financed Accelerating Renewable Energy Integration and Sustainable Energy project, hybridisation of fourteen island grids is being done. Three projects under earlier WB program have been implemented or are in construction stage.
e. Preparing Outer Islands for Sustainable Energy Development project of ADB is transforming existing diesel-based energy minigrids into hybrid renewable energy systems in 160 inhabited islands, out of which installations on 48 islands have been commissioned.

ii. Barriers

a. There is a need to develop robust energy sector plans focusing on hybrid renewable energy projects to meet the increasing electricity demand in the country, lower electricity cost and reduce the import of diesel.
b. Investments in renewable energy projects in the country have been driven primarily by grants and loans from multilateral agencies. GoM faces a substantial foreign debt burden, which limits opportunities for direct public financing of renewable energy expansion. Commercial bank financing or private sector financing is in its nascent stage since they are still reluctant to accept the risks associated with renewable energy technologies and invest in the sector.
c. Utility companies in Maldives have been implementing only conventional energy projects and only in last few years renewable energy projects have started to come up. Therefore, there is limited experience and expertise available locally regarding renewable energy technologies, their design, installation, and operation.

iii. Recommendations

a. Ministry of Environment and Energy with the support of Maldives Energy Authority and Electric Utility Companies (FENAKA and STELCO) may develop national level energy plans looking into the future energy demand and supply aspects, and identify potential sites and targets for the deployment of renewable energy hybrid projects in the country.
b. To mobilize private interest and investment in the sector, de-risking mechanisms such as power purchasing agreement arrangement should be developed and implemented in future projects. A PPA guarantees a price for electricity to be sold and the private sector earns a guaranteed return on its long-term investment. Also, coordination with development finance institutions to source concessional financing should remain important in the near-term.
c. Technical and vocational training on renewable energy technologies and projects should be developed and delivered to utility companies, government departments, financing institutions, project developers and professionals with the help of development partners and local educational institutions, to ensure enough properly trained professionals to support private sector investment.

5.1.6 Nepal

i. Prospects and drivers

a. There is still 7% of the population in Nepal that lacks access to electricity. Government of Nepal has been providing electricity through both on-grid as well as off-grid decentralized generation. Off-grid electricity generation is provided mainly through micro/mini hydro and other renewable energy based minigrids. Nepal has implemented subsidy grant program to scale up investment in isolated minigrids as part of a national rural electrification strategy. There has been strong and increasing interest for minigrid development from rural communities as well as local governments of Nepal after witnessing the success of previously implemented projects.
b. The fifteenth plan of GoN aspires for 12% contribution of RE in total energy generation by 2024. The country is also targeting to install solar minigrid projects in mountains and upper hills region. Government of Nepal has allocated budget for detailed feasibility study of minigrid projects around the country. *Ujyalo* Nepal program is providing 90% upfront subsidy from the Federal Government and 10% matching fund from the local level for minigrid projects. The proposed minigrid in the country is expected to provide Tier-3 level of electricity access to the rural households.
c. The private sector companies in Nepal are either involved in design, supply, and installation of minigrids or equity financing of minigrids as RESCOs. The World Bank "Private Sector-Led Mini-Grid Energy Access Project" aims to mobilize RESCOs to increase capacity of RE minigrids. The program will provide credit facility to the private sector to support renewable minigrid sub-projects as well as technical assistance to RESCOs and partner banks to ensure smooth and sustainable implementation and operation.
d. Minigrids in Nepal are being developed as grid compatible power generation and distribution system so that they could be connected to the national grid upon its arrival. The implementation cycle of minigrids (especially solar minigrid) is short, in general 6 to 8 months only. The private sector in Nepal has good know-how of the technical aspects in the entire value chain of the solar minigrids. This reflects confidence towards quality supply, design, installation, and operation of minigrids in Nepal.

ii. Barriers

a. Minigrids have been designed mainly for basic needs without the consideration of future energy demand of households and productive loads. After the installation of minigrid, it is often observed that the aspirational demand of the consumers increases leading to unmet demand as minigrids are designed without considering the growth in energy demand.
b. Minigrid power is expensive compared to power from the grid because developers are interested to recover their investment within first few years. Therefore, consumers prefer to get connected to the national grid.
c. Despite the successful interconnection of several MHPs and minigrid projects to the national grid, the policy for grid connection of minigrids is still ambiguous.

d. Project developers continue to struggle to achieve financial closure on time as subsidy and their equity are not enough to cover the total project cost and bank financing is difficult to access.

iii. Recommendations

a. Future minigrid projects should be designed and developed considering anchor loads such as irrigation, local energy-based enterprises, health, school, etc. and future demand of electricity in households for running modern appliances. Minigrid planning process should include the community from the beginning to understand the productive uses that can be connected at the end-user level to increase the uptake of productive appliances.
b. Electricity Regulatory Commission of Nepal may develop measures to reduce minigrid-based electricity tariffs and bring them at a rate comparable to grid-based tariffs. This will encourage minigrid consumers to use electricity as per their demand and not limit their consumption due to high tariff. AEPC should encourage commercial bank financiers to invest in minigrid projects and promote business models that are beneficial to the investors as well.
c. AEPC may develop guidelines for minigrid implementation including design, tendering, construction, and operation of future minigrids, tailored to Nepal based on data collected from existing minigrids. The guideline should also clearly explain the interconnection of minigrid to the national grid after its arrival.
d. Future minigrids should incorporate learnings from the existing successful minigrid projects on technical, financial, and operational aspects.

5.1.7 Pakistan

i. Prospects and drivers

a. The electrification rate in the country has improved from 55.7% in 2005 to 79.2% in 2019. However, there are still around 45 million people without access to electricity with majority falling in the rural areas. Despite having surplus power generation capacity, long hours of load shedding persist in several areas of the country
b. Alternative Energy Development Board has issued Alternative and Renewable Energy Policy 2019 which has set a target of at least 20% and 30% RE generation by capacity by the year 2025 and 2030 respectively in the country. The current share of renewable energy in the power mix is only 5.5% of installed capacity. The Policy has included mini/microgrid solutions in its scope and envisages that minigrids based electricity services systems will be one of the key interventions to accomplish the targets set forth therein.
c. Minigrids tariffs have shown lower cost of electricity for domestic consumers, compared to grid electricity tariff. The cost of grid electricity for end-consumers has been on the rise owing to various reasons such as high T&D losses, low recovery, fuel cost, under-utilization of efficient power plants etc.
d. Private sector companies and not-for-profit companies are active in developing off-grid projects including minigrids supported by donors. Pakistan Poverty Alleviation Fund has implemented several community micro-hydropower projects and solar minigrid projects using donor grant as well as microfinance schemes. Private companies such as Nizam Bijli,

EcoEnergy have implemented PAYG projects in off-grid areas to provide affordable solar home solutions.

ii. Barriers

a. Lack of institutional support at the national level for rural electrification and distributed renewable energy projects is a barrier. Government has been primarily focusing on utility-scale renewable energy projects and electrification of urban areas through national grid as there is increased demand for power.
b. Policies and regulations covering issues like permitting and licensing, tariff setting, financial incentives, and regulations for minigrid in the event of grid arrival are not available. These are necessary to build private sector interest and confidence.
c. Financing for minigrids in the country has been driven primarily by grants and loans from multilateral agencies. Commercial bank and private-sector financing for minigrids in rural areas is challenging because of high perceived commercial risks, high investment costs, and lack of government support.
d. Absence of standardization in minigrid design & installation has also resulted in poor performance of these projects and lowered end-user confidence. Lack of technical expertise to design, install, operate, and maintain minigrids is another limiting factor.

iii. Recommendations

a. The study recommends that NEPRA should develop a least-cost rural electrification plan outlining the potential sites for minigrids, national grid extension and others. GIS based spatial least cost planning tools for rural electrification may be used to optimize electricity supply options following techno-economic or multisector approach.
b. AEDB may develop policies/ regulations covering permitting & licensing requirements, "grid arrival" rules, procedures & guidelines for interconnecting with the grid, tariff setting, among others for minigrids in the country. Grid arrival rules should include the interconnection and/or compensation mechanisms to allay risks associated with main grid arrival. To facilitate minigrid licensing and other regulatory requirements, a single-window clearance facility may be established.
c. Financing programmes or financial support schemes utilizing government or donor funding available in the country should be established to scale up minigrids. Dedicated rural electrification funds can be created that pool together public and donor finances and make available to private developers for minigrid project financing.
d. For providing access to electricity in remote and hard to reach locations, the country can replicate the SOLshare model, discussed in section 4.2, allowing the residents to install and interconnect rooftop solar systems into smart peer to peer microgrids and thus facilitating buy and sell of electricity with each other.
e. Technical standards for the equipment deployed in minigrid power plants should be developed and enforced with clear regulations. Technical codes for interconnection with the national grid should be notified. Capacity building programs in the areas of design, installation, and O&M of minigrids for government departments, financing institutions and project developers should be designed and implemented with the technical and financial support from multilateral/ bilateral institutions.

5.1.8 Sri Lanka

i. Prospects and drivers

a. The country is fully electrified and is serviced by a single entity in the form of Ceylon Electricity Board, which acts as the sole transmission and distribution utility in the country. The strategy of Government of Sri Lanka is to transition the current generation mix to increased share of RE resources. The potential for minigrid development is relatively muted.

b. There is potential for energizing outlying islands, about ten (10) of whom are inhabited. The Sri Lankan government seeks to replace diesel minigrids by RE based minigrids. These are being driven by the Ceylon Electricity Board. Prominent among them are the Analaitivu, Delft and Nainativu islands, in addition to Eluvaithivu island, which was one of the first to be converted from diesel to RE.

c. The plan for energizing these outlying islands, with support from Asian Development Bank, stand out as an example of inter-agency cooperation. Although the minigrids are anchored and owned by CEB, other agencies have taken responsibilities of specific subcomponents such as promotion of RE based enterprises (Ministry of Power and Renewable Energy), water related interventions (National Water Supply and Drainage Board), skill-based training and education (Sri Lanka Sustainable Energy Authority) and Renewable Energy based Microgrid Pilot Project (Lanka Electricity Company (Private) Limited).

ii. Barriers

a. Due to 100% electrification achieved in Sri Lanka, and its focus on centralized grid-based delivery supplemented by Independent Power Projects in the wind and other RE that are also connected to the main grid, there is limited scope for development of minigrids in Sri Lanka.

b. The existing electricity regulatory provision, the National Energy Policy and Strategies (revised 2019) restricts electricity transmission and distribution functions to CEB, thereby negating any role of private sector owned minigrids. There is also no specific minigrid policy in Sri Lanka. However, in the past, prior to achieving national grid-based universal access to electricity, with World Bank and GEF support, over 200 micro-hydro minigrids were developed and provided electricity services to about 10,000 households. As these were developed under the cooperative model where electricity use was deemed self-consumption by the cooperative members, it was permitted by the Electricity Act (Harsha Wickramasinghe, 2014). Several of these isolated micro-hydro generators have now been connected to the grid and continue to be operate and sell electricity to the CEB under the Standardized Power Purchase Agreement (Kapila Subasinghe, 2017).

iii. Recommendations

a. Policy advocacy to Sri Lankan government to support tail end generation and enterprise development using RE powered minigrids could significantly alter prospects of minigrids in the country.

b. Within the purview of this regulatory limitation, the grids installed in the islands and proposed replacement of diesel grids by RE powered grids stand out as potential areas where RE hybrid grid architecture can be used to support local economic development based on securing sustainable livelihoods and an improved quality of life. The RE hybrid minigrids can provide electricity at least cost compared to diesel-powered minigrids. This niche application for minigrids should be explored further.

5.2 Overall recommendations

Besides country level efforts to accelerate the minigrid development, there is much to be gained for each SAARC Member State through cooperation and collaboration at regional level. The study has suggested following specific recommendation/ action plan to foster cooperation in the region to achieve the above:

1. ***Regional Minigrid cooperation mechanism***: a platform to facilitate coordination and exchange of good practices and learnings among Member states. The mechanism could operate through a task force consisting of officials from relevant ministry, renewable energy department, public distribution utilities, regulatory authority of each SAARC Member State. The mechanism will allow representatives of Member States to interact and discuss on regular basis as well as take assistance from other Member States on development of policies and regulations, technical standards, among others. Member States of SAARC have signed SAARC framework agreement on Energy Cooperation in November 2014 to enhance cooperation in the energy sector by facilitating energy trade, development of efficient conventional and renewable energy projects as well as enable knowledge sharing and joint research. The cooperation mechanism can be built around this framework agreement to support minigrid projects in Member States.
2. ***Specialized course on design and operation of minigrids***: short term specialized course on minigrid design and operational aspects that can be offered to government officials, private sector players and renewable energy service companies in the SAARC Member States for their capacity building. The course would build on contemporary thinking and technologies available and used in minigrid sector. The course may be offered by recognized technical institutions in the SAARC Member States. The course should provide flexibility to tailor content where possible to the requirements of the SMS.
3. ***Finance facilitation desk/ unit***: an online e-platform to connect minigrid project developers, services providers, and financiers/investors. The facilitation desk would support the deployment of minigrid projects by helping project developers secure financing more efficiently and supporting investors and lenders to build stronger project portfolios. Multilateral, bilateral, and local financial institutions, project developers, service providers from the region may be registered themselves as partner of the platform based on some key criteria. The project developers will submit their project ideas and proposals to obtain support for project development and/or access to finance. Where feasible, the facilitation desk/ unit may support the project developers in meeting investors and lenders requirements, facilitating access to suitable financing and/or risk mitigation instruments, and other activities.

Table 2: Summary of Prospects, Drivers and Barriers with Specific Recommendations

Parameters / Countries	Prospects and drivers	Barriers	Recommendations
Afghanistan	• Only one-third of population with electricity access • Clear mandate given to MRRD by RE policy for development of minigrids; Ongoing efforts to set up 25 minigrids in the country by MRRD • GCF supporting the development of 8 minigrids as well as capacity building and development of regulatory documents • Strong enterprise demand in several provinces and presence of a strong renewable energy industry union	• No specific minigrid policy to stimulate the market • Weak enabling environment for private sector growth • Safety and security concerns associated with movement of goods and services • Lack of technical expertise/ support for operation and maintenance of minigrids	• National electricity utility DABS, and MRRD to jointly develop and introduce a least cost electrification master plan • Capacity building of key stakeholders and project developers on minigrid design and O&M • Creation of Business-to-Business network to facilitate AREU members in exploring collaborations and accessing technical know-how
Bangladesh	• Government's focus to reach 100% electrification via expansion of national grid; opportunities for minigrids in remote off-grid islands only • Target to generate 10% of electricity from RE sources	• No specific policy or strategy of the Government to develop minigrid projects • High minigrid tariff compared to tariff paid by the grid consumers • Land availability and restrictions on use of agricultural land	• Formulate and introduce a special policy for development of minigrids in remote areas • Upgrade existing minigrids and connect them to national grid; Government to purchase electricity from future minigrids and sell to consumers at grid tariff • Prioritize minigrid projects in the roadmap
Bhutan	• Reliability issue in electricity supply despite 100% electrification • Government's mandate to maintain 60% of the country's land under forest covers, thus offering preference to decentralized generation over expansion of T&D lines • Increased demand for reliable electricity for rural enterprises • Interest of Government to produce RE electricity for local consumption, to enable more export of grid electricity for revenue generation	• No dedicated policies or targets for electricity generation via minigrids • Public electric utilities unable to generate fair returns on their assets, resulting in private sector's unwillingness to enter the sector • Lack of technical and financial expertise to develop and operate minigrid	• Formulate minigrid policy or regulation with clear guidelines on future arrival of national grid and measures for de-risking minigrid business • Set up national target for minigrid projects in the country in terms of capacity or numbers • Formulate tariff regulation for minigrid sector to ensure fair return on investment • Capacity building trainings and vocational programs on minigrid • Replicate the lessons learnt from success stories from Nepal since the geographies are same
India	• 5.5 million people still lack access to electricity despite achieving 100% electrification; reliability and quality of electricity remains an issue in rural areas • Minigrid policies in two states driving private sector interest; minigrids being promoted to provide electricity for public institutions and enterprise development in rural areas • Diesel based minigrids being converted/ hybridized into RE minigrids in large and densely populated islands and hilly areas	• Lack of clarity in policies regarding future grid arrival at the place of minigrid site • Electrification of public infrastructures not included in the state minigrid policies • Need to design and implement innovative business models to promote minigrid • Minigrid power expensive compared to power from the grid • Lack of funds to finance the operational expenses as well as lack of patient capital to finance minigrids	• Draft national minigrid policy should be approved; other states to also develop specific minigrid policies • Develop business models around unreliable, poor-quality supply and inability to operate enterprise loads on the national grid • Engage with community from the beginning of the project to increase uptake of productive uses • Promote grid interactive minigrid projects • Design and implementation of innovative payment collection mechanism

Parameters / Countries	Prospects and drivers	Barriers	Recommendations
	• According to ESMAP, around 1,905 minigrids are planned		
Maldives	• Government promoting hybridization of diesel minigrids with RE to reduce dependency on diesel fuel and reduce overall electricity cost • Target to reach net zero GHG emissions in the country by 2030 • Hybridization of 14 island grids being done under WB-ARISE project and installation of RE hybrid minigrid in 160 inhabited islands under ADB - POISED project	• Need to develop robust energy sector plans focusing on hybrid renewable energy projects • Limited opportunities for direct public financing. Commercial bank financing or private financing in its nascent stage • Private sector companies reluctant to accept the risks associated with renewable energy technologies • Limited experience and expertise available locally	• Develop concrete energy expansion plans for the deployment of additional renewable energy hybrid projects • Implementation of PPA arrangement in future projects to mobilize private investment • Provide technical and vocational training on renewable energy technologies and projects
Nepal	• 7% of the population lack access to electricity • Strong interest for minigrid development from rural communities as well as local governments • Target of 12% RE generation in total energy mix by 2024 • Government targeting to install solar minigrid projects in mountains and upper hill regions • WB program to mobilize RESCOs for minigrid development • Improved know-how of minigrid design and operation in the country	• Most of the minigrids implemented cater to basic lighting and fan only, with less focus on future energy demand and productive loads • Minigrid power expensive compared to power from the grid • Policy for grid connection of minigrids still ambiguous despite successful interconnection of several MHPs and minigrids • Project developers continue to struggle to achieve financial closure on time	• Develop future minigrid projects considering anchor loads and future demand of electricity in households • Minigrid planning process to include community from the beginning to increase uptake of productive uses • Develop measures to reduce minigrid-based electricity tariffs at a rate comparable to grid-based tariffs • Develop guidelines for minigrid implementation including design, tendering, construction, and operation
Pakistan	• Around 45 million people without access to electricity; long hours of load shedding in several grid connected areas • Target of at least 20% and 30% RE generation capacity by 2025 and 2030 respectively • RE policy prioritizing mini/microgrid solutions as key intervention to accomplish the targets • Minigrids tariffs lower for domestic consumers, compared to grid electricity tariff • Private sector companies and not-for-profit companies' interest to develop off-grid projects	• Lack of institutional support at the national level for rural electrification and distributed renewable energy projects • Lack of policies and regulations for minigrid sector, necessary to build private sector interest • Dearth of private-sector investment in rural areas • Lack of standardization in minigrid design & installation • Lack of technical expertise available for O&M of minigrids	• Develop a least-cost approach for rural electrification outlining potential sites for minigrid • Set in place legislation/regulations covering permitting & licensing requirements, grid arrival rules, among others • Establish financing programs or schemes utilizing government or donor funding available in the country • Replicate the SOLshare model for providing access to electricity in remote and hard to reach locations • Develop technical standards and grid connection codes; Implement capacity building programs

Parameters / Countries	Prospects and drivers	Barriers	Recommendations
Sri Lanka	• Achieved 100% electrification and current focus on centralized grid-based delivery supplemented by utility scale RE projects • Potential and interest of government to energize outer islands running on diesel generators through RE hybrid minigrids	• Limited scope for development of minigrids due to government's focus on centralized grid-based delivery • Existing electricity regulatory provision restricts electricity transmission and distribution functions to CEB only	• Develop policy to support tail end generation and enterprise development using RE minigrids • Promote and implement RE hybrid minigrids to provide electricity at least cost compared to diesel-powered minigrids to outer islands

6 BIBLIOGRAPHY

100% Renewable Energy Atlas . (2019, 01 21). *Bamiyan, Afghanistan*. Retrieved from 100% Renewable Energy Atlas : https://www.100-percent.org/bamiyan-afghanistan/

Aaron Zvi. (n.d.). *How-to-calculate-carbon-dioxide-emissions-from-a-diesel-generator*. Retrieved from Hunker website: https://www.hunker.com/12284423/how-to-calculate-carbon-dioxide-emissions-from-a-diesel-generator

Abdul Haq Omari. (2021, April 10). *Nangarhar: Electricity to be Bought With Prepaid Cards*. Retrieved from Tolo News: https://tolonews.com/business-171272

Acumen. (2021, August 5). *Investments/ companies*. Retrieved from Acumen: https://acumen.org/?investment=rve-sol

ADB. (2014). *Project Administration Manual: POISED.* ADB. Retrieved from https://www.adb.org/projects/documents/preparing-outer-islands-sustainable-energy-development-project-pam

ADB. (2016). *Detailed Description of Project Components.* ADB. Retrieved from https://www.adb.org/sites/default/files/linked-documents/49216-002-sd-01.pdf

ADB. (2017). *100% Electricity Generation through Renewable Energy by 2050: Assessment of Sri Lanka's Power Sector.* ADB. Retrieved from https://www.adb.org/publications/electricity-generation-renewable-energy-2050-sri-lanka

ADB. (2017). *Deployment of Hybrid Renewable Energy Systems in Mini Grids.* Manila: ADB. Retrieved from https://www.adb.org/sites/default/files/institutional-document/376151/hybrid-renewable-energy-systems-minigrids.pdf

ADB. (2017). *Developing Renewable Energy Mini Grids in Myanmar.* Manila: ADB. Retrieved from https://www.adb.org/sites/default/files/institutional-document/391606/developing-renewable-mini-grids-myanmar-guidebook.pdf

ADB. (2019). *Sri Lanka Energy Sector Assessment, Strategy, and Roadmap.* ADB. Retrieved from https://www.adb.org/sites/default/files/institutional-document/547381/sri-lanka-energy-assessment-strategy-road-map.pdf

ADB. (2020). *A Brighter Future for Maldives Powered by Renewables - Roadmap for the energy sector 2020- 2030.* ADB. Retrieved from https://www.adb.org/sites/default/files/publication/654021/renewables-roadmap-energy-sector-maldives.pdf

ADB. (2020, September 30). *ADB Approves $110 Million Grant to Enhance Power Supply in Afghanistan*. Retrieved from ADB: https://www.adb.org/news/adb-approves-110-million-grant-enhance-power-supply-afghanistan

ADB. (2021, May 26). *Helping Sri Lanka to go green - Project Result / Case Study* . Retrieved from ADB: https://www.adb.org/results/helping-sri-lanka-go-green

ADB Institute. (2018). *Green Finance in Pakistan: Barriers and Solutions.* ADB Institute. Retrieved from https://www.adb.org/sites/default/files/publication/460346/adbi-wp880.pdf

ADB, & ITP India. (2017). *Renewable Energy Roadmap for Afghanistan 2032.* Manila: ADB. Retrieved from https://policy.asiapacificenergy.org/sites/default/files/Renewable%20Energy%20Roadmap%20for%20Afghanistan%20RER2032.pdf

Afghanistan Renewable Energy Companies Union. (n.d.). *About AREU*. Retrieved from Afghanistan Renewable Energy Companies Union: https://areu.af/about-us/about-areu/

Agenbroad, J., Carlin, K., Ernst, K., & Doig, S. (2018). *Minigrids in the Money: Six Ways to Reduce Minigrid Costs by 60% for Rural Electrification.* Nigeria: Rocky Mountain Institute. Retrieved from https://rmi.org/wp-content/uploads/2018/12/rmi-seeds-minigrid-report.pdf

Ajmal Haidari. (2020). Renewable Energy (Solar) and its Impact on Rural Households' Welfare (Case Study of Badakhshan Province, Afghanistan). *Journal of Economics and Business, Vol.3 No.2*. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3649406

Alisha Pinto, Yoo, H. K., Portale, E., & Rysankova, D. (2019). *Nepal Beyond Connections: Energy Access Diagnostic Report Based on the Multi-Tier Framework.* World Bank Group. Retrieved from https://energydata.info/dataset/e4526938-1f13-45b2-b4f4-467fbb02b722/resource/35124cc5-0ebf-49c7-b7df-ec7fc961eb1d/download/mtf-energy-access-country-diagnostic-report_nepal-9.2019.pdf

Alternative Energy Development Board . (2019). *Alternative & Renewable Energy Policy.* Government of Pakistan. Retrieved from https://www.aedb.org/images/ARE_Policy_2019_-_Gazette_Notified.pdf

Alternative Energy Promotion Center. (2019). *Progress at a Glance: A Year in Review FY 2075/76 (2018/19).* Kathmandu: Alternative Energy Promotion Center. Retrieved from https://www.aepc.gov.np/uploads/docs/progress-at-glance-a-year-in-review-fy-207576-201819-1572879503.pdf

Alternative Energy Promotion Centre . (2016). *Piloting sustainability monitoring for micro hydropower plants.* Kathmandu. Retrieved from https://www.aepc.gov.np/rerl/public/uploads/documents/QPYUelyFoWy5600f1iCidbu8wXB18hAt2z32RjnG.pdf

Alternative Energy Promotion Centre . (2017). *Establishing Sustainable Model for Financing Community-based Micro-hydro Projects (MHP) through Local Financial Institutions.* Retrieved from https://www.aepc.gov.np/rerl/public/uploads/documents/JX2wah8VDqBiHYWKIZAxeeRu52nhVEzQ4ixk53Ay.pdf

Alternative Energy Promotion Centre . (2019). *Mini Grid Special Program Operation Rules.* Kathmandu: Alternative Energy Promotion Centre . Retrieved from https://www.aepc.gov.np/uploads/docs/l-l-1577767651.pdf

Anu Bhambhani. (2020, October 20). *Study sees 40 GW solar energy potential for Bangladesh*. Retrieved from Taiyang News: http://taiyangnews.info/markets/study-sees-40-gw-solar-energy-potential-for-bangladesh/

ARE. (2019). *Private Sector Driven Business Models for Clean Energy Mini-Grids - Lessons learnt from South and South-East-Asia.* Brussels: Alliance for Rural Electrification. Retrieved from https://www.ruralelec.org/sites/default/files/2020-02-06%20-%20Private%20Sector%20Driven%20Business%20Models%20of%20Clean%20Energy%20Mini-Grids%20in%20SEA%20-%20Final.pdf

ARE, & UNIDO ITPO. (2021). *Decentralised Renewable Energy Innovations to Boost Agri-Sector Productivity & Address Global Food System Challenges.* ARE, UNIDO ITPO. Retrieved from https://www.ruralelec.org/sites/default/files/2020-02-05%20-%20DRE%20%26%20Agri%20Publication%20-%20Final.pdf

Ashden. (2020). *SOLShare / Giving villagers in Bangladesh the power to trade electricity*. Retrieved from Ashden: https://ashden.org/winners/solshare/

Ashden. (n.d.). *Sarhad Rural Support Programme (SRSP) / The power of water brings new life to mountain villages*. Retrieved from Ashden: https://ashden.org/winners/sarhad-rural-support-programme-srsp-1/

Bangladesh, G. o. (2020). *National Solar Energy Roadmap 2021-2041.* Dhaka: Government of Bangladesh.

Beath, A., Christia, F., & Enikolopov, R. (2015). *The National Solidarity Program: Assessing the Effects of Community-Driven Development in Afghanistan.* Washington DC: World Bank Group. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/22653/Infrastructure0developing0economies.pdf?sequence=1&isAllowed=y

Bhupendra Shakya. (2012). Mini Grid Development in Nepal:An Experience from RERL. *Proceeding of Workshop on Experience sharing of Mini Grid and Biomass Gasifi cation.* Kathmandu. Retrieved from https://www.researchgate.net/publication/286580026_Mini_Grid_Development_in_Nepal_An_Experience_from_RERL

Bhushan, C., Bharti, P., Sreenivasan, P., Singh, M., Jhawar, P., Koshy, S. M., & Sambyal, S. (2019). *The State of Renewable Energy in India.* New Delhi: Centre for Science and Environment. Retrieved from https://shaktifoundation.in/wp-content/uploads/2019/04/State-of-Renewable-Energy-in-India.pdf

Bhutan Electricity Authority. (2016). *Tariff Determination Regulation.* Bhutan: Royal Government of Bhutan. Retrieved from https://www.moea.gov.bt/wp-content/uploads/2017/07/dhps2-1.pdf

Bhutan Power Corporation. (2020). *Meeting Bhutan's Electricity Needs.* Bhutan: Bhutan Power Corporation. Retrieved from https://www.bpc.bt/wp-content/uploads/2021/06/BPC-Annual-Report-2020.pdf

Bhutta, Z. (2021, February 13). *Govt jacks up power tariff by Rs1.95*. Retrieved from The Express Tribune: https://tribune.com.pk/story/2283789/govt-jacks-up-power-tariff-by-rs195

BNEF, & SEforAll. (2020). *State of the Global Mini-Grids Market Report.* BNEF, SEforAll. Retrieved from https://www.seforall.org/system/files/2020-06/MGP-2020-SEforALL.pdf

Burger, C., & Weinmann, J. (2020). Business models beyond subsidies –which core competencies are needed? In C. Burger, A. Froggatt, C. Mitchell, & J. Weinmann, *Decentralised Energy — a Global Game Changer* (pp. 177–260). London: Ubiquity Press. Retrieved from https://www.ubiquitypress.com/site/chapters/10.5334/bcf.k/download/3998/

Business Call to Action. (n.d.). *Members*. Retrieved from Business Call to Action: https://www.businesscalltoaction.org/member/nizam-energy

CDKN. (2019). *Solar mini grids: Investment case Bangladesh.* Climate and Development Knowledge Network. Retrieved from https://cdkn.org/wp-content/uploads/2019/09/Investment-case-solar-mini-grids.pdf

Central Renewable Energy Fund . (2017). *Vendor Finance Challenge Fund.* Kathmandu. Retrieved from https://www.aepc.gov.np/rerl/public/uploads/documents/XWQscyuu3U3yD63njF5MvGog9SS5ml75w12C2zzS.pdf

Centre for Science and Environment. (2020). *Renewabe energy factsheet 7 Mini Grids.* Centre for science and environment. Retrieved from https://cdn.cseindia.org/userfiles/07Factsheet-Mini-Grid.pdf

Ceylon Electricity Board. (2021). *Statistical Digest 2020.* CEB. Retrieved from https://ceb.lk/front_img/img_reports/1626946210CEB-Statistical_Digest-Form-2020-Web_Version.pdf

Ceylon Electricity Board. (n.d.). *Tariff Plan*. Retrieved from Ceylon Electricity Board: https://ceb.lk/commercial-tariff/en

Chris Greacen. (2019). *Mini Grid Costing and Innovation: Mini grids for half a billion people.* World Bank. Retrieved from https://atainsights.com/wp-content/uploads/2019/06/4.A.Chris-Greacen.World-Bank-consultant-notes.pdf

CIF. (2014, May 28). *Afghanistan eoi*. Retrieved from Climate Investment Funds: https://www.climateinvestmentfunds.org/sites/cif_enc/files/meeting-documents/afghanistan_eoi_0.pdf

CIF. (2019). *POISED CIF-GDI Delivery Challenge Case Study.* Climate Investment Funds. Retrieved from https://www.climateinvestmentfunds.org/sites/cif_enc/files/knowledge-documents/66436_191219_maldives_case_study_v7s.pdf

CLEAN, & Margdarshan Advisory & Consultancy Services. (2020). *Sensitizing financial institutions towards lending to decentralized renewable energy enterprises and end-users.* New Delhi: CLEAN. Retrieved from https://www.thecleannetwork.org/pdf/financial-report-final.pdf

Collaboration on Energy and Environmental Markets. (n.d.). *Tokelau Case Study: Part 1 of a series on Energy Resilience in Pacific Island Countries and Territories.* Collaboration on Energy and Environmental Markets. Retrieved from http://www.ceem.unsw.edu.au/sites/default/files/event/documents/4-PICTsEnergyResiliencePlanningWorkshopTokelauBruce_0.pdf

Dawa Gyelmo. (2021, October 6). *Bhutan looks beyond hydropower to solar.* Retrieved from The Third Pole: https://www.thethirdpole.net/en/energy/bhutan-looks-beyond-hydropower-to-solar/

Duggal, S. (2021, June 22). *Solar energy news*. Retrieved from Saur Energy International: https://www.saurenergy.com/solar-energy-news/the-maldives-opens-pre-qualification-for-11-14-mw-solar-pv-tender

Ecowas Centre for Renewable Energy and Energy Efficiency. (2020). *TOR - Technical Assistance to ensure the long-term sustainability of the clean energy mini-grid projects in Bambadinca and Bissorã in Guinea-Bissau.* Ecowas Centre for Renewable Energy and Energy Efficiency. Retrieved from http://www.ecreee.org/sites/default/files/procurment/attachments/200603_tor_gefgb-mini-grids.pdf

Efficiency for Access Coalition. (2021). *Business Model Innovations Addressing Environmental Sustainability and Circularity: Case Studies.* Efficiency for Access Coalition. Retrieved from https://endeva.org/publication/business-model-innovations-addressing-environmental-sustainability-and-circularity

energymeteo. (2020). *energymeteo*. Retrieved from products/power_forecasts/wind-solar-power-forecasts.php: https://www.energymeteo.com/products/power_forecasts/wind-solar-power-forecasts.php

Energypedia. (n.d.). *Pakistan Energy Situation*. Retrieved from Energypedia: https://energypedia.info/wiki/Pakistan_Energy_Situation

Engineering Consultancy for Constructive Development Efforts. (2013). *Techno-Socio-Economic Study of Baglung Mini Grid.* Engineering Consultancy for Constructive Development Efforts. Retrieved from Techno-Socio-Economic Study of Baglung Mini Grid

ESMAP. (2017). *Benchmarking study of solar PV mini grids investment costs: preliminary results.* World Bank Group. Retrieved from https://documents1.worldbank.org/curated/en/569621512389752401/pdf/121829-ESM-PVHybridminigridsCostingbenchmarkTTAESMAPConfEdtemplateDecv-PUBLIC.pdf

ESMAP. (2017). *Ghana mini-grids for last mile electrification.* ESMAP. Retrieved from https://www.eca-uk.com/wp-content/uploads/2017/08/ESMAP-Ghana_Mini_grids_for_last_Mile_Electrification_Optimized.pdf

ESMAP. (2017). *Mini grids in Bangladesh: A case study of an incipient market.* Washington DC: World Bank. Retrieved from https://documents1.worldbank.org/curated/en/669331512390210193/pdf/ESM-aBangladeshCountryCaseStudy-PUBLIC.pdf

ESMAP. (2018). *Mini grids and the arrival of the main grid: Lessons from Cambodia, Sri Lanka, and Indonesia.* Washington DC: World Bank. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/29018/134326.pdf?sequence=6&isAllowed=y

ESMAP. (2019). *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers. Executive Summary.* Washington DC: World Bank. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/31926/Mini-Grids-for-Half-a-Billion-People-Market-Outlook-and-Handbook-for-Decision-Makers-Executive-Summary.pdf?sequence=1&isAllowed=y

ESMAP. (2019). *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers. Executive Summary.* Washington DC: World Bank.

EU-GIZ ACSE . (2016). *Case Study: Reducing Diesel Cost with Solar Hybrid Mini-Grids in Tokelau.* EU-GIZ ACSE Programme. Retrieved from http://acsepacific.org/wp-content/uploads/2017/03/GIZ-ACSE_Tokelau-FS_22March2017.pdf

Foster, R., Woods, T., & Hoffbeck, I. (2015, November 08). Bamiyan 1 MWp Solar Mini-Grid (Afghanistan). *Solar World Congress (SWC).* International Solar Energy Society (ISES). Retrieved from Research Gate: https://www.researchgate.net/profile/Robert-Foster-

17/publication/283915024_Bamiyan_1_MWp_Solar_Mini-Grid_Afghanistan/links/564a207908ae44e7a28d96dd/Bamiyan-1-MWp-Solar-Mini-Grid-Afghanistan.pdf
GardaWorld. (2021, May 12). *Afghanistan: Power disruptions likely in Kabul following May 12 attack on transmission towers /update 1*. Retrieved from Garda World: https://www.garda.com/crisis24/news-alerts/477841/afghanistan-power-disruptions-likely-in-kabul-following-may-12-attack-on-transmission-towers-update-1
GCF. (2020). *Funding Proposal: Afghanistan Rural Energy Market Transformation Initiative – Strengthening Resilience of Livelihoods Through Sustainable Energy Access.* Green Climate Fund. Retrieved from https://www.greenclimate.fund/sites/default/files/document/fp129-undp-afghanistan_0.pdf
GCF. (n.d.). *FP129 - Afghanistan Rural Energy Market Transformation Initiative – Strengthening Resilience of Livelihoods Through Sustainable Energy Access*. Retrieved from Green Climate Fund: https://www.greenclimate.fund/project/fp129
GIZ IDEA . (2017). *Enabling PV Afghanistan.* GIZ. Retrieved from https://www.solarwirtschaft.de/fileadmin/user_upload/report_enabling_pv_afg.pdf
GNESD. (2014). *Renewable energy-based rural electrification: The Mini-Grid Experience from India.* New Delhi: The Energy and Resources Institute (TERI) for Global Network on Energy for Sustainable Development (GNESD). Retrieved from https://unepdtu.org/wp-content/uploads/2014/09/renewable-energy-based-rural-electrification-the-mini-grid-experience-from-india.pdf
Government of Afghanistan. (2013). *Afghanistan Rural Renewable Energy Policy.* Kabul: Islamic Rebuplic of Afghanistan. Retrieved from https://policy.asiapacificenergy.org/sites/default/files/4.3-Rural-Renewable-Energy-Policy.pdf
Government of Afghanistan. (2015). *Renewable Energy Policy.* Kabul: Ministry of Energy and Water. Retrieved from https://policy.asiapacificenergy.org/sites/default/files/Afghanistan-Renewable-Energy-Policy-English-and-Dari.pdf
Government of Bangladesh. (2020). *National Solar Energy Roadmap 2021-2041.* Dhaka: Government of Bangladesh. Retrieved from sreda.gov.bd/sites/default/files/files/sreda.portal.gov.bd/notices/fba98896_568a_4efd_a48b_8d92bfc04049/2020-10-22-17-12-7b0e5a0c0dabd4c17492bcf3bd7488b4.pdf
Government of Bangladesh. (2020). *National Solar Energy Roadmap 2021-2041.* Dhaka: Government of Bangladesh.
Graber, S., Narayanan, T., Alfaro, J., & Palit, D. (2019). Perceptions towards solar mini-grid systems in India: A multistakeholder analysis. *Natural Resources Forum 43*, 253–266. Retrieved from https://css.umich.edu/sites/default/files/publication/CSS19-49.pdf
GSEP. (2017). *The Dhiffushi Solar Ice Project in the Republic of Maldives.* Global Sustainable Electricity Partnership (GSEP). Retrieved from https://www.globalelectricity.org/content/uploads/FINAL-Dhiffushi-interactive-publication.pdf
Harsha Wickramasinghe. (2014). *Off-grid Village Hydro Schemes in Sri Lanka: A success story.* Sri Lanka Sustainable Energy Authority. Retrieved from https://www.dmu.ac.uk/documents/technology-documents/research-faculties/oasys/project-activities/sustainable-energy-for-all---regulation-and-govern/experience-from-sri-lanka---mr-harsha-wickramasinghe.pdf
IEA. (2021). *Tracking SDG7: The energy progress report.* Washington DC: World Bank. Retrieved from https://www.irena.org/publications/2021/Jun/Tracking-SDG-7-2021
IEA. (n.d.). *SDG7: Data and Projections. Access to electricity*. Retrieved from IEA: https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity

IEA. (n.d.). *Sri Lanka Key Energy Statistics 2018*. Retrieved from IEA: https://www.iea.org/countries/sri-lanka

IFC. (2017). *Operational and Financial Performance of Mini-Grid DESCOS.* IFC. Retrieved from https://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/IFC_Minigrids_Benchmarking_Report_Single_Pages_January_2017.pdf

IGC. (2019, September 9). *Flexible payment plans for improved access to off-grid energy in Pakistan*. Retrieved from International Growth Centre: https://www.theigc.org/blog/flexible-payment-plans-for-improved-access-to-off-grid-energy-in-pakistan/

Infrastructure Development Company Limited . (2020). *A year of resilience: Redesigning tomorrow.* Bangladesh: IDCOL. Retrieved from https://idcol.org/annual_report/IDCOL-Annual-Report_2020.pdf

Institute for Transformative Technologies. (n.d.). *Solar mini-grids*. Retrieved from Institute for transformative technologies: https://transformativetechnologies.org/portfolio/solar-mini-grids/

IRENA. (2016). *Innovation Outlook Renewable Mini-Grids.* Abu Dhabi: IRENA. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Innovation_Outlook_Minigrids_2016.pdf

IRENA. (2018). *Renewables Readiness Assessment: Pakistan.* International Renewable Energy Agency. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_RRA_Pakistan_2018.pdf

IRENA. (2019). *Renewable Readiness Assessment: Kingdom of Bhutan.* Abu Dhabi: International Renewable Energy. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Dec/IRENA_RRA_Bhutan_2019.pdf

IRENA. (2019). *Renewables Readiness Assessment.* Abu Dhabi: International Renewable Energy Agency.

IRENA. (2020). *Renewable Power Generation Costs in 2019.* Abu Dhabi: International Renewable Energy Agency. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf

IRENA. (2021). *Renewable Power Generation Costs in 2020.* Abu Dhabi: International Renewable Energy Agency. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jun/IRENA_Power_Generation_Costs_2020.pdf

ITP Australia. (2013). *Tokelau Renewable Energy Project Review.* NZ MFAT. Retrieved from http://prdrse4all.spc.int/system/files/energy_tokelau_pv_system_review_-_final.pdf

ITP Australia. (n.d.). *Tokelau Renewable Energy Expansion Project*. Retrieved from ITP Australia: https://itpau.com.au/projects/tokelau-renewable-energy-expansion-project/

Jaffer, H. (2016). *MINIGRIDS (India) Current Challenges and Future Strategies.* Tata Center for Technology and Design. Retrieved from https://www.selcofoundation.org/wp-content/uploads/2017/04/IAP_MinigridsIndiaReportTATA_Huda.pdf

James Knuckles. (2019). *State of the mini grid market globally - Mini Grids for Half a Billion People.* World Bank Group. Retrieved from https://atainsights.com/wp-content/uploads/2019/06/2.B.James_.Knuckles.World-Bank-1.pdf

Kapila Subasinghe. (2017). *Grid Interconnection of Off-grid Community-based Projects: What happened when the Grid Arrived - Sri Lankan Experience.* DFCC Bank. Retrieved from https://energypedia.info/images/f/f2/Grid_Interconnection_-_Sri_Lanka.pdf

M Ramesh. (2019, April 23). *The microgrid revolution in Bihar*. Retrieved from The Hindu Business Line: https://www.thehindubusinessline.com/specials/clean-tech/the-microgrid-revolution-in-bihar/article26924569.ece

MGP. (2021, August 5). *Who we are*. Retrieved from Mini-Grids Partnership: https://minigrids.org/about/

Ministry of Energy, Water Resources and Irrigation. (2021). *Annual Development Program FY 2078/79.* Kathmandu: Government of Nepal. Retrieved from https://www.moewri.gov.np/storage/listies/July2021/annual-development-program-2078-79-with-cover.pdf

Ministry of Environment and Energy. (2013). *Maldives SREP Investment Plan.* Ministry of Environment and Energy. Retrieved from https://policy.asiapacificenergy.org/sites/default/files/Maldives%20SREP%202013-2017%20%28EN%29.pdf

Ministry of Finance. (2021). *Budget Speech 2078/79.* Kathmandu: Ministry of Finance. Retrieved from https://www.mof.gov.np/site/publication-detail/3064

Ministry of Finance. (2021). *Economic Survey 2077/78.* Kathmandu: Government of Nepal. Retrieved from https://www.mof.gov.np/uploads/document/file/1633341980_Economic%20Survey%20(Engslish)%202020-21.pdf

Ministry of Finance. (n.d.). *Background*. Retrieved from Office of the Deputy Minister for Policy, Ministry of Finance: http://policymof.gov.af/home/national-priority-programs/background/

Ministry of Law and Justice. (2003). *The Electricity Act.* Government of India. Retrieved from https://cercind.gov.in/Act-with-amendment.pdf

Ministry of Mahaweli Development and Environment. (2016). *Nationally Determined Contributions.* Government of Sri Lanka. Retrieved from https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Sri%20Lanka%20First/NDCs%20of%20Sri%20Lanka.pdf

Ministry of New and Renewable Energy. (2016). *Draft National Policy on RE based Micro and Mini Grids.* Government of India. Retrieved from http://www.indiaenvironmentportal.org.in/files/file/draft-national-Mini_Micro-Grid-Policy.pdf

Ministry of New and Renewable Energy. (n.d.). *Bio energy - Current status*. Retrieved from MNRE Website: https://mnre.gov.in/bio-energy/current-status

Ministry of New and Renewable Energy. (n.d.). *Small Hydro Current Status*. Retrieved from MNRE Website: https://mnre.gov.in/small-hydro/current-status

Ministry of New and Renewable Energy. (n.d.). *Solar Energy: Overview*. Retrieved from MNRE: https://mnre.gov.in/solar/current-status/

Ministry of New and Renewable Energy. (n.d.). *Wind Current Status*. Retrieved from MNRE Website: https://mnre.gov.in/wind/current-status/

Ministry of Power. (2016). *Tariff Policy.* Government of India. Retrieved from https://powermin.gov.in/sites/default/files/webform/notices/Tariff_Policy-Resolution_Dated_28012016.pdf

Ministry of Power, Energy and Business Development. (2019). *National Energy Policy and Strategies of Sri Lanka.* Government of Sri Lanka. Retrieved from http://www.energy.gov.lk/images/resources/downloads/national-energy-policy-2019-en.pdf

Mlinda. (2018). *Renewable Energy for Rural Communities*. Retrieved from Mlinda: https://www.mlinda.org/democratising-energy-supply/

MOXA. (2019). *cdn-cms.azureedge.net.* Retrieved from Moxa/media/Global/Site%20Content/Case%20Studies/PDF/thingnario-EN_4.pdf: https://cdn-cms.azureedge.net/Moxa/media/Global/Site%20Content/Case%20Studies/PDF/thingnario-EN_4.pdf

Nafees Ahmad Khan. (2021). *Presentation - Renewable Energy Program.* Pakistan Poverty Alleviation Fund .

National Electric Power Regulatory Authority . (2020). *State of Industry Report.* NEPRA.

National Electric Power Regulatory Authority. (2020). *State of Industry Report.* National Electric Power Regulatory Authority. Retrieved from https://nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202020.pdf

Nelis Global. (2020, November 3). *SOLshare: Driving renewables adoption in Bangladesh by monetizing solar energy for all*. Retrieved from Nelis Global: https://socialmedia-nelis.medium.com/solshare-driving-renewables-adoption-in-bangladesh-by-monetizing-solar-energy-for-all-a39d3fe162ec

New Zealand Ministry of Foreign Affairs and Trade . (2013). *Tokelau Renewable Energy Project Case Study March 2013.* New Zealand Ministry of Foreign Affairs and Trade. Retrieved from http://prdrse4all.spc.int/system/files/trep-case-study.pdf

NREL. (2010). *Afghanistan Resource Data and Geospatial Toolkit (GsT).* National Renewable Energy Laboratory.

Pakistan Poverty Alleviation Fund . (2021). *Renewable energy programme.* Pakistan Poverty Alleviation Fund. Retrieved from https://www.ppaf.org.pk/HRE-programme

Power Technology. (2013, February 12). *Tokelau – the world's first solar power sufficient nation*. Retrieved from Power Technology: https://www.power-technology.com/features/featuretokelau-world-first-solar-power-sufficient-nation/

Power Technology. (2016, September 25). *Ghazanfar Group signs agreement to develop new gas power plant in Afghanistan*. Retrieved from Power Technology: https://www.power-technology.com/uncategorised/newsghazanfar-group-signs-agreement-to-develop-new-gas-power-plant-in-afghanistan-5014418/

Priti Kumar. (2015). *Nepal - Scaling up electricity access through mini and micro hydropower applications : a strategic stock-taking and developing a future roadmap.* Washington, D.C.: World Bank Group. Retrieved from https://documents.worldbank.org/en/publication/documents-reports/documentdetail/650931468288599171/nepal-scaling-up-electricity-access-through-mini-and-micro-hydropower-applications-a-strategic-stock-taking-and-developing-a-future-roadmap

Priyavrat Bhati, & Mandvi Singh. (2018). *Mini-grids in Uttar Pradesh: Policy Lessons.* New Delhi: Centre for Science and Environment. Retrieved from http://cdn.cseindia.org/attachments/0.58005500_1530179433_Mini-grid-in-UP-report.pdf

Renewable Energy for Rural Livelihood. (2019). *RERL Quarterly Updates.* Kathmandu: Renewable Energy for Rural Livelihood. Retrieved from http://www.aepc.gov.np/rerl/public/uploads/documents/HVhJgfdN3s18saWHYcxK1wEJALl2h2cIU6joooHu.pdf

Renewable Energy for Rural Livelihood. (2020). *Annual Progress Report.* Kathmandu. Retrieved from http://www.aepc.gov.np/rerl/public/uploads/documents/My504x18JCxI0hwAPt66NL7zCUfylu9BloSGvmdB.pdf

Renewable Energy for Rural Livelihood. (2020). *Intervention in renewable energy for sustainable development.* Kathmandu: Renewable Energy for Rural Livelihood Program. Retrieved from http://www.aepc.gov.np/rerl/public/uploads/documents/3YDLLh8AGKhgAjnab9cW5y4psuftriw8Hf9yes27.pdf

Reon Energy. (n.d.). *Uncategorized*. Retrieved from Reonenergy: https://www.reonenergy.com/are-solar-microgrids-a-solution-to-pakistans-energy-crisis/

Rockefeller Foundation. (2021, August 19). *Smart Power India* . Retrieved from Smart Power India : https://smartpowerindia.org

Royal Government of Bhutan. (2001). *Electricity Act of Bhutan.* Bhutan: Royal Government of Bhutan. Retrieved from https://www.nab.gov.bt/assets/uploads/docs/acts/2014/Electricity_act_2001_Eng.pdf

Royal Government of Bhutan. (2013). *Alternative Renewable Energy Policy.* Bhutan: Royal Government of Bhutan. Retrieved from https://www.moea.gov.bt/wp-content/uploads/2017/07/Final-Alternative-RE-Policy-April-2013.pdf

Saleh, N. (2019, November 7). *Country Report Pakistan*. Retrieved from Energy Democracy: https://energy-democracy.org/mini-grids-in-pakistan-bottom-up-option-for-renewable-electrification/#_ftn1

Santosh Rai. (2019, September). Introduction to RE Mini Grid Projects in Nepal. Kathmandu. Retrieved from https://energypedia.info/images/6/6a/Session_0_Introduction_AEPC_Mr._Rai_090419.pdf

Saral Urja Nepal. (2021, July 29). *Project details - Dubung*. Retrieved from Saral Urja: http://www.saralurja.com/project-details-dubung.php#details

SE4All. (2012). *Rapid Assessment Gap Analysis.* Bhutan: Royal Government of Bhutan. Retrieved from https://www.seforall.org/sites/default/files/Bhutan_RAGA_EN_Released.pdf

Smart Power India. (First Edition). *Demand Generation for Solar mini grid.* Haryana: Smart Power India.

Solano-Peralta, M., Moner-Girona, M., van Sark, W., & Vallve, X. (2009). "Tropicalisation" of Feed-in Tariffs: A custom-made support scheme for hybrid PV/diesel systems in isolated regions. *Renewable and Sustainable Energy Reviews*, 13(9):2279-2294. Retrieved from Researchgate website: https://www.researchgate.net/figure/a-LCOE-for-the-different-PV-scenarios-compared-to-the-diesel-generation-system-with_fig8_223178620#:~:text=The%20LCOE%20for%20the%20diesel,with%20diesel%20market%20prices%20(Fig.

SOLshare. (n.d.). *From energy access in Bangladesh to the future of energy utilities globally* . Retrieved from SOLshare: https://me-solshare.com/

SOLshare. (n.d.). *What we do*. Retrieved from SOLshare website: https://me-solshare.com/what-we-do/

Sri Lanka Sustainable Energy Authority. (2020). *Renewable Energy Resource Development Plan 2021-2026.* Sri Lanka Sustainable Energy Authority. Retrieved from http://www.energy.gov.lk/images/renewable-energy/renewable-energy-resource-development-plan-en.pdf

SteamaCo. (2020). *off-grid-smart-metering-platform*. Retrieved from SteamaCo: https://steama.co/off-grid-smart-metering-platform

Sushil Sah. (2019, November 25). *Power-Less to Powerful.* Retrieved from World Bank: https://www.worldbank.org/en/news/feature/2019/11/25/power-less-to-powerful

Sustainable and Renewable Energy Development Autho. (n.d.). *National Database of Renewable Energy*. Retrieved 07 07, 2021, from SREDA: http://www.renewableenergy.gov.bd/index.php?id=7

Sustainable and Renewable Energy Development Authority. (2021, June 17). *Solar Home System*. Retrieved from SREDA website: http://www.sreda.gov.bd/site/page/61db6522-9cf1-48c9-8ea4-c30a53b01272/-

Sustainable and Renewable Energy Development Authority. (2021, July 7). *SREDA*. Retrieved from National Database of Renewable Energy: http://www.renewableenergy.gov.bd/index.php?id=1&i=5

Sustainable and Renewable Energy Development Authority. (2021, August 11). *SREDA*. Retrieved from National Database of Renewable Energy: http://www.renewableenergy.gov.bd/index.php?id=2&i=1

Sustainable Development Goals Partnership Platform. (n.d.). *India plans to produce 175 GW of renewable energy by 2022*. Retrieved from Susatainable Development Goals Partnerships Platform: https://sustainabledevelopment.un.org/partnership/?p=34566

The Business Standard. (2021, February 3). *SOLshare: Using the Uber model to share solar power*. Retrieved from The Business Standard: https://www.tbsnews.net/feature/panorama/solshare-using-uber-model-share-solar-power-195445

Tom Kenning. (2017, September 25). *Construction starts on 10MW Afghanistan solar project in Kandahar*. Retrieved from PV-Tech: https://www.pv-tech.org/construction-starts-on-10mw-afghanistan-solar-project-in-kandahar/

Transmission and Generation Planning Branch. (2019). *Long Term Generation and Expansion Plan 2020 - 2039 (Draft).* Ceyloan Electricity Board. Retrieved from https://ceb.lk/front_img/img_reports/1560836289LTGEP_2020-2039_(Draft).pdf

UNDP. (2021, April 5). *Renewable Energy Lights Up Dar-i Noor*. Retrieved from UNDP : https://www.af.undp.org/content/afghanistan/en/home/presscenter/pressreleases/2021/RenewableEnergyLightsUpDar-i-Noor.html

UNIDO. (2017). *Renewable energy based mini grids: the UNIDO experience.* UNIDO. Retrieved from https://open.unido.org/api/documents/5367940/download/RENEWABLE%20ENERGY-BASED%20MINI-GRIDS%20-%20THE%20UNIDO%20EXPERIENCE

USAID. (2018, February 13). *Bamiyan Renewable Energy Program*. Retrieved from USAID: https://www.usaid.gov/energy/mini-grids/case-studies/afghanistan-hydropower

USAID. (2018, February 14). *Energy/Mini-grids/ Technical design*. Retrieved from USAID website: https://www.usaid.gov/energy/mini-grids/technical-design/components

USAID. (2018, February 14). *What are the technical components of a mini-grid?* Retrieved from USAID website: https://www.usaid.gov/energy/mini-grids/technical-design/components

USAID. (2018, February 13). *What ownership models are used for mini-grids?* Retrieved from USAID: https://www.usaid.gov/energy/mini-grids/ownership/models/

USAID. (2020, February 4). *Key steps in mini-grid technical design*. Retrieved from USAID Website: https://www.usaid.gov/energy/mini-grids/technical-design/key-steps/

USAID. (n.d.). *Bamiyan Renewable Energy Program*. Retrieved August 11, 2021, from USAID: https://www.usaid.gov/energy/mini-grids/case-studies/afghanistan-hydropower

Wame. (2014). *Bambadinca sta claro!* Retrieved from Wame: https://www.wame2030.org/project/1075/

Water and Energy Commission Secretariat. (2013). *Nepal's Energy Sector Vision 2050 A.D.* Nepal: Government of Nepal. Retrieved from https://wecs.gov.np/storage/listies/October2020/vision-2050.pdf

Wheeldon, S. (2017, November 28). *Blogs*. Retrieved from GOGLA: https://www.gogla.org/about-us/blogs/off-grid-solar-a-new-hope-for-pakistans-double-energy-crisis

World Bank. (2021). *Setting Course to Recovery.* Washington DC: World Bank. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/35363/Afghanistan-Development-Update-Setting-Course-to-Recovery.pdf?sequence=2&isAllowed=y

World Bank. (n.d.). *population data*. Retrieved from World bank: https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=BD

Xenakis, G. (2017, December 4). *Community Programme for Access to Renewable Energy in Bambadinca* . Retrieved from ALER: https://www.aler-renovaveis.org/en/communication/news/bambadinca/

Xenakis, G. (n.d.). *Presentation of Bambadinca PV Mini Grid.* TESE. Retrieved from https://www.aler-renovaveis.org/contents/activitieseventsspeakersdocuments/georgios-xenakis_tese_3623.pdf

7 ANNEXURE

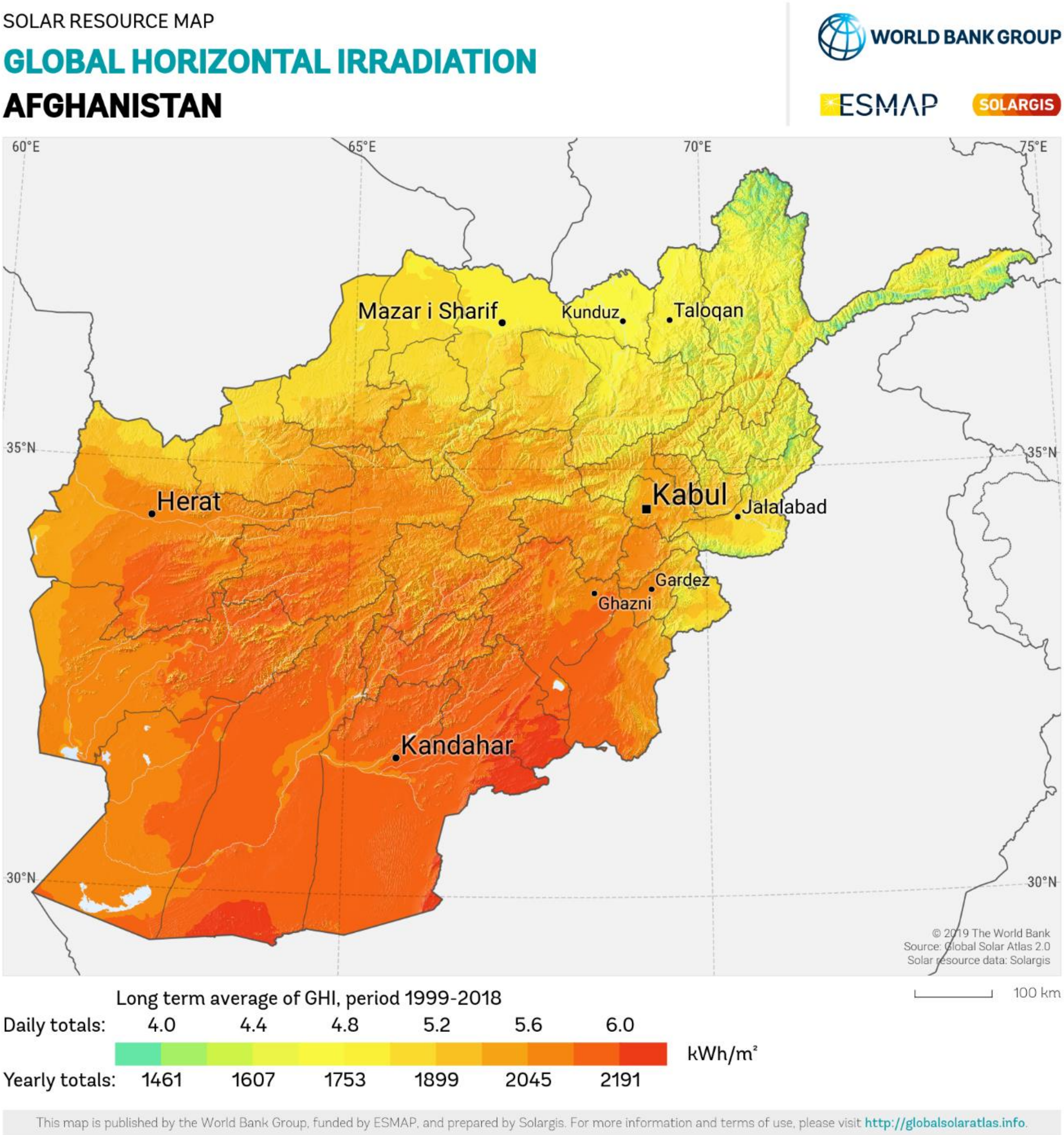
7.1 Annexure 1: List of stakeholders and experts consulted for the study

Name of the organization	Name of the person	Designation of the person
Ministry of Rural Rehabilitation and Development (MRRD), Afghanistan	Mohammad Ajmal Shinwari	Project Manager
	Ahmad Hussain Rasooli	Senior Technical Specialist
Power Cell, Ministry of Power, Bangladesh	Q. A. Sharhan Sadique	Deputy Director
	Mohammad Shakil Khan	Assistant Director
Sustainable and Renewable Energy Development Authority (SREDA), Bangladesh	Engr. Md. Rashedul Alam	Assistant Director, RE (Solar)
Alternate Energy Division, Department of Renewable Energy, Bhutan	Passang	Chief Engineer
	Choten Duba	Executive Engineer
Hamara Grid Private Limited, India	Vijay Bhaskar	Managing Director
GIZ, Nepal	Khem Raj Bhandari	Technical Advisor
Energy Consultancy, Maldives	Ahmed Inaan	Director and Engineering Consultant
Pakistan Poverty Alleviation Fund, Pakistan	Nafees Ahmad Khan	Sr. General Manager
	Iqbal Ahmed Memon	Senior Manager
Sri Lanka	Anil Cabraal	Former Lead Energy Specialist, The World Bank

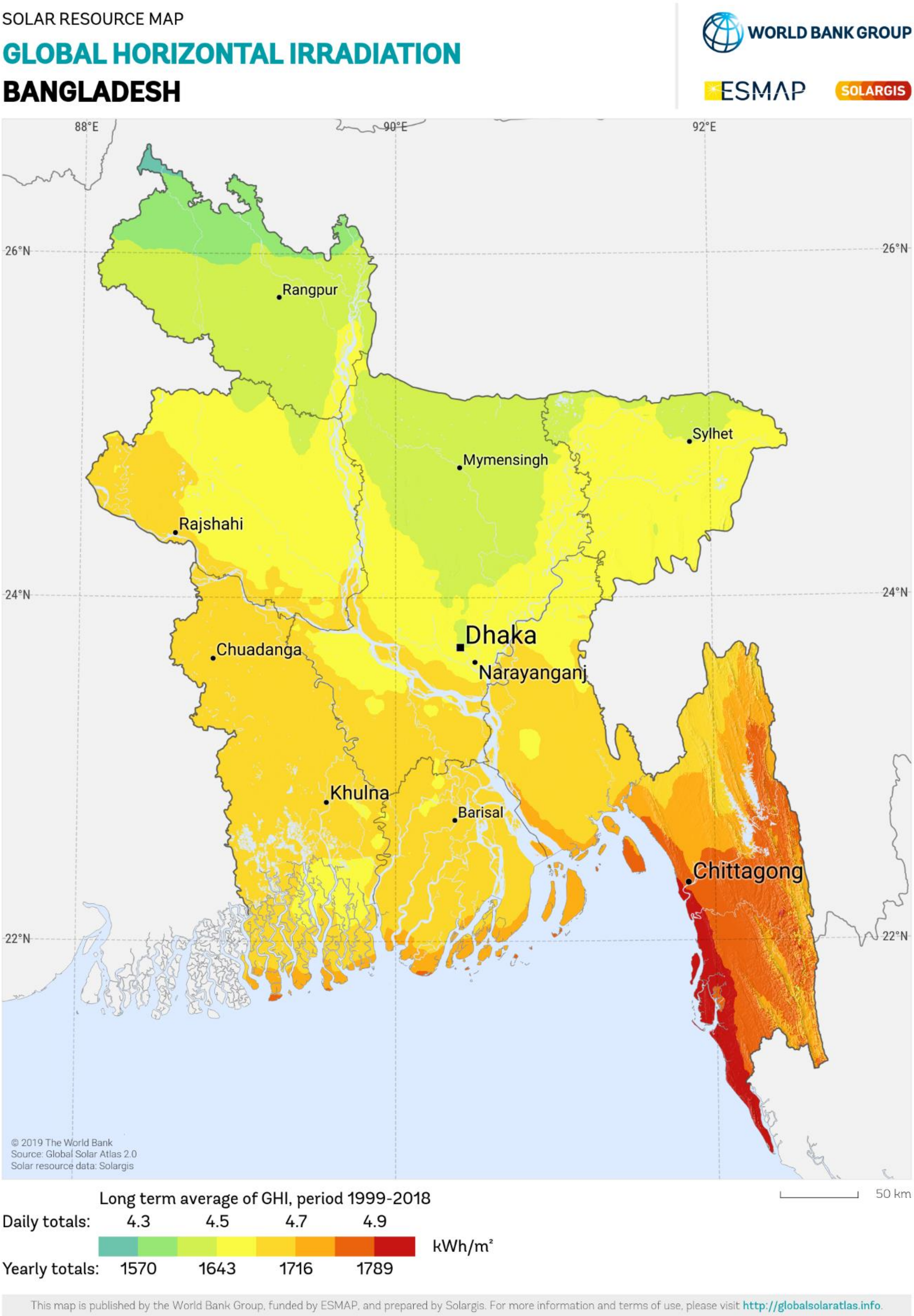
7.2 Annexure 2: Solar GHI maps of SAARC Member States

The World Bank and the International Finance Corporation, collectively The World Bank Group, have developed solar atlas for countries. The World Bank Group has used Solargis solar data and related solar energy assessment services. The solar GHI maps of countries can be downloaded from https://globalsolaratlas.info/map. This section provides the solar GHI maps of SAARC Member States.

AFGHANISTAN

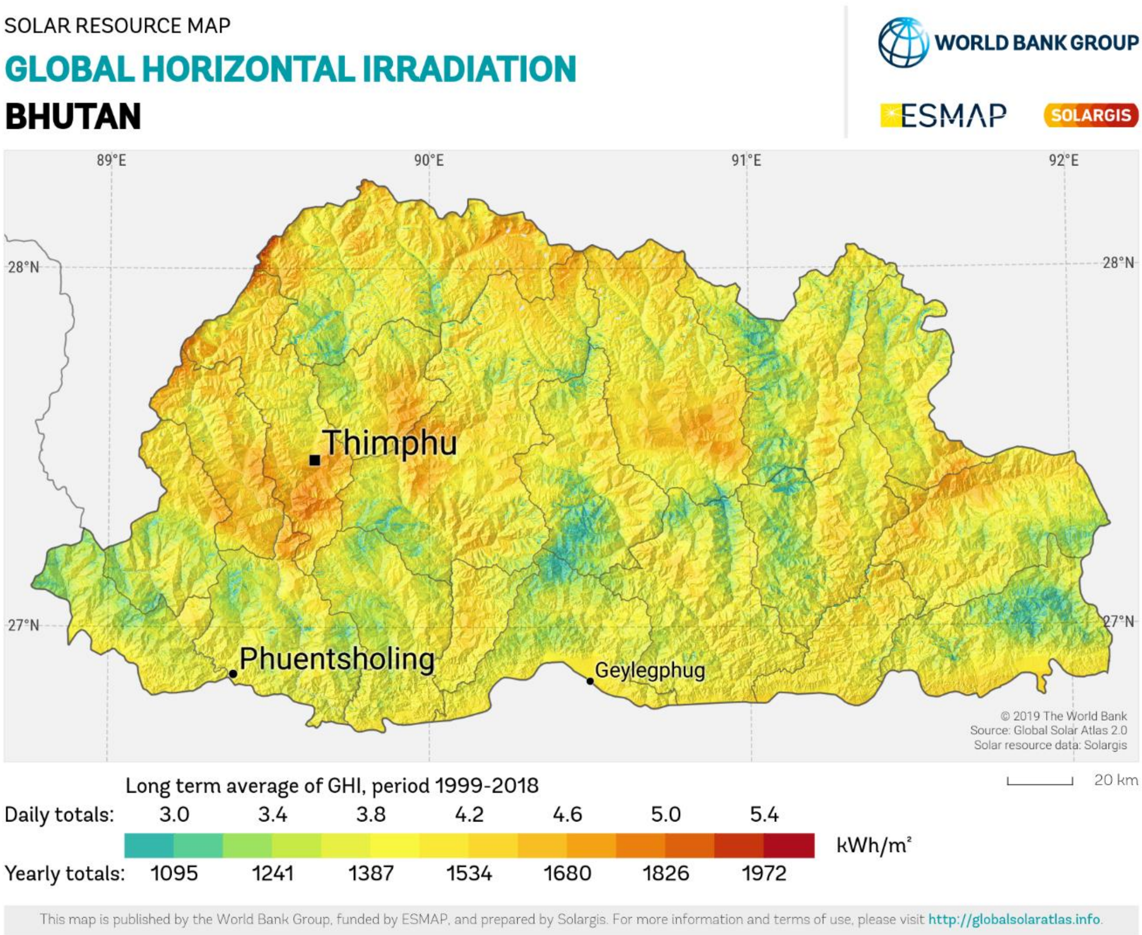


BANGLADESH

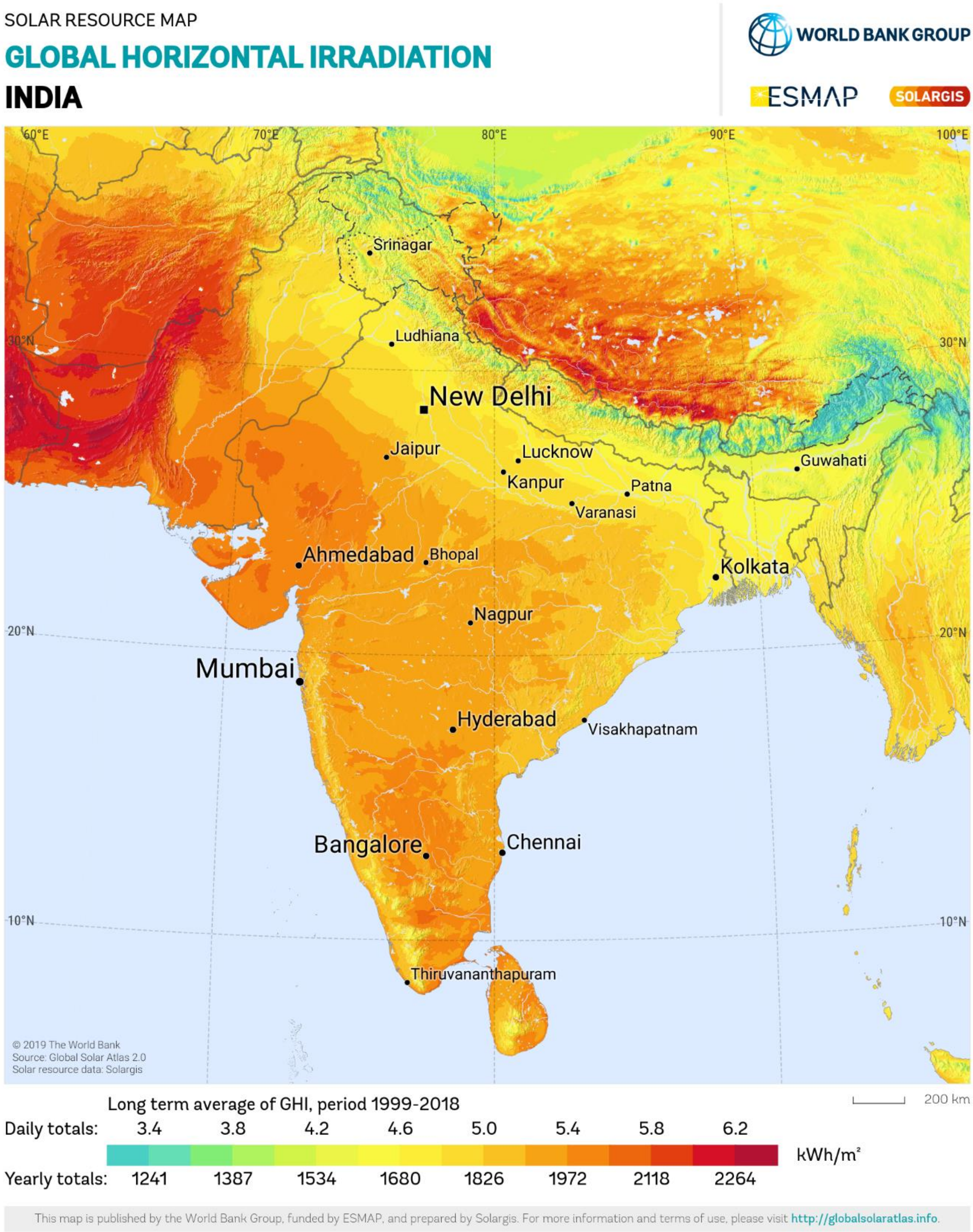


SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
BANGLADESH
WORLD BANK GROUP
ESMAP
SOLARGIS
88°E
90°E
92°E
26°N
24°N
22°N
Rangpur
Sylhet
Mymensingh
Rajshahi
Dhaka
Narayanganj
Chuadanga
Khulna
Barisal
Chittagong
© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis
50 km
Long term average of GHI, period 1999-2018
Daily totals: 4.3 4.5 4.7 4.9
kWh/m²
Yearly totals: 1570 1643 1716 1789
This map is published by the World Bank Group, funded by ESMAP, and prepared by Solargis. For more information and terms of use, please visit http://globalsolaratlas.info.

BHUTAN

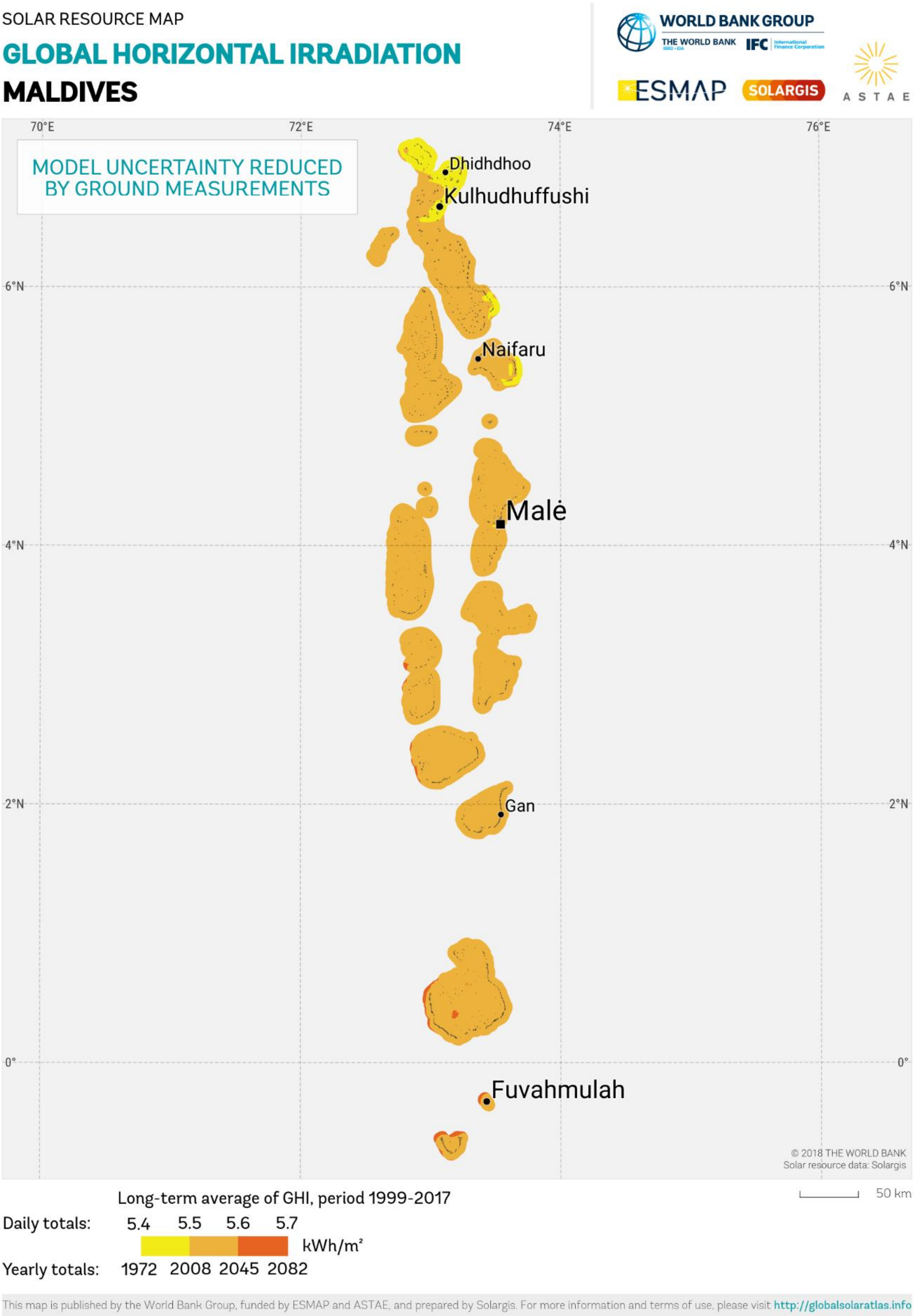

SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
BHUTAN
WORLD BANK GROUP
ESMAP
SOLARGIS
89°E
90°E
91°E
92°E
28°N
27°N
Thimphu
Phuentsholing
Geylegphug
© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis
20 km
Long term average of GHI, period 1999-2018
Daily totals: 3.0 3.4 3.8 4.2 4.6 5.0 5.4
kWh/m²
Yearly totals: 1095 1241 1387 1534 1680 1826 1972
This map is published by the World Bank Group, funded by ESMAP, and prepared by Solargis. For more information and terms of use, please visit http://globalsolaratlas.info.

INDIA



SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
INDIA
WORLD BANK GROUP
ESMAP
SOLARGIS
60°E
70°E
80°E
90°E
100°E
30°N
20°N
10°N
Srinagar
Ludhiana
New Delhi
Jaipur
Lucknow
Kanpur
Guwahati
Patna
Varanasi
Ahmedabad
Bhopal
Kolkata
Nagpur
Mumbai
Hyderabad
Visakhapatnam
Bangalore
Chennai
Thiruvananthapuram
© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis
200 km
Long term average of GHI, period 1999-2018
Daily totals: 3.4 3.8 4.2 4.6 5.0 5.4 5.8 6.2
Yearly totals: 1241 1387 1534 1680 1826 1972 2118 2264
kWh/m²
This map is published by the World Bank Group, funded by ESMAP, and prepared by Solargis. For more information and terms of use, please visit http://globalsolaratlas.info.

MALDIVES


SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
MALDIVES
WORLD BANK GROUP
THE WORLD BANK
IFC
ESMAP
SOLARGIS
ASTAE
MODEL UNCERTAINTY REDUCED BY GROUND MEASUREMENTS
70°E
72°E
74°E
76°E
6°N
4°N
2°N
0°
Dhidhdhoo
Kulhudhuffushi
Naifaru
Malé
Gan
Fuvahmulah
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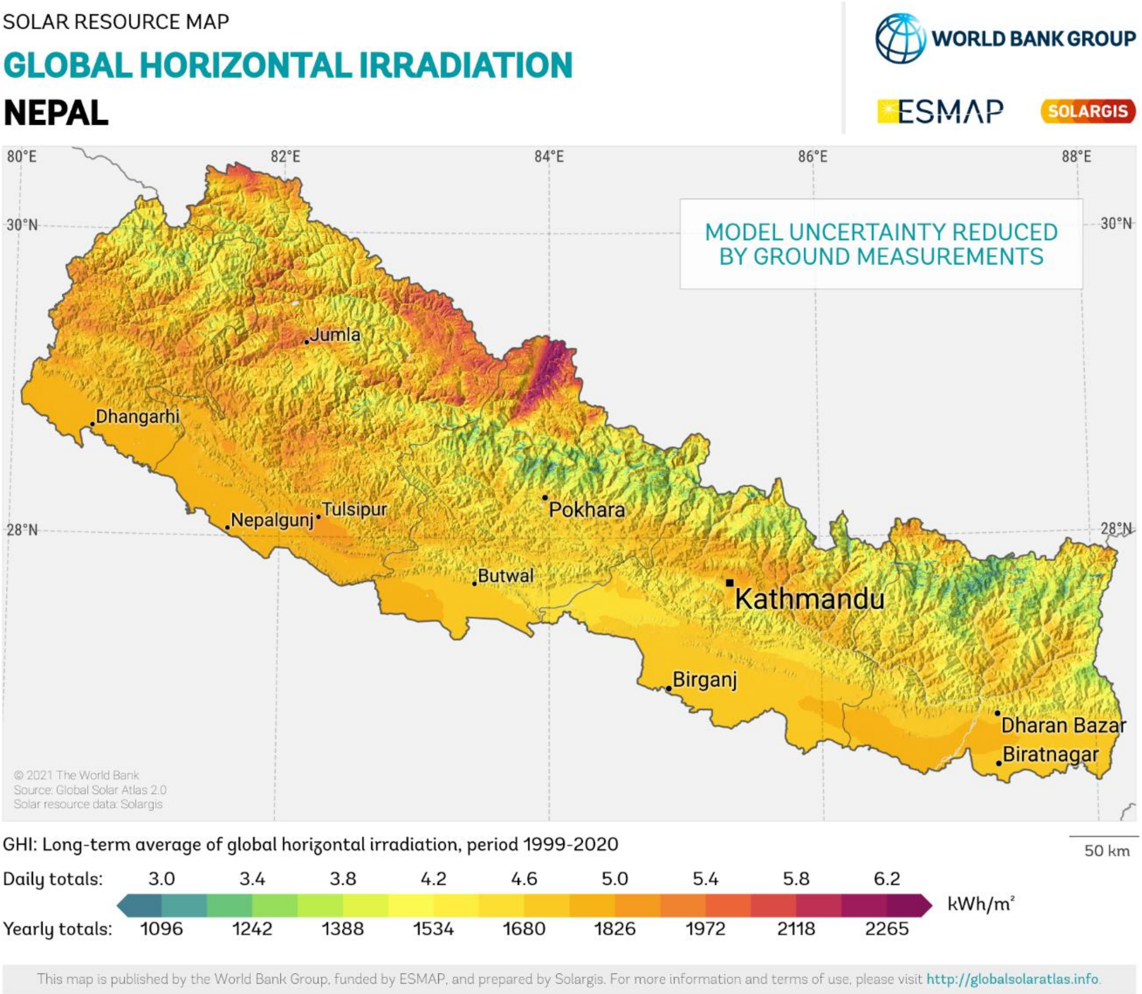
Solar resource data: Solargis
50 km
Long-term average of GHI, period 1999-2017
Daily totals: 5.4 5.5 5.6 5.7
kWh/m²
Yearly totals: 1972 2008 2045 2082
This map is published by the World Bank Group, funded by ESMAP and ASTAE, and prepared by Solargis. For more information and terms of use, please visit http://globalsolaratlas.info

NEPAL


SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
NEPAL
WORLD BANK GROUP
ESMAP
SOLARGIS
MODEL UNCERTAINTY REDUCED BY GROUND MEASUREMENTS
80°E
82°E
84°E
86°E
88°E
30°N
28°N
Jumla
Dhangarhi
Nepalgunj
Tulsipur
Pokhara
Butwal
Kathmandu
Birganj
Dharan Bazar
Biratnagar
© 2021 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis
GHI: Long-term average of global horizontal irradiation, period 1999-2020
50 km
Daily totals: 3.0 3.4 3.8 4.2 4.6 5.0 5.4 5.8 6.2
Yearly totals: 1096 1242 1388 1534 1680 1826 1972 2118 2265
kWh/m²
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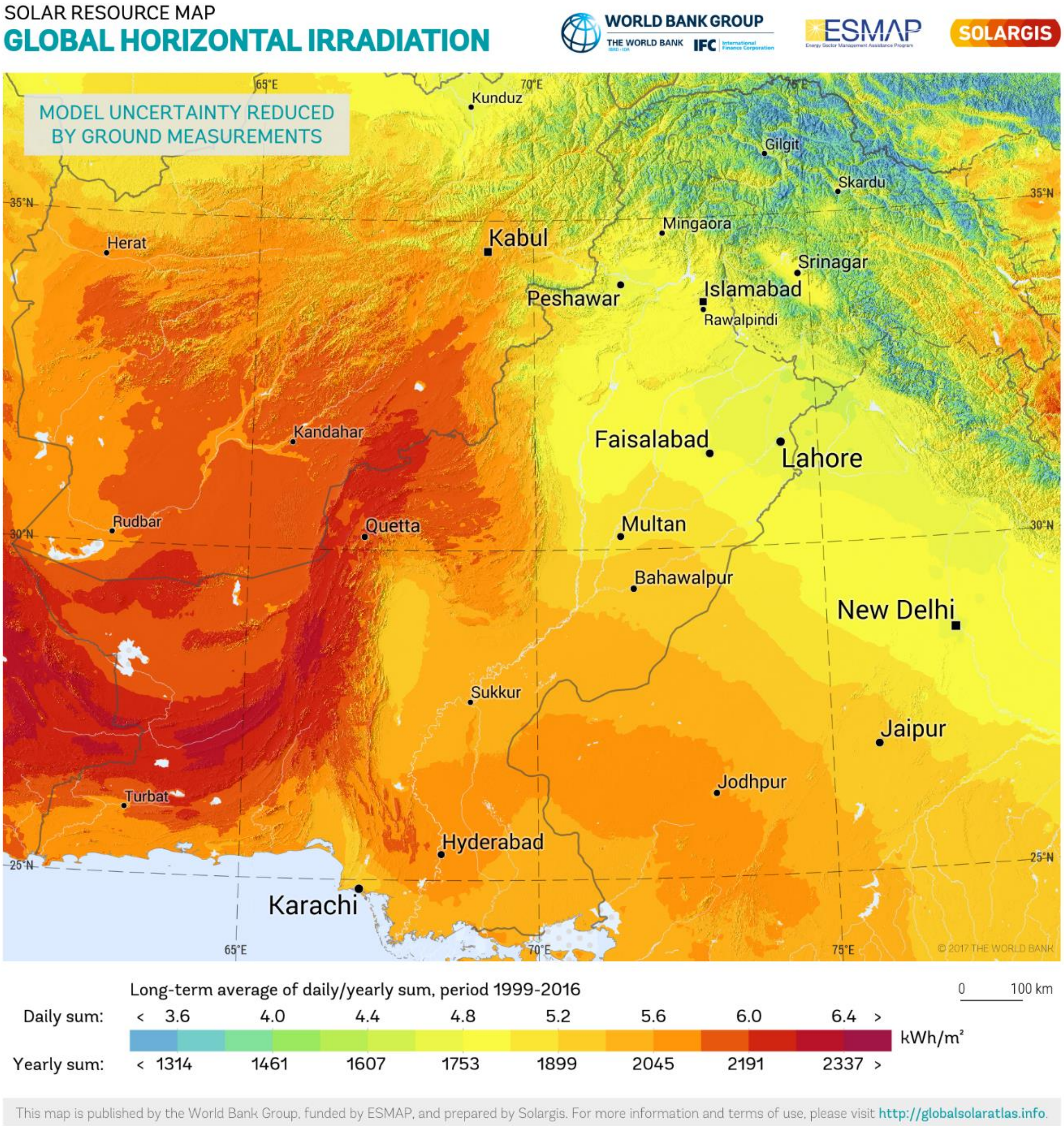
PAKISTAN


SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
WORLD BANK GROUP
THE WORLD BANK
IFC
ESMAP
SOLARGIS
MODEL UNCERTAINTY REDUCED BY GROUND MEASUREMENTS
65°E
70°E
75°E
35°N
30°N
25°N
Kunduz
Gilgit
Skardu
Mingaora
Herat
Kabul
Srinagar
Peshawar
Islamabad
Rawalpindi
Kandahar
Faisalabad
Lahore
Rudbar
Quetta
Multan
Bahawalpur
New Delhi
Sukkur
Jaipur
Jodhpur
Turbat
Hyderabad
Karachi
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Long-term average of daily/yearly sum, period 1999-2016
0 100 km
Daily sum: < 3.6 4.0 4.4 4.8 5.2 5.6 6.0 6.4 >
kWh/m²
Yearly sum: < 1314 1461 1607 1753 1899 2045 2191 2337 >
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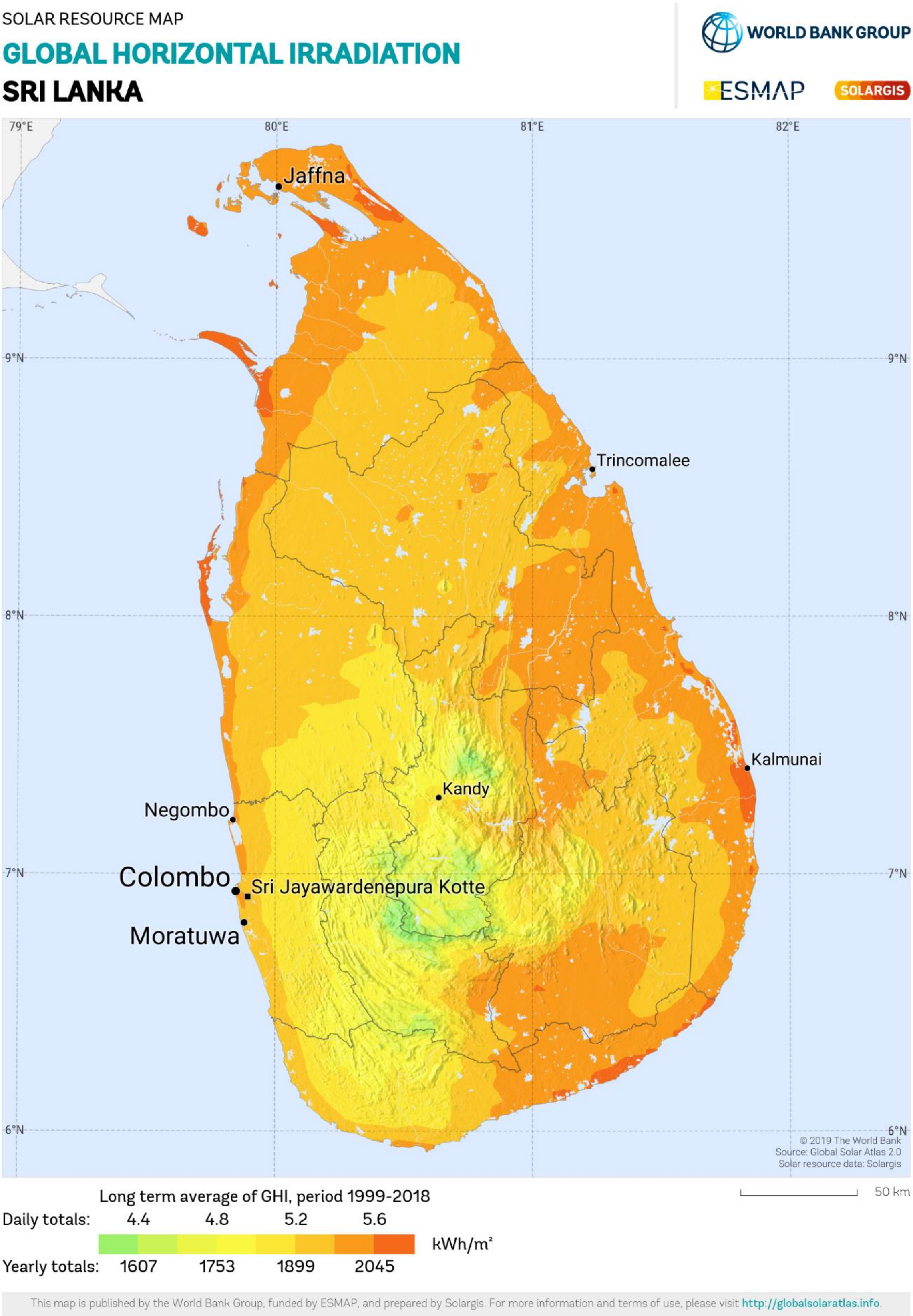
SRI LANKA



SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
SRI LANKA
WORLD BANK GROUP
ESMAP
SOLARGIS
79°E
80°E
81°E
82°E
9°N
8°N
7°N
6°N
Jaffna
Trincomalee
Kalmunai
Kandy
Negombo
Colombo
Sri Jayawardenepura Kotte
Moratuwa
© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis
50 km
Long term average of GHI, period 1999-2018
Daily totals: 4.4 4.8 5.2 5.6
kWh/m²
Yearly totals: 1607 1753 1899 2045
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